The Economics of Large-scale Mangrove Conservation and Restoration in Indonesia

Technical Report

April, 2022

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

GPS
Global Program on Sustainability

SLMP INDONESIA
SUSTAINABLE LANDSCAPE MANAGEMENT PROGRAM

The Economics of Large-scale Mangrove Conservation and Restoration in Indonesia

Table of Content

Acknowledgements

This work was developed by a team led by Juan Pablo Castaneda and Raffaello Cervigni. The report was prepared by Boris van Zanten, Luke Brander, Daniela Gutierrez, Paula Uyttendaele, Diego Herrera, Desta Patrama, and David Kaczan. We are also grateful for the continuous support from Ann Jeannette Glauber and Andre Rodrigues de Aquino, with the latter providing the strategic and technical guidance to the overall project, which included several intermediate outputs that fed into this report.

This work will not have been possible without the valuable assistance to this project provided by the team from WRI Indonesia (Yayasan Institut Sumber Daya Dunia), including Willy Daeli, Indah Andesta, Aryo S. Sujiwo, Komariah Ervita, Khesyia A. Makhas, and Armyanda Tussadiah. Early support provided by Kim Reuter and Barakalla Robyn is acknowledged.

We would like to acknowledge the invaluable contributions of Prof. Michael Beck, Benjamin Brown, Dr. Catalina Jakovac, Dr. Pelayo Menendez, Dr. Mark Spalding and Dr. Bernardo Strassburg who shared datasets that are the foundation of the current assessment.

The generous financial support of the donors to GPS is gratefully acknowledged, including the UK's Department for Environment Food & Rural Affairs (DEFRA); Germany's Federal Ministry for Economic Cooperation and Development (BMZ); and Switzerland's State Secretariat for Economic Affairs (SECO).

List of Figures

List of Tables

List of Boxes

Abbreviations

COVID-19	Coronavirus Disease 2019
FAO	United National Food and Agriculture Organization
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GOI	Government of Indonesia
GPS	Global Program on Sustainability
IPCC	International Panel on Climate Change
ISOP	Indonesia Sustainable Oceans Program
LAUTRA	*Lautan Sejahtera*
MoEF	Ministry of Environment and Forestry
NCA	Natural Capital Accounting
NDC	Nationally Determined Contribution
NPV	Net Present Value
NTT	East Nusa Tenggara (Nusa Tenggara Timur)
PIPPIB	Indicative Moratorium Map
RPJMN	National Medium-Term Development Plan
RTRW-N	National Spatial Plan
SDG	Sustainable Development Goal
SEEA	System of Environmental-Economic Accounting
SISNERLING	Indonesian System of Environmental-Economic Accounts
SLMP	Sustainable Landscapes Management Program
SNA	System of National Accounts
tCO_2e	Tons of carbon dioxide equivalent
UN	United Nations
USD	United States Dollars
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
KLHK	Ministry of Environment and Forestry
BRGM	Peatland and Mangrove Restoration Agency
KKP	Ministry of Marine Affairs and Fisheries

1. Background

1.1. Introduction

Indonesia's intensive use of its natural capital has fueled economic development and reduced poverty.[1] Ocean resources, including coastal and marine ecosystems, contribute to over USD 280 billion annually, more than a quarter of the nation's GDP (World Bank, 2021). These "blue sectors" include capture fisheries and aquaculture, coastal tourism, marine construction, and transportation. The Government of Indonesia, the private sector, and the public, recognize that the blue economy is vital for generating economic and social benefits and ensuring ocean's long-term environmental sustainability. However, inadequate management and underinvestment are degrading ocean resources, particularly mangroves,[2] and threatening prospects for future economic growth.

Indonesia is home to an estimated 20 percent of the world's mangroves, the largest mangrove ecosystems in the world. Its 3.3 million hectares[3] of mangrove forests contribute ecosystem services to the national economy worth at least USD 1.5 billion annually (World Bank, 2020). With more than 17,500 islands, 108,000 kilometers of coastline, and three-quarters of its territory spread across the sea, Indonesia depends on mangrove ecosystems for its prosperity (Coordinating Ministry of Maritime Affairs and Investment, 2021). Mangroves serve as nursery grounds for species essential for Indonesia's commercial fish catch and food security. They provide food and livelihoods for coastal communities, protect shorelines from storms, tsunamis, and other climate-related disasters, reduce risks from floods and erosion, and store significant amounts of carbon.

Indonesia's coastal ecosystems are being degraded in ways that jeopardize mangrove forests and the enormous economic and ecological benefits they provide to coastal communities, the nation, and the world. Mangroves are being cut down to clear land for aquaculture and palm oil production and for coastal urban development (World Bank, 2020). Over half of Indonesia's mangrove forests, 1.8 million of the country's 3.5 million hectares, are already degraded. About 52 thousand more hectares are lost every year (MMAF and MoEF, 2019). The drivers of degradation vary according to region. In Java, Sulawesi and part of Kalimantan, mangrove forests are mainly being cleared to make way for fisheries and aquaculture. In the Western part of Indonesia, covering Sumatra and some parts of Kalimantan, mangroves are largely being cleared to make way for oil palm and pulp wood plantations.

1 Indonesia is the world's largest exporter of steam coal, refined tin and, until recently, nickel ore. It is also a leading exporter of gold, bauxite, lead, zinc, and copper. Its potential in renewable resources is also huge. It has become the world's number one palm oil producer and exporter. In addition, it is the second-largest producer of rubber, Robusta coffee and fisheries products, and holds 40% of the world's geothermal energy reserves. Indonesia's top five exports are all commodities. Refer to Dutu (2015) for additional information on natural resource dependency and the economic structure of Indonesia.

2 The term mangrove is loosely used to describe a wide variety of trees and shrubs (around 80 species), that share characteristics of being adapted to conditions of high salinity, low oxygen and changing water levels (Saenger et al., 1983). The mangrove biome dominates tropical and sub-tropical coastlines between latitudes 32°N and 38°S and covers approximately 22 million hectares. Around 28% of global mangroves are in Southeast Asia with Indonesia alone accounting for about 25%.

3 Goldberg et al, 2020, Murdiyarso et al., 2015)

1.2. Objectives, Target Audience and Structure of The Report

This report's objective is to inform sustainable mangrove management policies in Indonesia, by quantifying the values and net benefits of mangrove conservation and restoration. It uses a nation-wide spatial cost-benefit analysis (CBA) to examine spatial variations in the costs and benefits of mangrove restoration and conservation.[4]

This study responds to the Government of Indonesia's (GoI) demand to inform its mangrove restoration strategy. It is designed to help the Government, the private sector, and other stakeholders across Indonesia, to better understand the risks, opportunities, and most effective strategies for managing coastlines and mangrove forests sustainably. It adds value by providing a novel methodological approach that can rapidly provide answers. The new information it brings to the table, based on spatially explicit cost/benefit assessments, can contribute to the development of Indonesia's national-level implementation strategy for mangrove restoration and conservation. The main findings and related policy messages are particularly useful for Government officials from the Ministry of Marine Affairs and Fisheries (KKP), Ministry of Environment and Forestry (KLHK), Peat and Mangrove Restoration Agency (BRGM), Ministry of Finance (Kemenkeu), and other line ministries that are part of the decision-making process. The report's innovative methodological application also offers new tools and knowledge that can inform think tanks, universities and NGOs working on coastal management.

These new tools can inform other natural capital management decisions as well. Spatially explicit cost-benefit analysis reveals the net benefits of interventions and how these differ from region to region. This identifies the most suitable areas to invest. This study also contributes to the broader discussion of how to institutionalize environmental valuation, which is gaining increasing attention from policymakers in Indonesia (Phelps et al, 2017).[5]

The next three sections describe: the methodology applied (Section 2), the key findings (Section 3) and the main policy messages (Section 4).

Photo by Aldino Hartan Putra on Unsplash

4 Spatial CBA includes: the identification of the benefits (or ecosystem services), the identification of costs (including the opportunity costs of alternative uses of land) and the valuation of these costs and benefits. Valuation was conducted either using value transfer or market prices. For further details on the methods applied please refer to Annex 1, Methods Technical Report.

5 The approach used in this report compares the costs and benefits of conservation and restoration (Figure 6). A spatial database was compiled with all cost and benefit components. Initially a set of relevant ecosystem services where identified and a selection of appropriate datasets and valuation methods was made. Information to be used had to fulfill a set of minimum criteria, including to: (1) be comprehensive enough to include the whole of Indonesia, (2) be susceptible to measurement at least at province level, and, (3) be publicly and readily available. As show in Figure 6, the values of costs and benefits had a different track, but the ultimate goal was to conduct a cost-benefit analysis and obtain the cost-benefit ratios for each district prone to mangrove management investments and obtain values per hectare. The steps were not necessarily sequential, and some feedback loops allowed to control for the quality of the data used.

Photo by Mohmed Nazeeh on Unsplash

2. Methods and Data

2.1. Overall Approach

This study uses a national-level spatial cost-benefit analysis (CBA) to measure the net benefits of alternative mangrove management policies. CBA, also called benefit-cost analysis (BCA), was created as a technique for evaluating investments in the private sector. It then spread into public policymaking as a tool to analyze the economic and financial feasibility of projects, programs, or economic policy instruments (Koopmans and Oosterhaven, 2010). This investment evaluation technique assumes that all the benefits and costs of a project can be quantified in monetary terms. It also adopts the principle of the "intertemporal discount of values," the idea that future benefits and costs will be discounted in comparison to the same benefits and costs in the present.

The spatial dimension added to the CBA in this study provides an innovative application seldom seen in these types of analysis. Geographic Information Systems (GIS), introduced in the late 20th Century, make the widespread use of spatial CBA possible, because we can now process and correlate spatial data with monetary information on costs and benefits. Up until now, Spatial CBA has mainly been used to assess damages and the costs of remediation after disasters strike. Recent ex-post studies evaluate flood risk mitigation. But rarely has spatial CBA been used before the fact, to forecast or make ex-ante comparisons of options for preventing future disasters and managing ecosystems sustainably. There are major gaps to be filled (Torrieri and Rossitti, 2021).

Because the Government of Indonesia's priorities are conservation and restoration activities, this study focuses on analyzing these policies. The Government is emphasizing restoration, because it rapidly creates jobs and appears to yield greater returns in the short term. However, as this report shows, restoration is seldom the most efficient way to manage mangroves sustainably. By comparing the costs and benefits of both restoration and conservation activities in specific locations, the report can help policymakers chose the right mix of interventions for each place.

To compare the costs and benefits of investing in conservation and restoration across districts in Indonesia (Figure 1), this study compiled a spatial database of all cost and benefit components. It identified a set of relevant ecosystem services and selected appropriate datasets and valuation methods. Information used had to fulfill a set of minimum criteria. It had to be comprehensive enough to include the whole of Indonesia, be susceptible to measurement at least at province level, and be publicly and readily available.

The approach consists of the five methodological steps. The steps are not necessarily sequential and there are feedback loops.

- Scoping and identifying relevant benefits (or ecosystem services) and selecting appropriate datasets and valuation methods.
- Assessing benefits by estimating per hectare values of mangrove benefits per district that has mangrove cover)
- Reviewing available unit cost information for the proposed investments in mangrove restoration and conservation

- Constructing a dataset of unit costs and benefits of mangrove restoration and conservation, making it possible to estimate a benefit-cost ratio per hectare at district level
- Using this data to conduct a cost-benefit analysis for spatially explicit mangrove restoration and conservation scenarios.

Valuation of Benefits and Costs

The benefits reflect the value of the key ecosystem services that mangroves provide in Indonesia. The costs include expected outlays for restoration and conservation operations, including the actual cost of implementing the techniques to be used, the capital expenses, and the operating costs. Cost calculations also factor in the opportunity cost of land (income not generated by alternative land uses).

To quantify the value of the ecosystem services that mangroves provide, this study consolidated the geospatial results of state-of-the-art academic valuation studies. These services assessed include coastal flood protection (Menendez et al., 2020), nature-based tourism (Spalding & Parret, 2019), and blue carbon (Jakovac et al., 2020; Strassburg et al., 2020). The study also calculated values for provisioning ecosystem services, such as the catch of mangrove dependent fish species and the extraction of raw materials. The study team conducted a meta- regression analysis (or metanalysis), utilizing and summarizing findings from numerous site-specific valuation studies of mangrove ecosystem services, to extrapolate and calculate values for the study site. This value transfer methodology is described in Brander et al. (2012), and is a procedure that allows researchers to estimate the value of an ecosystem, or the services it provides, by applying an existing valuation estimate for a similar ecosystem (Navrud and Ready, 2007).

