



UNIVERSIDAD  
**NACIONAL**  
DE COLOMBIA

# **Manglares para la protección de socio-ecosistemas costeros. Caso de estudio Punta Soldado, Pacífico Colombiano**

**Natalia Zapata Delgado**

Universidad Nacional de Colombia  
Facultad, Departamento de Geociencias y Medio Ambiente  
Medellín, Colombia  
2024

# **Mangroves for protection of coastal social-ecological systems. Case study Punta Soldado, Colombia's Pacific Coast**

**Natalia Zapata Delgado**

Tesis o trabajo de investigación presentada(o) como requisito parcial para optar al título  
de:

**Maestría en Ingeniería – Recursos Hidráulicos**

Director:

Ph.D. Andrés Fernando Osorio Arias

Codirectora:

Ph.D. Clara Inés Villegas Palacio

Línea de Investigación:

Procesos y Manejo de Zonas Costeras

Grupo de Investigación:

Grupo de Investigación en Oceanografía e Ingeniería Costera - OCEANICOS

Universidad Nacional de Colombia

Facultad, Departamento de Geociencias y Medio Ambiente

Medellín, Colombia

2024



*A Nancy, Luz Dary, Guillermina, Selena y Jacinta; las mujeres piangüeras y sembradoras del manglar de Punta Soldado.*

*A las concheras y piangüeras de todo el Pacífico Colombiano.*

*A la comunidad de Punta Soldado y en especial a los jóvenes que se han propuesto emprender el camino del liderazgo para el crecimiento regenerativo de su territorio: Michell y Breyenner.*

*A los líderes comunitarios del Pacífico que luchan todos los días por sus territorios y todas las personas que quieren aportar desde lo colectivo...*

***El Propósito es Pacífico***

## Agradecimientos

A mi mamá como consejera quien me invitó a seguir el camino de los sueños y las pasiones. A Lina Margarita, Johana y Juan Guillermo quienes estuvieron siempre pendientes de mi proceso fomentando la importancia de la familia y el descanso. A Kira, Coco y Mar, mis gaticas que me acompañaron mucho más en este último año y que gracias a ellas tuve la fuerza para levantarme en los días buenos y no tan buenos; y que perdón por tanta trasnochadera.

A mi papá y mamá académicos, el profe Andrés y la profe Clara gracias por guiar y motivar este proceso siempre abriendo las posibilidades a las nuevas ideas, pero aterrizando a la realidad.

A Luisa y David, que, a pesar de la distancia y el cambio de horario, se mantienen cerquita de mi corazón. A Acosta y Alejo por estar allí acompañando y dando ánimos por todo lado.

A Dianis por ser luz en este proceso retador (el propio parto) que tuve la suerte de compartir con ella.

A los amigos de la 303 Hanna y Alejo que estuvieron ahí todos los días en la oficina para el brunch de las 4 pm y hablar de la vida, el trabajo y la tesis.

A los OCEANICOS con quienes hemos compartido grandes experiencias desde el Pacífico, el Caribe y más allá del Atlántico; a Juancho, Dani, Daniel, Pauli. Gracias a Cesi mi compañero del manglar, cómplice del barro, los modelos y el baile. A los que iniciaron este proceso tan bonito en la isla de Punta Soldado: Johann, Simón, Frank y Camilo por ser tan tesos y prender este motor que sigue prendido. A los que mantienen vivo este proceso hasta ahora: Gato, Irene, Ana y Sebas (con esas fotos espectaculares de manglares y aves).

Y por supuesto a la amiga, mico y mejor project manager que pueda existir, Ballan por ser la mejor líder del mundo mundial y ejemplo a seguir, quien ha liderado esta hermosa historia en la isla.

A Michell, la mayor inspiración para culminar este proceso que se extiende más allá de esta tesis.

A la comunidad de Punta Soldado, sus líderes, jóvenes y piangueras por abrirme las puertas de su territorio y su corazón; y por darme aliento en los últimos momentos de escritura de esta tesis en el Kiosko de doña Nubia.

Al CEMarin, el Programa de Soluciones Costeras y la Universidad Nacional de Colombia.

Al Pacífico Colombiano que me ha dejado entrar para conocer y trabajar con su gente y sus ecosistemas.

A la vida por permitirme vivir el mar como un trabajo hermoso y apasionante.

Gracias bendito mangle por permitirme entrar más allá del raicero. Este proceso terminó donde empezó, en los manglares y con la gente de esta playa bella que es Punta Soldado.

## Resumen

### **Manglares para la protección de socio-ecosistemas costeros. Caso de estudio Punta Soldado, Pacífico Colombiano**

Los manglares son sistemas socioecológicos (SSE) costeros en los que los factores biofísicos y socioeconómicos interactúan continuamente a diferentes escalas de tiempo y espacio. Estos ecosistemas desempeñan un papel crucial en la adaptación de las comunidades costeras a la variabilidad climática, ya que se ha comprobado que los manglares aportan múltiples Contribuciones de la Naturaleza a las Personas (NCP). Algunas de ellas son el papel de los manglares como barreras protectoras contra la acción de las olas y las inundaciones, el sustento de la pesca y otras especies marinas y la provisión de recursos esenciales y valores culturales para las comunidades costeras.

La Costa Pacífica Colombiana (CPC) alberga extensas áreas de manglares, con una significativa importancia ecológica y socioeconómica. Sin embargo, estos ecosistemas han sufrido una severa degradación debido a la variabilidad climática y a la intervención humana. En este estudio, se lleva a cabo una evaluación interdisciplinar (desde enfoques biofísicos, económicos y sociales) del impacto de los fenómenos de variabilidad climática en la contribución de los manglares a la protección costera y otros NCP asociados. Para realizar esta evaluación se utilizan los marcos SSE y NCP propuestos por la IPBES. Se propone un marco metodológico y se aplica a un SSE de manglares en la CPC. Este nuevo marco integra la modelización numérica del papel de los manglares en la protección costera, la investigación cualitativa y los enfoques de valoración económica; para proponer un modelo cualitativo de sistemas dinámicos que ayude a ilustrar las interacciones entre las diferentes variables del sistema en escenarios de variabilidad climática.