Discount rate, timeline, and sensitivity analysis

This study calculates benefit-cost ratios of mangrove restoration and mangrove conservation at district level. It bases the net present value of these costs and benefits for restoration and conservation on a 30-year lifetime and assuming that mangroves are a 30-year coastal infrastructure asset. The study team applied a discount rate of 5.5%, along with a sensitivity analysis with a 0% and 10% discount rate to compare results under different scenarios. The discount rate represents the annual depreciation of costs and benefits because people place a higher value on the present than the future. The 5.5% discount rate was selected based on discussions with the Government of Indonesia, and is close to the 6% usually used in project economic analysis for these types of investments (World Bank, 2017). A benefit-cost ratio higher than 1 per hectare of mangrove restoration or conservation indicates a positive net present value of the investment. A positive net present value (in current dollars or other currency) means the projected net earnings generated by the project or investment exceeds the anticipated cost and that the investment is expected to be profitable. The values of costs and benefits represent the weighted mean values per hectare for the whole country.

Several key factors differentiate calculations of the net present value for conservation and restoration investments:

- Restoration costs USD 3,900 per hectare.
- It takes 30 years after planting for mangroves to be fully rehabilitated and providing benefits.
- Restoration offers more potential to monetize the value of greenhouse gas reduction than conservation.

Although tourism benefits provided by mangroves are among the highest found, this study counts them only in sites identified by Spalding and Parret (2019) where mangroves support tourism activities and are part of nearby landscape. Additional information is provided in the Annex.

Advantages and Limitations

Advantages:

The main advantage of the methodology used in this study is that it allows researchers and policymakers to rapidly compare the economic viability of mangrove restoration and conservation in different geographic areas. Rapid valuation is possible because we use spatially explicit global datasets on mangrove benefits (such as coastal protection), and meta-regression analysis (or metanalysis), to generate value transfer functions. Meta-regression analysis enables us to combine, compare, and synthesize research findings from multiple studies, using context variables to help predict benefits based on values observed at other locations (Brander et al., 2012). Initiatives such as the Ecosystem Services Value Database (ESVD) help make this possible by compiling and standardizing primary ecosystem services valuation studies from all over the world. Drawing on existing data reduces the need for new, large scale national-level ecosystem services valuation studies using primary data. It saves these resources to be applied, instead, to detailed assessments of benefits at project site level.

The use of value transfer to inform decision making is generally less expensive and time consuming than conducting primary research. Value transfer can also be applied on a scale that would be unfeasible for primary research seeking to estimate values in large numbers of sites. Value transfer offers the advantage of providing consistency in estimating values across policy sites (Rosenberger and Stanley, 2006).

National-level rapid assessment can identify priority areas and interventions and inform national strategies for mangrove restoration and conservation. The district-level benefit-cost dataset can help develop scenarios that optimize the distribution of mangrove interventions across the country, based on the cost and benefit components considered. This study is a hybrid type of assessment that considers both benefits based on market prices (e.g. coastal protection and fisheries) and those based on welfare economics, or the well-being of the public, (e.g. tourism and blue carbon).

Limitations:

The methodology used in this study is intended to inform national-level programs, strategies, and investment plans for mangrove interventions, and identify priority areas for follow-up studies. It does not provide sufficient granularity for (pre-) feasibility level studies or project design. These require on-site, economic studies using primary data.

This approach relies on secondary data on ecosystem services and benefits and depends on the quality of these datasets. For some locations or ecosystems, function-based value transfer will be more challenging because of a lack of data points in similar contexts. Ecosystem services valuation methods also omit some benefits. For instance, there is no comprehensive and well-established toolbox to quantify the value of cultural ecosystem services.

Confirming the internal validity of value estimates from existing nonmarket valuation studies can be difficult. Primary valuation estimates that might be used for benefit transfers can also be tainted by publication bias. This occurs when a study's outcome influences the researchers' choice of whether to submit it for publication or the editors' choice of whether to accept it. Determining which study cases are suitable candidates to become policy cases is also subject to discussion and here expert judgement plays a big role. Incomplete reporting or lack of access to primary information can distort study results.

The limitations inherent in the methods and data used, and gaps in quantitative knowledge about some key ecological relationships, underscore the need for further inquiry. However, using standardized approaches such as natural capital accounting (NCA), enables this study to overcome some of these limitations. NCA is a standard conceptual framework for measuring the contribution of natural capital to the economy and the impact of economic development on natural capital.[6] None of the caveats listed above are meant to diminish the importance of this or other meta-analyses of nonmarket valuation studies. The team that developed the study consulted with experts, followed best practices, and strongly supports making the best possible use of the relevant information available, whether it was collected in an experimental or an observational setting.

Photo by David Clode on Unsplash

6 Further information on NCA and the System of Environmental-Economic Accounting can be found in www.wavespartenrship.org

2.2. Scoping and Benefits Assessment

Mangroves provide a number valuable ecosystem services that contribute to human well-being. These benefits to different populations include provisioning (e.g., timber, fuel wood, and charcoal), regulating (e.g., flood, storm and erosion control; prevention of saltwater intrusion), habitat (e.g., breeding, spawning and nursery habitat for commercial fish species; biodiversity), and cultural services (e.g., recreation, aesthetic, non-use) (Spaninks and Beukering, 1997, UNEP, 2006, TEEB, 2010). Data sources are described in Table 1, along with instructions in the Methods Annex to find additional details on the specific methods and estimations.

This study includes only ecosystem services susceptible to measurement and monetary valuation. These include coastal protection, climate regulation, support services to fisheries, provision of raw materials, and cultural services:

- **Coastal protection.** Mangroves shield coastal communities and assets from storm surges, coastal erosion, and rising seas. By building a living seawall they can slow or halt erosion, diminish wave energy, and temper the flooding driven by storm surges. The case for mangrove restoration for coastal protection is straightforward: beside offering protection from rising seas and storms surges, restoration is two to five times cheaper than building engineered structures like underwater breakers (Beck et al, 2019).

- **Climate regulation.** Mangroves are one of the most effective ecosystems for capturing, sequestering, and storing carbon dioxide from the atmosphere. They pull carbon dioxide from the atmosphere (known as blue carbon) and store it in their biomass and in rich organic soils, where it remains stable (Worthington et al., 2019).

- **Support to fisheries.** Mangroves support capture fisheries by providing nursing grounds and habitat needed to re-generate fish stocks. A significant proportion of commercial fish species and other marine fauna found in Indonesian coastal waters depend on, or are associated with, mangroves for some or all their life cycle. About 55% of the total biomass of fish landings in Indonesia consists of mangrove dependent species (FAO, 2014).

- **Provision of raw materials.** Mangroves provide raw materials that can be used by surrounding communities. Villagers can extract timber using sustainable practices which ensure that ecosystems remain viable and available in the long-term. Wood from mangroves can be burned as fuel for cooking in coastal communities. Mangrove ecosystems also provide non-timber forest products, including fodder, food, fish and meat.

- **Cultural services.** Mangroves offer opportunities for wildlife viewing and education, and grow close to tourist attractions such as coral reefs and sandy beaches (IUCN, 2017). The intrinsic value of mangroves is difficult to calculate/monetize but can be high in areas such as Papua where local people consider mangroves and associated fauna to be ancestors.

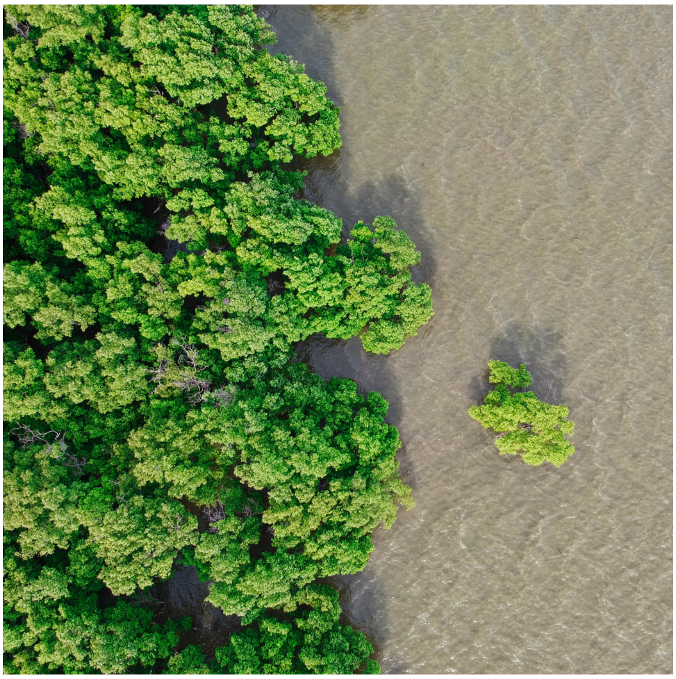


Photo by Waranont (Joe) on Unsplash

Undervaluation of mangrove benefits

Mangroves provide vital ecosystem services to local communities and to the global population. In 2015, approximately 120 million people around the world lived within 10 km of significant mangrove forests. In developing countries in Asia and West and Central Africa, the majority of these people depend on mangrove resources for their livelihoods and well-being (Mukherjee et al., 2014). These services (benefits obtained from healthy ecosystems) have not been fully considered in decision making, to the detriment of mangroves and human well-being (Hernández-Blanco et al., 2021).

Mangroves' ecosystem services (especially regulating and cultural services) are a public good. They are non-excludable, meaning individuals cannot be kept from enjoying their benefits, and non-rivalrous, meaning one person's enjoying these benefits does not diminish them for others. As a result, markets for these benefits do not exist and there is limited potential to use conventional markets to manage them (Brander et al., 2012). Because it is difficult to estimate the value of these non-marketed services, mangroves are often undervalued in benefit-cost analysis weighting conservation against commercial uses of land (Salem & Mercer, 2012, Acharya, 2002). This has fueled their destruction around the globe. Valuing the multiple ecosystem services that mangroves provide to society is necessary to provide a rationale and a means to sustainably manage and protect these ecosystems.

The term "valuation" here means the relative contribution of a good or service to sustainable well-being (Costanza et al. 2014). The valuation of ecosystem services helps decision makers understand their importance to society, the cost of their loss, or the benefit of their preservation (Mukherjee et al., 2014; Himes-Cornell, Pendleton, & Atiyah, 2018; Acharya, 2002; Brander et al., 2012). The value of ecosystem services depends on the relative contribution of natural capital, interacting with built, social, and human capital, to sustainable human well-being (Costanza et al., 2014, Turner et al., 2016).

Valuation studies and purposes

The list of studies on economic valuation is extensive. Spalding provides a series of economic values for ecosystem services from global, regional and national studies (Spalding, 2010). The author argues that total economic values of mangroves ranges from USD 13,819/ha/year (UNEP/GPA, 2003) to USD 22,526/ha/year (Chong, 2006). Salem and Mercer (2012) also provide a good summary of valuation studies on mangroves, in which they cite mean USD values per hectare per year for fisheries (23,613), forestry (38,115), coastal protection (3,116), recreation and tourism (37,927), nutrient retention (44), carbon sequestration (967), non-use (17,373), biodiversity (52), water and air purification/waste assimilation (4,748) and traditional uses (114), based on 149 observations (Salem & Mercer, 2012). Other lists of value estimates can be found in Russi et al., (2013); Lal, (2003); De Groot et al., (2012); Vo, Künzer, Vo, Moder, & Oppelt, (2012); Mukherjee et al., (2014); Mehvar et al., (2018); and Barbier et al., (2011).

Estimating the value of ecosystem services from mangroves can be useful in at least 3 ways. It can:

- Raise awareness of the narrow economic paradigm that dominates government decisions, excluding or downplaying the value of ecosystem services
- Point to the need for parallel ways of measuring natural resources as a complementary conservation strategy
- Allow comparisons between commercial and conservation alternatives based on criteria such as net present value and benefit-cost ratios that give adequate weight to non-market goods and services
- Calculate the price a commercial developer might need to pay as compensation for an environmental impact on mangroves (Lal, 2003).

Table 1. Mangrove benefits, valuation methods and data sources

Types of ecosystem services and mangrove benefits analyzed	Valuation method	Source	Section in the Methods Annex
Regulating services			
Coastal protection (i.e., coastal flood protection)	Avoided damage costs	Menendez et al., 2020	Section 3.1
Climate regulation (i.e., carbon sequestration and avoided emissions)	Voluntary market price estimate for avoided emissions and carbon sequestration	Estimations based on Mudiyarso et al. (2015); Jakovac et al. (2020); Cameron et al (2018); Cameron et al (2019).	Section 3.2
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)	Section 3.3
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)	Section 3.3
Cultural services	Value transfer in areas where mangroves are used for tourism activities.	Estimations using the median of meta-dataset of mangrove tourism estimates in SE Asia (Data from ESVD). Mangrove tourism use areas are depicted by Spalding et al. (2019).	Section 3.4

Source: Own elaboration

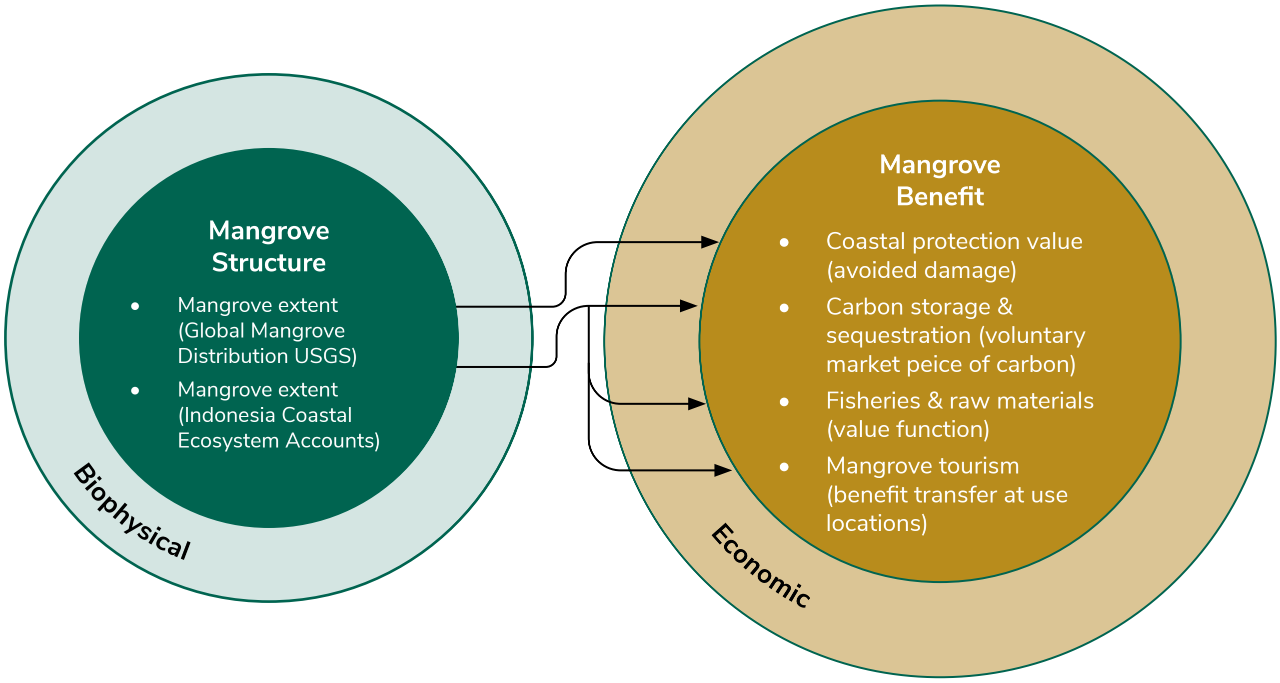
While benefits of mangroves at district level can vary according to valuation methods and type of services assessed, they are directly linked to the configuration and composition of mangrove extent (range or area covered) in the district. For mangrove dependent fisheries, the size of mangrove patches and abundance of mangroves in the district are critical, and for mangrove tourism, the abundance of mangroves near mangrove tourism sites is an important variable. Two different mangrove extent datasets have been used to quantify benefits at district level (Box 1). These are the mangrove extent data from the Indonesia Coastal Capital Accounts, and the Global Distribution of Mangroves from the US Geological Survey (USGS) (Figure 1).

Box 1 Describing mangrove structure: geospatial mangrove extent datasets

The Indonesia Coastal Ecosystem Accounts: In the accounts, the coastal ecosystems that have been considered include seagrass, coral reefs and mangroves. The dataset is prepared by the Department of Forestry Planning and Environmental Management *(Planologi kehutanan dan tata lingkungan)* of the Ministry of Environment and Forestry (MoEF) based on manual interpretation of Landsat data. The nomenclature of the land cover map includes mangroves as well as 21 other land cover classes. The dataset has national coverage and is frequently updated.

Global Distribution of Mangroves USGS: The mangrove coastal protection model prepared by Menendez et al., (2020) utilized the Global Distribution of Mangroves from USGS as a global mangrove extent layer. The dataset was created using Global Land Survey (GLS) data and the Landsat archive. Approximately 1,000 Landsat scenes were interpreted using hybrid supervised and unsupervised digital image classification techniques. A detailed description of the methodology is found in Giri et al., (2011).

Figure 1. The relation between the spatial biophysical mangrove datasets and the approaches for the valuation of mangrove benefits per district



2.3. Costs Assessment

Costs of restoring and conserving mangroves include the measurable opportunity costs of forgoing land conversion. Data sources for the estimations are described in Table 2 with instructions on where to look in the Methods Annex section for additional details on the specific methods used and estimations made. It is important to point out that not all costs where included, only those that were susceptible to monetary valuation within the framework and criteria previously described.

Costs of restoring. Costs of active mangrove restoration projects depend on the techniques chosen and the accompanying capital and operating expenses. Active mangrove restoration projects create job opportunities, renew degraded ecosystems, improve the quality of ecosystems, trap the sediment that passes through the mangrove restoration areas, improve coastal resilience, prevent coastal erosion, and mitigate coastal hazards. In Southeast Asia, the process of mangrove restoration can involve more than just planting or transplanting seeds, propagules and seedlings. For example, it can entail restoring hydrological systems to a more natural state and constructing artificial habitats such as detached breakwaters. Capital expenditures include costs for planning, purchasing, land acquisition, materials, and equipment (such as pumps, vehicles, computers, fencing) and financing. Operating costs encompass maintenance, monitoring, and equipment repair and replacement.

Costs of conserving. Mangrove conservation projects involve the protection and sustainable use and management of mangrove forests. Mangrove protection activities include formal and informal education programs, sale of carbon credits, monitoring of forest growth, measurements of carbon deposited below ground by different mangrove species, fundraising activities, mapping and marking of agreed protected areas, and perimeter patrols and policing of illegal mangrove harvesting. Costs of mangrove protection projects can be classified into project development expenses and operational costs. Mangrove conservation projects require long-term incentives which can be provided through the sale of mangrove-related goods and services, such as certified organic shrimp or sustainably harvested crab. In general, these kinds of projects require 50 percent of the budget for the first year, 30 percent of the budget for the second year, and 20 percent for the third year (Flint et al. 2018).

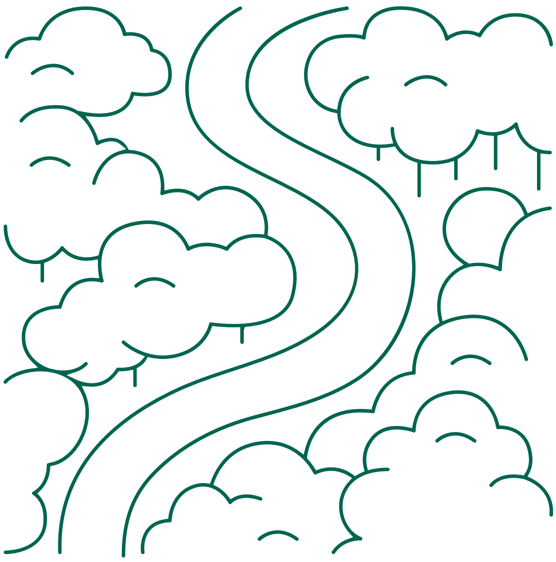
Opportunity costs of land. This cost assessment factors in opportunity costs of not converting mangrove forest land for alternative uses. Agriculture and aquaculture have been the main drivers of mangrove loss and degradation over the last decades (Jakovac et al. 2020). In Southeast Asia, between 2000 and 2012, 38 percent of converted mangrove areas were being used to cultivate rice and oil palm, while 30 percent supported aquaculture (Richards and Friess, 2015). Because agriculture has encroached so extensively on mangrove forests, and because data on aquaculture productivity is not available for most mangrove-holding countries, opportunity costs were estimated at a 5 km resolution based on the average productivity of agriculture and pastures for all mangrove-holding countries.

Table 2. Cost estimates and data sources

Cost category	Valuation method	Cost Estimate	Source	Section in the Methods Annex
Restoration costs	Based on secondary data of costs for techniques applied, capital expenditures and operating costs. Based on joint estimation with the GoI of capital costs.	Restoration cost per hectare of USD 3,900 constant across all districts.	Estimations of cost of techniques based on Motamedi et al (2014); Primavera and Esteban (2008); Narayan et al (2016); Hashim et. al (2010); Ministry of Marine Affairs and Fisheries, 2020). Estimations of capital expenditures based on Bayraktarov et al. (2016); Flint et al. (2018). Operating costs based on Bayraktarov et al. (2016).	Section 4.1
Conservation costs	Based on secondary data of maintenance costs.	Proxy indicator: Management cost of marine protected areas per hectare from GoI	Estimations base on Flint et al. (2018) and consultations with Government.	Section 4.2
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 cost are considered as district-level averages	Estimations based on Jakovac et al (2020); Strassburg et al (2019); Richards and Friess (2015).	Section 4.3

Source: Own elaboration

This study estimates the opportunity costs for 31 commodities based on the net present value of the amount that will be produced over 30 years using a 5.5 percent discount rate. The 31 commodities were chosen based on availability of data on current and potential productivity (Jakovac et al 2020). The net present values were translated into a per hectare value using the methodology applied in Jakovac et al (2020). For pastures, opportunity costs were estimated based on stocking rates, or the number of animals on a given amount of land over a certain period. These were converted from heads per hectare to tons produced per hectare based on the yields of tons per head. The opportunity costs for both agriculture and pasture were calculated assuming a 20 percent margin of profit (Strassburg et al 2019).

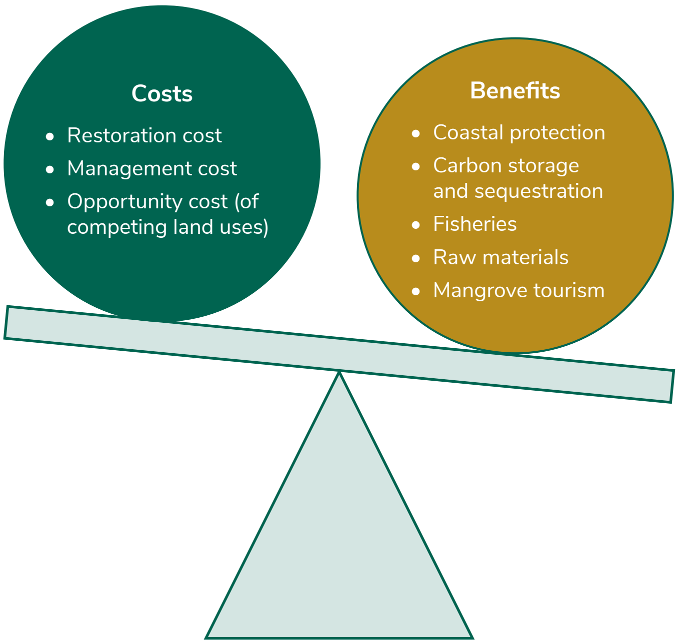


2.4. Benefit and Cost Analysis

Cost-benefit analysis (CBA) is an economic methodology used to compare the costs and benefits of a proposed investment over a period of time. The technique is similar to rate-of-return and appraisal methods adopted in business operations to assess the economic feasibility of investments. However, CBA takes a broader perspective, as it aims to monetize overall societal (welfare economic) benefits and costs rather than the mere financial gains of an individual organization (Kull, Mechler, & Hochrainer-Stigler, 2013; Shreve & Kelman, 2014). Consequently, CBA approaches often focus on internalizing the external, monetizing non-marketed and public goods and factoring these effects to the equation.