Se encontró que la función de protección costera de los manglares depende significativamente de las condiciones oceanográficas, como la dirección de las olas, su altura y el nivel relativo del mar. La relación no lineal entre la superficie del manglar y su capacidad de atenuación de las olas depende también de la altura de las olas. Para las condiciones medias del lugar de estudio, son necesarias 30 ha de manglares para garantizar una atenuación suficiente de las olas por este ecosistema.

Las percepciones de la comunidad local coinciden con estos hallazgos, especialmente en lo que respecta a la limitada capacidad de protección de los manglares, que también está condicionada por la oceanografía. Además, este PNC está relacionado con otras contribuciones, como el apoyo a la identidad y el sentido de pertenencia de la comunidad, y la provisión de trabajo y alimentos especialmente para las mujeres a través de la piangua

(Anadara sp.). El enfoque de valoración económica permitió comprender el papel del clima marino en el valor del PNC de protección costera de los manglares.

El modelo de sistemas dinámicos cualitativos mostró las conexiones entre los elementos clave que desempeñan un papel directo o indirecto en los PCN de protección costera de los manglares a la luz del marco del SES. Se trata de un sistema de 106 bucles que ilustra su complejidad, considerando cómo los cambios en un elemento (biofísico, económico o social) pueden afectar a otro tipo de elementos construyendo bucles tanto de refuerzo como de equilibrio en torno a la protección costera.

Este estudio pone de relieve la importancia de los enfoques interdisciplinarios para reforzar la resiliencia de los sistemas socioecológicos, no sólo frente al cambio climático, sino también frente a la variabilidad climática. Asimismo, los resultados obtenidos son aportaciones para que los profesionales y los responsables de la toma de decisiones propongan estrategias de reducción del riesgo que integren la gobernanza y los conocimientos locales y técnico-científicos.

**Palabras clave:** Manglares, Contribuciones de la Naturaleza a las Personas, Sistemas socioecológicos

## Abstract

### **Mangroves for protection of coastal social-ecological systems. Case study Punta Soldado, Colombia's Pacific Coast**

Mangroves are coastal social-ecological systems (SES) in which biophysical and socio-economic factors interact continuously at different scales of time and space. These ecosystems play a crucial role in the adaptation of coastal communities to climate variability, since mangroves have been found to provide multiple Nature Contributions to People (NCPs). Some of these are mangroves' role as protective barriers against wave action and flooding, sustaining fisheries and other marine species and providing essential resources and cultural values for coastal communities.

The Colombian Pacific Coast (CPC) is home to extensive areas of mangroves, with significant ecological and socio-economic importance. However, these ecosystems have suffered severe degradation due to climate variability and human intervention. In this study, an interdisciplinary assessment (from biophysics, economy and social approaches) is carried out of the impact of climate variability events on the contribution of mangroves on coastal protection and other associated NCPs. The SES and NCPs frameworks proposed by the IPBES are used to perform this evaluation. A methodological framework is proposed and applied to a mangrove SES in the CPC. This new framework integrates numerical modelling of the role of mangroves on coastal protection, qualitative research and economic valuation approaches; to propose a dynamic systems qualitative model that help illustrate the interactions among the different variables of the system in climate variability scenarios.

It was found that the coastal protection function of mangroves is significantly dependent on oceanographic conditions, such as wave direction, wave height and relative sea level. The non-linear relationship between mangrove area and its wave attenuation capacity is also dependent on the wave height. For average conditions in the study site, 30 ha of mangroves are necessary to guarantee enough wave attenuation by this ecosystem.

The perceptions of the local community agree with these findings, particularly regarding the limited protecting capacity of mangroves that are also conditioned by oceanography. Additionally, this NCP is related with other contributions, such as supporting the community's identity and sense of belonging, and the provisioning of work and food specially for women through *piangua* (*Anadara sp.*). The economic valuation approach

gave insights about the role of sea climate on the value of mangroves' coastal protection NCP.

The qualitative dynamic systems model showed the connections among the key elements that play a direct or indirect role in mangrove's coastal protection NCPs at the light of the SES framework. This is a 106-loop system that illustrates its complexity, considering how changes in one element (biophysical, economic or social) can affect other kinds of elements building both reinforcing and balancing loops around coastal protection.

This study highlights the importance of interdisciplinary approaches to strengthen social-ecological systems resilience not only for climate change but climate variability. Also, the results obtained are inputs for practitioners and decision makers to propose risk reduction strategies that integrate governance, local and technical-scientific knowledge.

**Keywords:** Mangroves, Nature Contributions to People, NCP, social-ecological systems

# Content

	Page.
<b>1. Introduction .....</b>	<b>1</b>
<b>2. Conceptual Framework.....</b>	<b>1</b>
2.1 Mangrove Social-Ecological Systems (SES) .....	1
2.2 Nature's Contributions to People (NCP) .....	2
2.3 Coastal Protection .....	3
<b>3. Mangroves biophysical contributions to protection.....</b>	<b>4</b>
3.1 Study area and biophysical features.....	6
3.2 Numerical model with vegetation.....	7
3.2.1 Flow model .....	8
3.2.2 Wave model.....	9
3.2.3 Rigid vegetation model .....	10
3.2.4 Mangroves area and parameters distribution .....	13
3.2.5 Waves and sea level variability .....	14
3.2