In a CBA, future costs and benefits are discounted based on a predefined discount rate. It represents the annual rate at which costs, and benefits depreciate because people place a higher value on the present than on the future. This depreciation stems from general uncertainties about the future, and from the opportunity cost of investing capital in any given project when money invested elsewhere could have yielded equal or greater returns. In CBA projects, the discount rate is often determined by estimating the internal rate of return (IRR) for alternative public projects. Project alternatives in a CBA are evaluated using three different indicators: the benefit/cost ratio, the internal or economic rate of return (IRR/ERR), and the net present value (NPV), meaning discounted benefits minus discounted costs over the project lifetime.

Figure 2. Costs and benefits considered in the analysis



The unique feature of the current CBA framework is that it enables decision makers to compare costs and benefits of mangrove restoration and conservation at administrative area level; districts in the case of Indonesia. This will allow them to rapidly gauge the relative viability of such interventions across districts and prioritize those that yield the greatest benefits and the lowest cost. Figure 3 shows the cost components and benefits included in this assessment. In this CBA, the present costs and benefits of mangrove restoration and conservation are estimated based on a 30-year project lifetime and assuming that mangroves are a 30-year coastal infrastructure asset. A discount rate of 5.5% is applied plus a sensitivity analysis with a 0% and 10% discount rate in the scenario analysis.

Benefit-cost dataset and maps

To provide the CBA framework needed to inform spatial prioritization, this study first constructed a benefit-cost dataset for each district, with annual and present estimates of the benefits and cost components. These values are extracted from the cost and benefits assessment aggregated to district level. Beck et al (Beck et al., 2020) adopt a similar CBA framework, with a comparison of costs and benefits of mangrove restoration across sites, but their study considers only flood protection benefits and excludes others. This analysis is more holistic, encompassing a broad range of benefits in the CBA (Figure 3).

Photo by pixmike on Unsplash

Photo by Waranont (Joe) on Unsplash

3. Key Findings

3.1. Mangroves in Indonesia Provide Significant, High Value Ecosystem Services

The combined quantified present value of mangrove benefits, over a 30-year timeline, ranges from under USD 2 million to over USD 50 million per district. The highest combined values of ecosystem services are found in Papua, Kalimantan, Sumatra, and Sulawesi. These aggregate per hectare conservation values of coastal flood protection, avoided greenhouse gas emissions, tourism, fisheries, and firewood/timber, multiplied by the mangrove extent per district. High values above USD 50 million are found in districts with large mangrove extents on Papua, Kalimantan, and Sumatra. Several districts in Sulawesi, Bali, Lombok, and Java are also in the top bracket even though they are home to a smaller mangrove extent. This is likely due to high values per hectare.

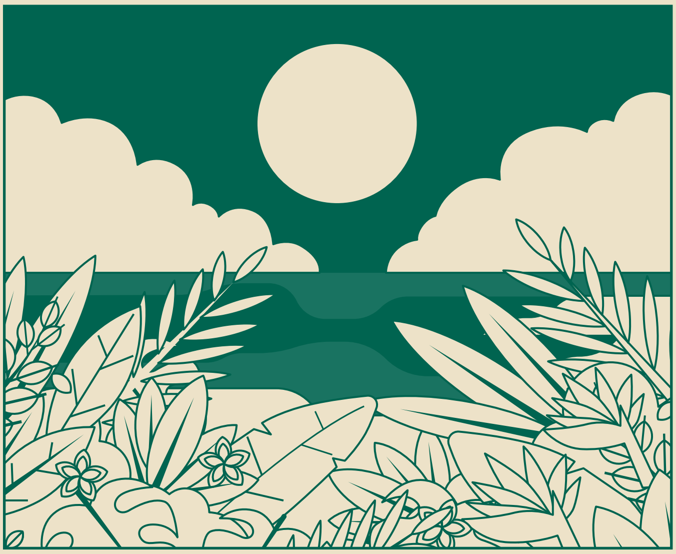
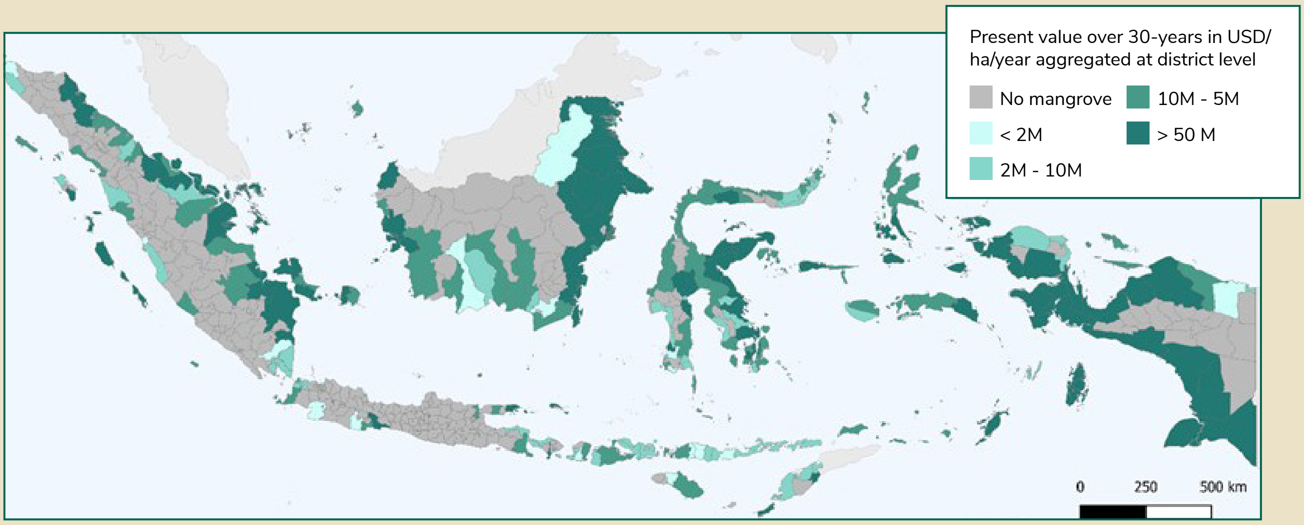


Figure 3. Spatial distribution of ecosystem services provided by mangroves (Values in USD/ha/year aggregated at district level)



Source: Own elaboration

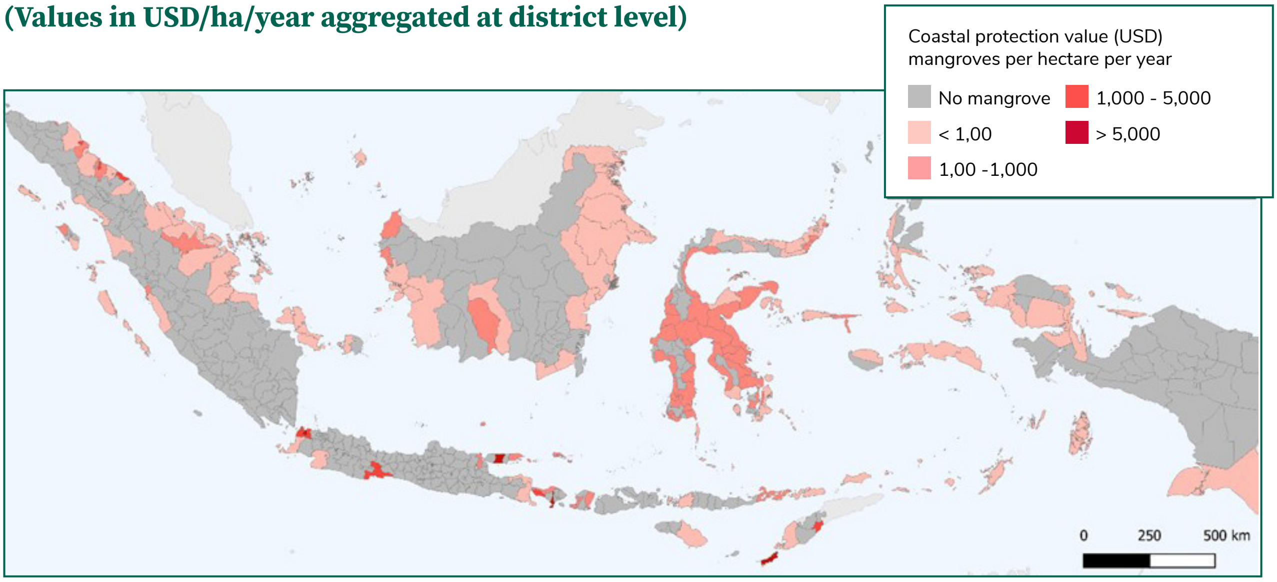
3.2. The Types and Value of Mangrove-Related Ecosystem Services Varies Substantially from Region to Region

Coastal protection services provided by mangroves are particularly valuable in Java, Northern Sumatra, Bali, Lombok, and parts of Nusa Tenggara Timur.

High annual per hectare values of coastal protection are clustered in more developed and more populated areas, such as in Java, Bali and Lombok (Figure 4), where there are more properties exposed to coastal flooding. The buffer mangroves provide against flooding, erosion, and storm damage makes them exceedingly valuable. In many high value areas, annual mangrove coastal protection benefits exceed USD 10,000 per hectare per year, and in some cases, they are modeled up to USD 100,000 per hectare per year.

Photo by @banjongseal324 on Freepik

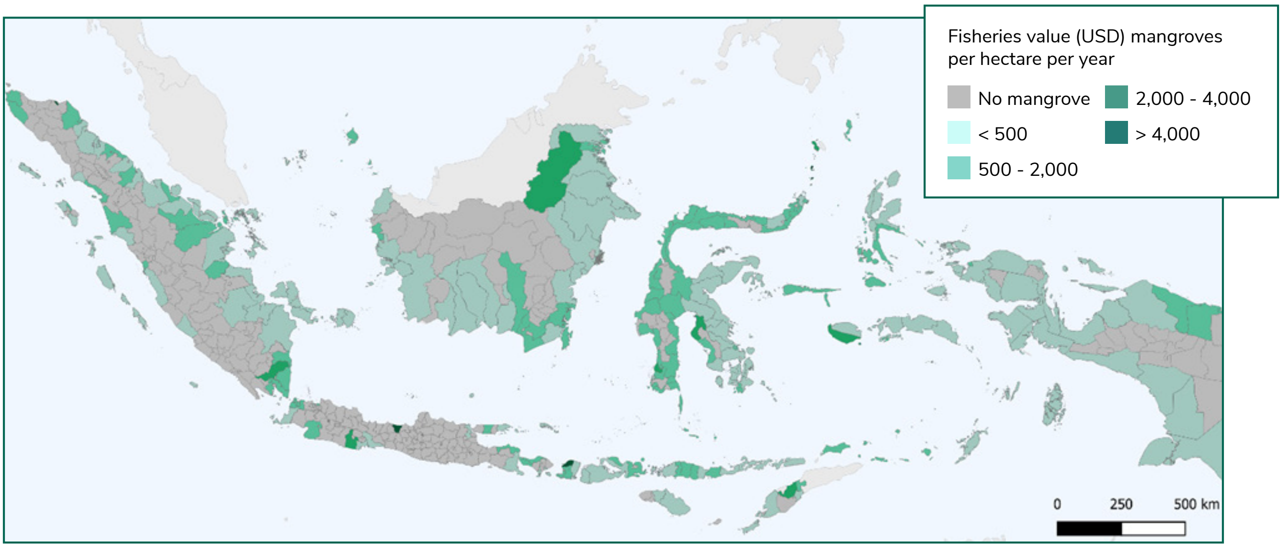
Figure 4. Spatial distribution of coastal protection benefits (Values in USD/ha/year aggregated at district level)



Source: Own elaboration based on Menendez et al. (2020)

Mangroves provide especially valuable support for fisheries services in Java, Nusa Tenggara Timur, Sulawesi and Southern Sumatra. The value to fisheries of each additional hectare is highest where mangroves are scarce, limited to small patches, and close to main roads (Figure 5). High values are found around Java, NTT, Sulawesi, and Southern Sumatra among other areas.

Figure 5. Spatial distribution of fisheries related ecosystem services (Values in USD/ha/year aggregated at district level)



Source: Own elaboration (See Annex A1, Methods Report)

Mangrove climate regulation services present an opportunity to generate income through carbon markets. Mangroves are vital to regulating the world's climate. Blue carbon is carbon captured and stored by the world's ocean and coastal ecosystems, and mangroves are one of the most effective ecosystems for doing this. They sequester carbon by drawing carbon dioxide (CO_2) through their leaves and water through their roots, then splitting and combining these molecules into glucose, which traps the carbon in mangroves' biomass and in rich organic soils. It remains stable there (Worthington et al., n.d.) unless humans or nature intervene to disturb it. Mangrove restoration both sequesters GHGs in biomass and buries them in soil. It also reduces baseline CO_2 emissions and GHG in the atmosphere. (See Annex for more details on the estimations).

To estimate the economic value of the climate regulation service that mangroves provide in Indonesia, this assessment measured two ecosystem functions: blue carbon sequestration and storage. Blue carbon storage was estimated by calculating the avoided CO_2 emissions due to the conservation of existing mangroves (i.e. carbon stocks). Mangroves allocate 50–90% of their carbon pool below ground and the rest is stored in biomass above the ground. There is uncertainty surrounding the share of stored blue carbon that will be released into the atmosphere if mangrove forests are cut down or degraded, so this assessment took a conservative approach in estimating the value of blue carbon storage in mangrove conservation areas. It assumed that preserving mangroves from deforestation avoided emissions amounting to 25% of the carbon stock (Jakovac et al., 2020). Based on a mean carbon density per hectare in mangroves of 1,083 metric tons of carbon dioxide (CO_2) equivalent (e) or tCO_2e (Murdiyarso et al., 2015), this study estimates that conserving one hectare of mangroves avoids GHG emissions equal to 271 tCO_2e.

Photo by Dimitry B on Unsplash

3.3. Scaling Up Investments Could Potentially Reduce The Average Restoration Costs Which are Currently of About USD 3,900

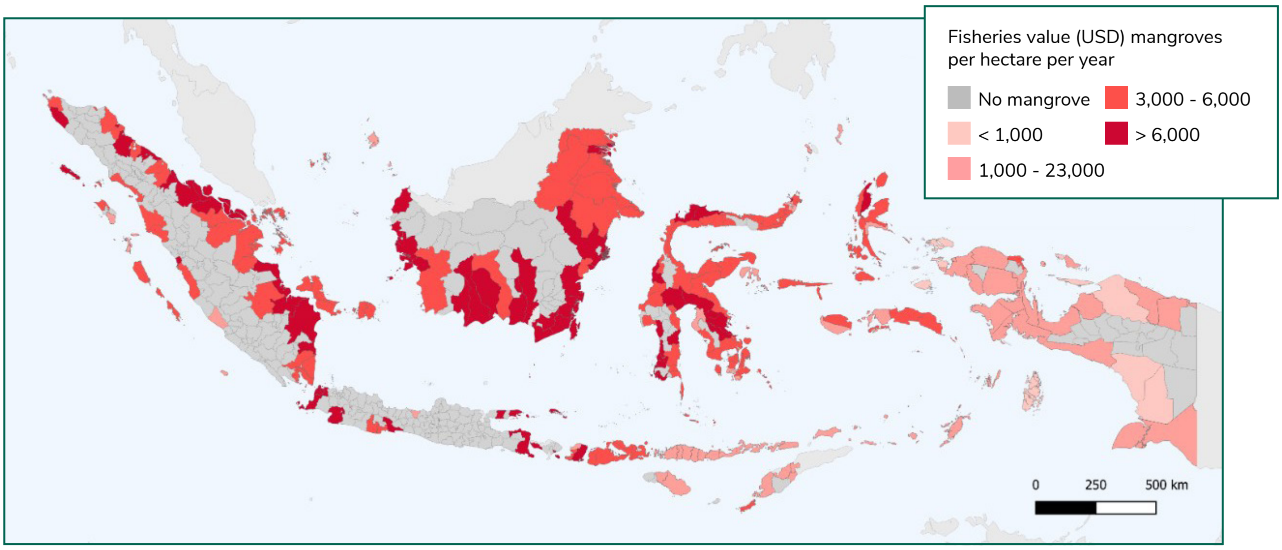
Cost estimates for mangrove restoration projects from the Government of Indonesia hover close to the median global cost estimates. The total cost for one hectare of mangrove restoration (planting 10,000 seeds) is about USD 3,550, which includes paying for mangrove seeds, planting facilities and infrastructure, and the work of planting (Ministry of Marine Affairs and Fisheries). On top of this amount, the government factors in additional investments of USD 330 for a mangrove center of excellence, community training, semi-permeable dams, and mangrove tourism infrastructure. This assessment combines government estimates and places the cost for restoration at USD 3,863 per hectare.

Photo by Nahel Abdul Hadi on Unsplash

3.4. Opportunity Costs of Land Vary Across Regions with Implications for The Policy Tools to Be Used for Sustainable Management

Land opportunity costs are highest (with a net present value of over USD 6,000 per hectare) in Southern Kalimantan, Eastern Sumatra, and parts of Java and Sulawesi (Figure 6). These areas have witnessed widespread mangrove deforestation over the past decades, and mangroves remain under pressure because replacing them with oil palm plantations, aquaculture, and agriculture is so profitable.

Figure 6. Spatial distribution of opportunity cost of alternative land uses



Source: Own elaboration based on Strassburg (2020); Jakovac et al. (2020) (See Annex A1, Methods Report)

3.5. Conservation Generally Provides Net Benefits More Efficiently Than Restoration, but Regional Differences Need to be Considered When Making Investment Decisions

Figure 7 illustrates the cost and benefit components considered for a hectare of mangrove restoration and conservation over a 30-year project lifetime. The values of costs and benefits represent the weighted mean values per hectare for the whole country.

But investment decisions also need to account for regional differences in costs and benefits. Spatially explicit cost-benefit analysis provides insights into where mangrove restoration and/or conservation is expected to be economically viable. A spatial overlay of cost and benefit information makes it possible to calculate cost-benefit indicators (such as net present value and benefit to cost ratios) in each district.

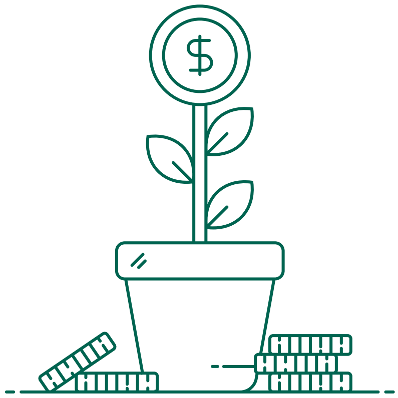
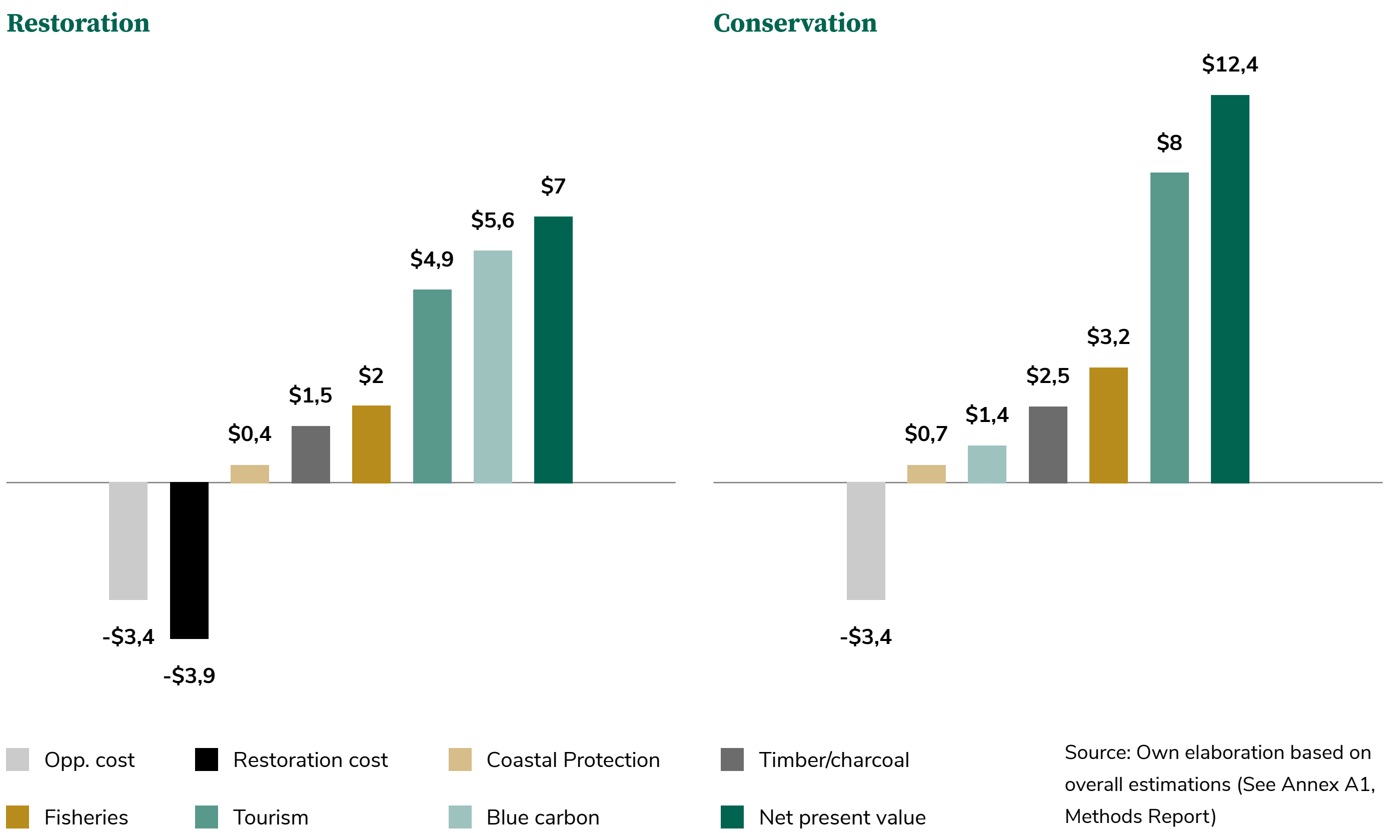


Figure 7. Costs and benefits of conservation and restoration across Indonesia (Weighted mean estimates in thousand US dollars per hectare)



Source: Own elaboration based on overall estimations (See Annex A1, Methods Report)

Figure 8 shows the benefit-cost ratio of mangrove conservation and mangrove restoration at district level. Considering a discount rate of 5.5% and a 30-year project lifetime, the benefit-cost ratio of a hectare of mangrove restoration is >1 in most districts indicating a positive net present value of the investment (Figure 8). In areas such as Eastern Sumatra and large parts of Kalimantan, where land opportunity cost area comparatively high and site-specific benefits such as coastal flood protection, fisheries and tourism are limited, the benefit-cost ratio of mangrove restoration is <1 indicating a negative net present value. In districts with low opportunity costs and high site-specific benefits, such as NTT and Western Papua, benefit-cost ratios range above 2 and in some districts exceed 5.

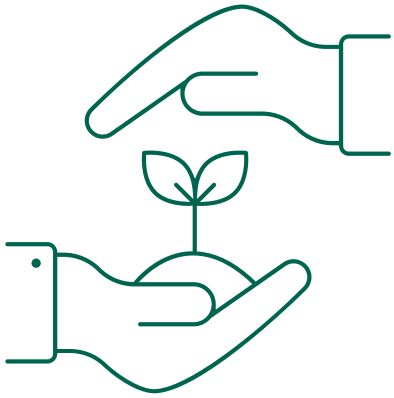
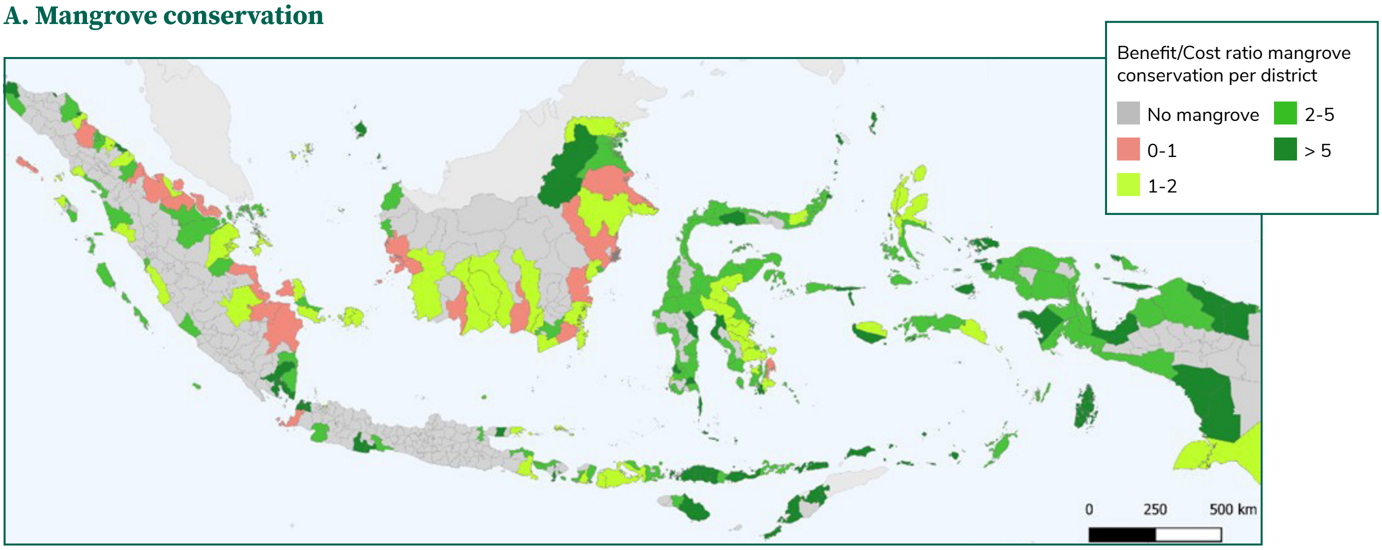
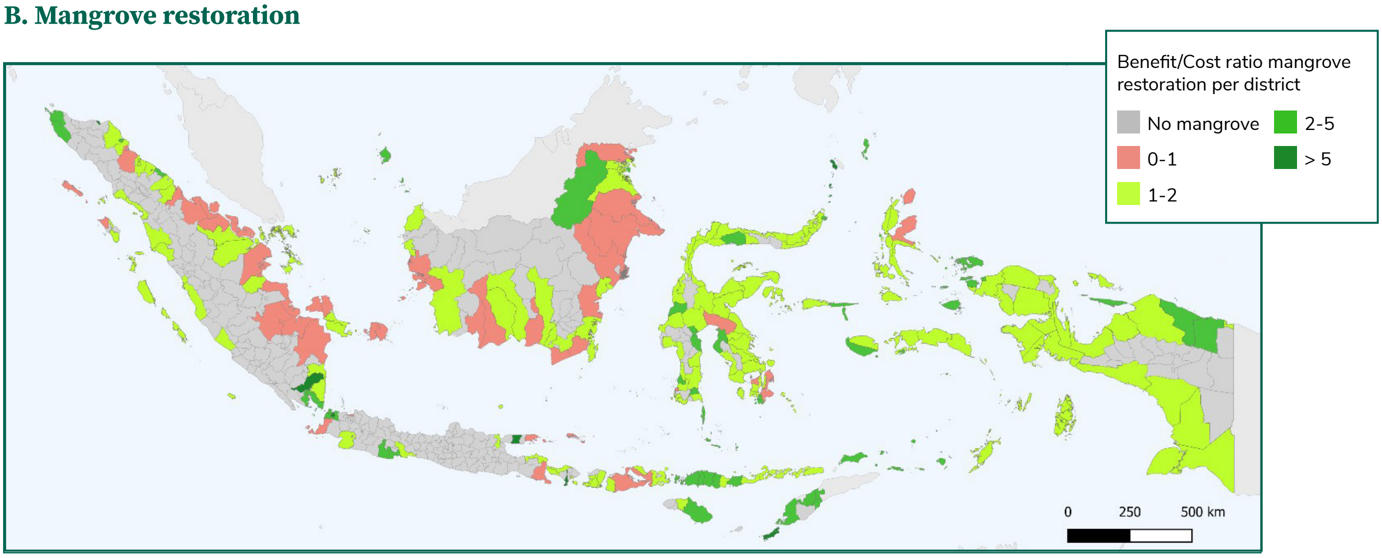


Figure 8. Spatial distribution of benefit-cost ratios for mangrove conservation and restoration

A. Mangrove conservation



B. Mangrove restoration



Source: Own elaboration based on Strassburg (2020); Jakovac et al. (2020)

3.6. An Optimal Mix of Conservation and Restoration Activities Could Lead to Better Mangrove Management Than Restoration Targets Alone

Equipped with this spatially explicit framework of district-level costs and benefits, decision makers can assess mangrove restoration and conservation investment scenarios and optimize the location of these investments across Indonesia. Strategically locating and prioritizing the best options can potentially lower the costs of managing mangroves sustainably, and improve the outcomes and benefits from these public investments. Spatially explicit CBA reveals which scenarios make the most sense. For example, in areas with lower opportunity cost for mangrove conservation and restoration, large scale conservation, co-financed by carbon offsets, is likely economically viable, while in areas with high site-specific benefits (e.g., flood protection, fisheries and tourism), large scale restoration is economically viable.

To determine where investing in restoration or conservation could be viable, benefits and costs are aggregated to create a scenario analysis. Land opportunity costs for areas to be restored are calculated considering a distribution of previous land uses: plantations and agriculture, aquaculture and fishponds, and degraded mangrove forests. These land use categories also inform the type of mangrove restoration technique to be applied and hence refine the restoration cost estimates. In this case, an expert judgement provides a baseline where the benefit-cost ratio is the sole consideration (single indicator of reference). However as described before, the rates of degradation and the contribution to total cover play a role when defining future scenarios.

Photo by @doraclub on Freepik

4. Policy Implications: Adopting an Integrated Conservation, Restoration, and Blue Finance Strategy

Mangrove restoration should be approached within the broader policy context of the Government of Indonesia's blue economy strategy, the targets set under its medium-term development plan (RPJMN) for 2020-24, and the Indonesia Oceans Policy. This broader suite of actions include:

- Improved fisheries governance through operationalization of the Fishery Management Area (WPP) system
- Development, integration, and implementation of spatial plans
- Expansion of marine protected areas
- A national action plan for marine debris
- An integrated and sustainable tourism development program

This study finds that an efficient mix of mangrove restoration and conservation activities could help the Government of Indonesia reach its goals of restoring 600,000 hectares of mangroves and (more importantly) managing mangroves sustainably. The spatial cost-benefit analysis helps identify where these each of these activities will produce higher returns. To produce the expected results, any mix of investments will require a combination of policy approaches or enabling actions. The government will need to:

- **Ensure restoration practices and financing provide adequately for long-term management and monitoring.** Efforts focused on replanting alone do not show high rates of long-term success. To succeed, policymakers will probably need to carefully prioritize areas for restoration (e.g. those that provide the highest net benefit). Restoration can provide significant environmental and economic benefits, but should be directed to areas where it provides maximum value in terms of benefit-cost ratios. Data show that the success of restoration activities depends on the adequacy of the:
    - Habitat to be restored (e.g. appropriate hydrology)
    - The materials used (quality of seedlings)
    - The medium-term management (e.g. tending, protection)
    - Long-term operational oversight.

- **Promote restoration methodologies that maximize labor utilization, especially as part of the COVID recovery stimulus investments.** It will be important to expand labor-intensive coastal and marine restoration activities such as mangrove restoration and coastal cleanups. This can provide both short-term employment during the post-COVID recession and long-term and resilient rehabilitation of mangrove benefits. This recommendation aligns with the findings of both this study and the High-Level Panel on Oceans, which recommended coastal ecosystems restoration as a top-five blue economic stimulus for the post-COVID recovery.

- **Strengthen the evidence base for improved enforcement and mangrove management.** This could include finalizing the Mangrove One Map to ensure an accepted and consistent whole-of-Government understanding of key facts and trends, including the extent and quality of mangrove forests and adjacent coastal ecosystems. Developing a credible and reliable valuation and accounting system could also offer opportunities for improved data and coordinated policy decision making. Natural capital accounting builds on improved data to support effective marine and coastal policies. It provides standardized data on the status and economic values of natural assets and how these assets are affected by human activity. Indonesia began building NCA through the Indonesian System of Environmental-Economic Accounts (SISNERLING) and could continue to include marine and coastal assets including mangroves.

- **Explore complementary policies such as implementing a mangrove moratorium.** Indonesia has a moratorium on land conversion for primary forests and peatlands. Despite their immense value, including their greater effectiveness at sequestering carbon, mangroves enjoy no such protection. Indonesia could broaden its moratorium on licensing the conversion of primary forest and peatlands to include mangroves as well. This could be accomplished through legislation. It would help Indonesia speed its progress and demonstrate its commitment to reaching its climate targets and achieving a blue economy.

- **Secure payments for blue carbon and ensure that benefits reach local communities.** Indonesia would need to develop blue carbon readiness to ensure Indonesia can benefit from international blue carbon financing, including carbon accounting, monitoring and verification tools. Likewise, by including mangroves as nature-based solutions for coastal adaptation and resilience in NDCs, Indonesia could come up with targets for coastal adaptation and resilience. Protecting, managing, or enhancing mangroves could provide nature-based and hybrid solutions enabling Indonesia to reach these targets.

5. References

Acharya, G. (2002). Life at the margins: The social, economic and ecological importance of mangroves. Madera y Bosques, 8(1).

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193.

Bayraktarov, E., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., Mumby, P. J., & Lovelock, C. E. (2016). The cost and feasibility of marine coastal restoration. Ecological Applications, 26(4), 1055–1074. https://doi.org/https://doi.org/10.1890/15-1077

Brander L.M, Alfred J. Wagtendonk, Salman S. Hussain, Alistair McVittie, Peter H. Verburg, Rudolf S. de Groot, Sander van der Ploeg. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application, Ecosystem Services, Volume 1, Issue 1, (2012). Pages 62-69, https://doi.org/10.1016/j.ecoser.2012.06.003.

Brander, L. M., Wagtendonk, A. J., Hussain, S. S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. Ecosystem Services, 1(1), 62–69.

Chong, V. C. (2006). Sustainable utilization and management of mangrove ecosystems of Malaysia. Aquatic Ecosystem Health & Management, 9(2), 249–260.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global Environmental Change, 26, 152–158.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., & Hein, L. (2012). Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services, 1(1), 50–61.

Ecoshape. (2021). Building with nature Indonesia. https://www.ecoshape.org/en/pilots/building-with-nature-indonesia/

Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011). Status and distribution of mangrove forests of the world using earth observation satellite data (version 1.4, updated by UNEP-WCMC). Global Ecology and Biogeography 20: 154-159. Paper DOI: 10.1111/j.1466-8238.2010.00584.x . Data DOI: https://doi.org/10.34892/1411-w728

Global Commission on Adaptation. (2019). ADAPT NOW: A GLOBAL CALL FOR LEADERSHIP ON CLIMATE RESILIENCE #AdaptOurWorld.

Hernández-Blanco, M., Costanza, R., & Cifuentes-Jara, M. (2021). Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology. Ecosystem Services, 49, 101258.

High Level Commission on Carbon Prices (2017). Report of the High-Level Commission on Carbon Prices. Washington, DC: World Bank.

Himes-Cornell, A., Pendleton, L., & Atiyah, P. (2018). Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. Ecosystem Services, 30, 36–48.

IUCN. (2017). What are mangroves worth? There's no easy answer https://www.iucn.org/news/forests/201704/what-are-mangroves-worth-there's-no-easy-answer

Jakovac, C. C., Latawiec, A. E., Lacerda, E., Leite Lucas, I., Korys, K. A., Iribarrem, A., Malaguti, G. A., Turner, R. K., Luisetti, T., & Baeta Neves Strassburg, B. (2020). Costs and Carbon Benefits of Mangrove Conservation and Restoration: A Global Analysis. Ecological Economics, 176. https://doi.org/10.1016/j.ecolecon.2020.106758

Jerath, M. (2012). An economic analysis of carbon sequestration and storage service by mangrove forests in Everglades National Park, Florida.

Lal, P. (2003). Economic valuation of mangroves and decision-making in the Pacific. Ocean & Coastal Management, 46(9–10), 823–844.

Mehvar, S., Filatova, T., Dastgheib, A., de Ruyter van Steveninck, E., & Ranasinghe, R. (2018). Quantifying Economic Value of Coastal Ecosystem Services: A Review. Journal of Marine Science and Engineering, 6(1), 5.

Menéndez, P., Losada, I.J., Torres-Ortega, S. et al. The Global Flood Protection Benefits of Mangroves. Sci Rep 10, 4404 (2020). https://doi.org/10.1038/s41598-020-61136-6

Ministry of Maritime Affairs and Investment. (n.d.). Statistics from reference data by the Coordinating .

MMAF and MoEF. (2019). Based on 2015 data.

Mukherjee, N., Sutherland, W. J., Dicks, L., Hugé, J., Koedam, N., & Dahdouh-Guebas, F. (2014). Ecosystem service valuations of mangrove ecosystems to inform decision making and future valuation exercises. PloS One, 9(9), e107706.

Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., Manuri, S., Krisnawati, H., Taberima, S., & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change, 5(12), 1089–1092. https://doi.org/10.1038/nclimate2734

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., van Wesenbeeck, B., Pontee, N., Sanchirico, J. N., Ingram, J. C., Lange, G.-M., & Burks-Copes, K. A. (2016). The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. PLOS ONE, 11(5), e0154735-. https://doi.org/10.1371/journal.pone.0154735

Rare Indonesia. (n.d.). Based on early survey data.

Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. Proceedings of the National Academy of Sciences of the United States of America, 113(2), 344–349. https://doi.org/10.1073/pnas.1510272113

Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., & Davidson, N. (2013). The economics of ecosystems and biodiversity for water and wetlands. IEEP, London and Brussels, 78.

Salem, M. E., & Mercer, D. E. (2012). The economic value of mangroves: A meta-analysis. Sustainability, 4(3), 359–383.

Spalding, M. & Parrett, C. Global patterns in mangrove recreation and tourism, Marine Policy, Volume 110, (2019), 103540, https://doi.org/10.1016/j.marpol.2019.103540

Spalding, M. (2010). World atlas of mangroves. Earthscan.

Spaninks, F., Beukering, P.V., 1997. Economic Valuation of Mangrove Ecosystems: Potential and Limitations. CREED Working Paper 14.

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., Braga Junqueira, A., Lacerda, E., Latawiec, A. E., Balmford, A., Brooks, T. M., Butchart, S. H. M., Chazdon, R. L., Erb, K.-H., Brancalion, P., Buchanan, G., Cooper, D., Díaz, S., Donald, P. F., … Visconti, P. (2020). Global priority areas for ecosystem restoration. Nature, 586(7831), 724–729. https://doi.org/10.1038/s41586-020-2784-9

TEEB (2010) The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Pushpam Kumar (Ed.), Earthscan, London and Washington

Tol, R. S. (2011). The social cost of carbon. Annu. Rev. Resour. Econ., 3(1), 419–443.

Tri, N. H., Hong, P. N., Manh, M. N. T., Tuan, M. L. X., Anh, M. P. H., Tho, M. N. H., … Tuan, M. L. D. (2000). Valuation of the Mangrove Ecosystem in Can Gio Mangrove Biosphere Reserve, Vietnam. UNESCO/MAB Programme National Committee, Center for Natural Resources and Environmental Studies (CRES), Hanoi University of Economics (HUE) and and Management Board of Can Gio Mangrove Biosphere Reserve, Hanoi.

Turner, K. G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., Dominati, E., Kubiszewski, I., Ogilvy, S., Porfirio, L., & others. (2016). A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. Ecological Modelling, 319, 190–207.

UNEP (2006) Marine and Coastal Ecosystems and Human Well-Being: A Synthesis Report Based on the Findings of the Millennium Ecosystem Assessment. United Nations Environment Programme, Nairobi

UNEP/GPA. (2003). The economic valuation of alternative uses of mangrove forests in Sri Lanka. UNEP/Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, The Hague.

Vo, Q. T., Künzer, C., Vo, Q. M., Moder, F., & Oppelt, N. (2012). Review of valuation methods for mangrove ecosystem services. Ecological Indicators, 23, 431–446.

Word Bank. (2021). Indonesia Sustainable Oceans Program.

World Bank (2021) Oceans for Prosperity: Reforms for a Blue Economy in Indonesia.

World Bank Group. (2016). Managing Coasts with Natural Solutions : Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. http://hdl.handle.net/10986/23775

World Bank. (2017). THE POTENTIAL OF THE BLUE ECONOMY Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. www.worldbank.org

World Bank. (2020a). Indonesia's mangroves for prosperous communities and a healthy planet- Factsheet.

World Bank. (2020b). Oceans for Prosperity: Reforms for a Blue Economy in Indonesia.

World Bank. (2021). Indonesia Sustainable Oceans Progr–m - News.

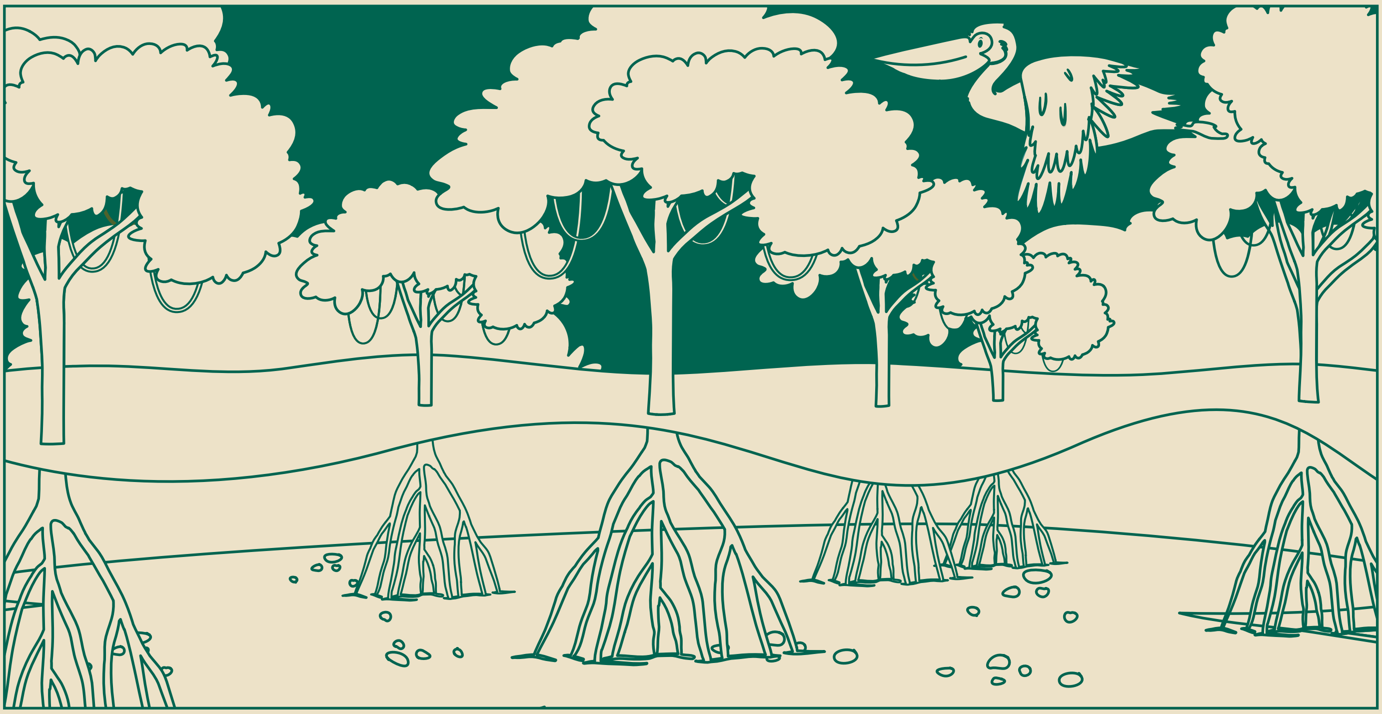
World Bank. (n.d.). Staff calculations based on BPS data.

World Bank. 2019. "Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica".

Worthington, T., Spalding, M., Herr, D., Hingorani, S., & Landis, E. (n.d.). Mangrove Restoration Potential A global map highlighting a critical opportunity. In Geological Survey. USDA Forest Service. www.globalmangrovewatch.org


Photo by Anton Lecock on Unsplash

6. Annexes



A1. Coastal Flood Protection Estimations

Mangroves protect coastal communities and assets against storm surges, coastal erosion, and rising seas. By building a living seawall they can slow or halt erosion, diminish wave energy, and temper the flooding driven by storm surges. This coastal protection depends on a wide variety of biophysical variables (e.g. mangrove forest extent, health, and topography) as well as social and economic ones (e.g. population density and value of private and public properties). Certain valuation methods such as replacement cost and value transfer can overestimate of the economic value of this service if they assume that similar mangrove ecosystems provide the same levels of protection everywhere. For instance, a large expanse of mangroves in an unpopulated area would have a lower economic value than one along a populated coastline (Hernandez-Blanco, et. al 2021). To account for biophysical, social and economic variables, it is necessary to examine the demand side, evaluating benefits actually derived.

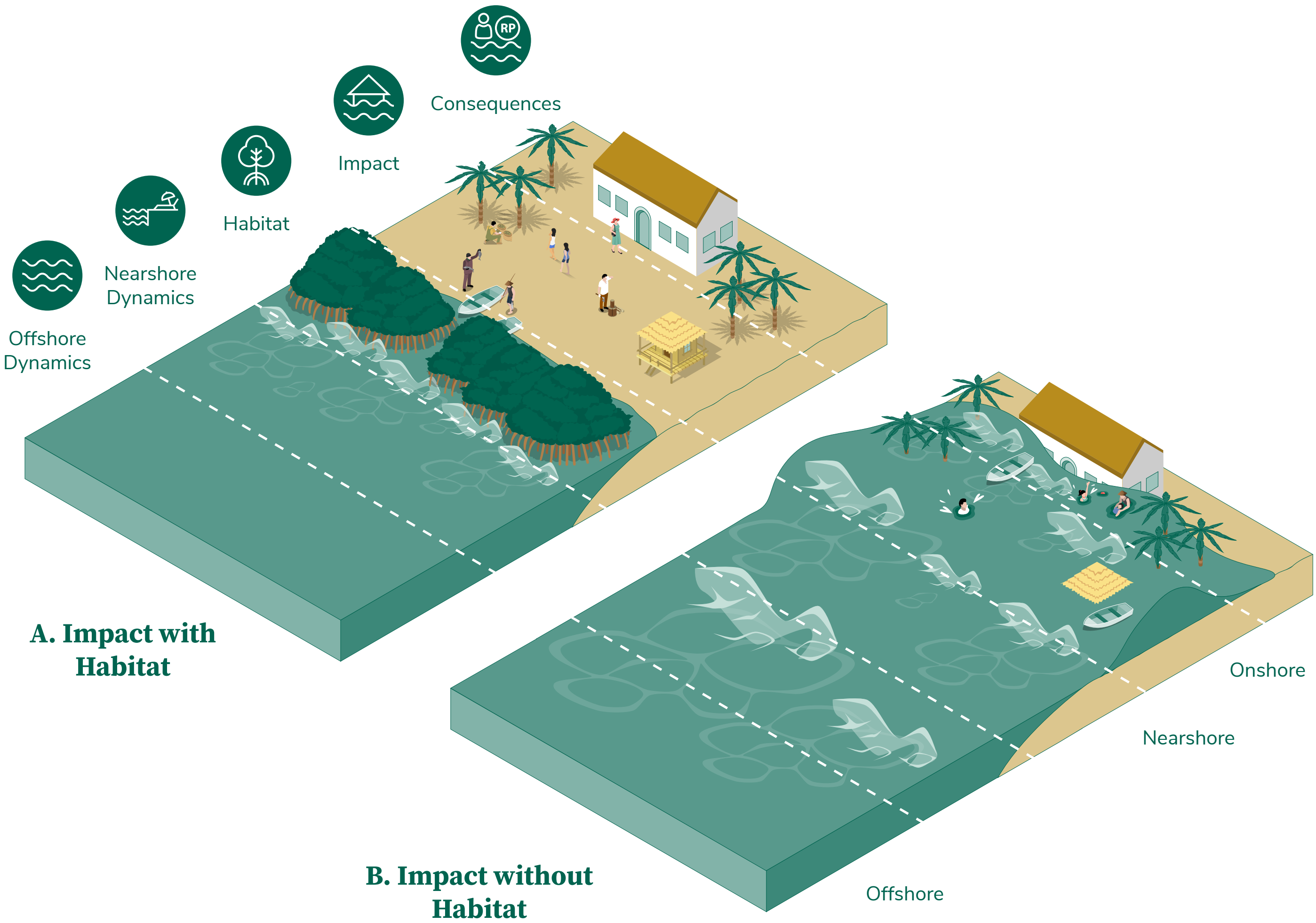
So this assessment used the avoided damage method to estimate the economic value of the coastal protection service mangroves provide throughout Indonesia. This method assigns a marginal economic value to the human and built capital that can be affected if natural capital (i.e. mangroves) are missing or are highly degraded.

We extracted our estimates from the global analysis conducted by Menendez et al. (2020) in using the avoided damage method. This applies a probabilistic, process-based valuation of mangroves' effects in protecting people and property in coastal communities. This method involved five steps (Figure 9).

- Estimating and characterizing offshore dynamic conditions (e.G. Wave height, wave period, storm surge and astronomical tide) produced from tropical cyclones and regular climate conditions
- Applying process-based models to downscale the offshore dynamics to the nearshore location of mangrove areas.
- Evaluating the role of mangroves in nearshore dynamics to obtain the flood heigh behind these ecosystems at the shoreward end of each section
- Estimating the amount of land flooded by storms or high water by intersecting the flood height at the shoreline with inland topography
- Calculating biophysical interactions between hydrodynamic conditions and mangroves and then contrasting expected impacts of flooding on populations, land and property, with and without, the presence of mangroves.

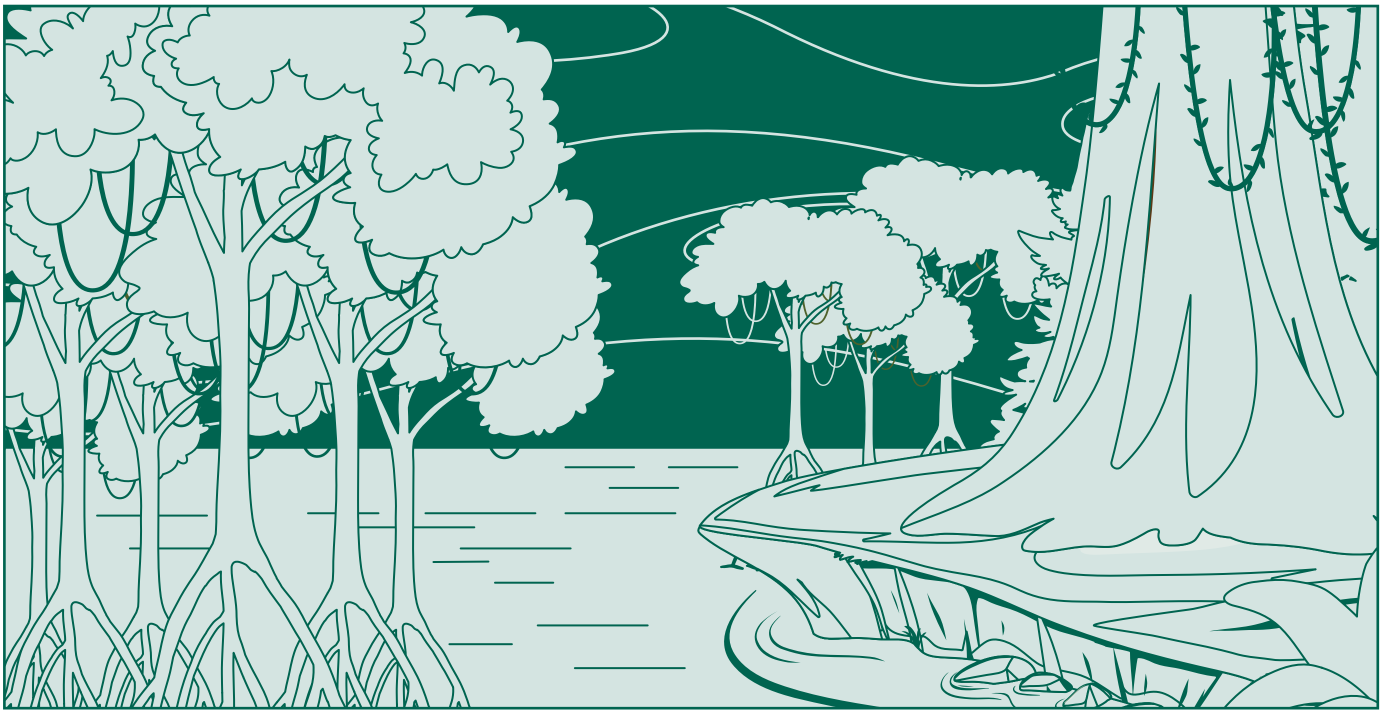
Industrial and residential property are included in this calculation, and the difference between the two scenarios equals coastal protection service from mangroves.

Figure 9. Steps for estimating consequences of damages



Step 1. Offshore dynamics: Oceanographic data are combined to assess offshore sea states. Step 2. Nearshore dynamics: Waves are modified by nearshore hydrodynamics. Step 3. Habitat: Effects of mangroves on wave runup are estimated. Step 4. Impacts: Flood heights are extended inland along profiles (every 1 km) for 1 in 10, 25, 50, 100-yr events with and without mangroves to estimate impacts. Step 5. Consequences: The consequences to land, people and built capital damaged under the flooded areas are estimated. Source: World Bank, 2019.

For Indonesia, local geospatial estimates of the annual flood protection value of mangroves are available at a 20 km resolution for coastal areas. There are limitations including those already recognized by Menendez et. al (2020). However, the flood protection values of mangroves calculated here are the first global estimates of flood protection benefits provided from process-based models. This work represents the state-of-the-art in mangrove flood protection benefits assessment and has been shown to provide better estimates than replacement cost approaches (Barbier et al., 2015; World Bank, 2016).



A2. Climate Regulation Estimations

This assessment calculates the value of Indonesian mangroves for carbon storage and sequestration in two ways: reduced greenhouse gas (GHG) in the atmosphere from mangrove restoration and avoided GHG emissions from conservation of existing mangrove ecosystems (Table 3, Right). Restoration reduces GHGs because, as they regrow, mangroves take carbon from CO_2, sequester it in their biomass and burry it in the soil. Restoration also reduces baseline GHG emissions, because mangroves typically replace a land uses that have been generating more GHGs, whether these are farms, fishponds or mudflats. The averted annual GHG emissions from such land uses is part of the blue carbon value of mangrove restoration (Table 3, Left).

We estimated blue carbon sequestration by calculating how much mangrove restoration reduced CO_2 concentrations in the atmosphere. We used measurements reported in Cameron et al. (2019) of GHG emissions of t 17 ± 5.6 tCO_2e per year from partially inundated aquaculture ponds in Indonesia with no mangrove coverage. Then, we added a 15 ± 5 tCO_2e per year biomass sequestration rate from mangrove restoration (average 35 years) as estimated by Cameron et al. (2018). Finally, we added the soil carbon burial estimated in 6.5 ± 2.1 tCO_2e per year by Alongi (2014) to come up with a total blue carbon reduction per year per hectare of 38.5 ± 12.7 tCO_2e.

We estimated blue carbon storage by calculating CO_2 emissions that the conservation of existing mangroves (i.e. carbon stocks) avoided. Mangroves allocate 50–90% of their carbon pool below ground and store the remainder in aboveground biomass. There is uncertainty about the share of stored blue carbon that mangrove deforestation or degradation will release into the atmosphere. To value blue carbon storage in mangrove conservation areas, this assessment used a conservative approach. It assumed that conservation would avert a loss of only 25% of mangroves' carbon stock (Jakovac et al., 2020). Considering a mean carbon density per hectare in mangroves of 1,083 tCO_2e (Murdiyarso et al., 2015), estimated avoided GHG emissions per hectare from conservation are 271 tCO_2e.

Table 3. Biophysical quantification approach for GHG reduction due to mangrove restoration (left) and avoided emissions due to mangrove conservation (right)

Mangrove restoration		Mangrove conservation	
GHG reduction components per ha		*Avoided emissions from deforestation per ha*	
GHG baseline reductions*	17 ± 5.6 tCO_2e per year	Avoided GHG emissions preventing mangrove deforestation, equaling 25% of the carbon density per hectare, estimated at 1,083 tCO_2e ha(Murdiyarso et al., 2015), over a 30-year time span (Jakovac et al., 2020)	
Biomass sequestration developing mangrove forest (average 35 years)**	-15 ± 5 tCO_2e per year		
Soil carbon burial (average for established mangrove forests)^	-6.5 ± 2.1 tCO_2e per year		
Total	-38.5 ± 12.7 tCO_2e year	Total	25% * 1,083 tCO_2e = 271 tCO_2e

* Based on GHG flux (sum CO2, CH4, N2O) from partially inundated aquaculture ponds in Indonesia with no mangrove coverage reported in Cameron et al. (2019). Use this number as it's likely to be in the same ball park as non-vegetated mudflats and degraded mangroves with sparse coverage, and .33% covers the potential range here.

** Sourced from Cameron et al. (2018), median values for coastal fringing and estuarine mangroves.

^ Sourced from Alongi (2014). This is the average carbon burial rate for an established forest, and rates of soil carbon capture / burial generally increase as forests develop over time but- as you note- this can also be really rapid initially in some instances e.g. when you knock pond walls down and soil accumulates and infills quickly. Again a .33% provides a decent and defensible buffer for the numbers you need in this proposal to cover a range of baseline scenarios.

Note: negative numbers = net sequestration (CO2 captured from the atmosphere), positive numbers = net GHG emissions to the atmosphere, which is consistent with the global literature, so the total = (biomass + soil) minus GHG baseline.

The price of carbon can vary significantly between countries, political contexts and financial mechanisms, and it could climb far higher than USD 5/ton. The High Level Commission on Carbon Prices (HLCCP) found that about 75% of the emissions that are covered by a carbon price are priced below USD 10/tCO_2. But is also found that, in order to achieve the GHG reductions needed to comply with the Paris Agreement and its temperature target, carbon prices should be around USD 40-80/tonCO_2 by 2020, and USD 50-100/tonCO_2 by 2030 (High Level Commission on Carbon Prices, 2017).

Other studies have considered different methodologies depending on whether they are determining values for carbon sequestration or carbon storage. For example, Hernández-Blanco et al. (2021) argues that, because carbon sequestration is a **flow,** a Social Cost of Carbon of USD 80/tonC as estimated by Toll (2011) is more accurate. This accounts for the cost of damage to human health, agricultural productivity and infrastructure caused by each ton of carbon emitted. On the other hand, the same study used a Marginal Abatement Cost of Carbon (MAC) of USD 125/tonC (as estimated by Jerath (2012) for the IPCC AR4) to value carbon storage, since MAC sums up the costs of eliminating each additional unit of carbon emissions. This can be translated to the economic benefit bestowed by maintaining **stocks** of carbon in the biosphere. The current array of methods and carbon prices can produce significant variations in the value assigned to mangroves' climate regulation service.


Photo by dapiki moto on Unsplash

The Economics of Large-scale Mangrove Conservation and Restoration in Indonesia

Technical Report

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP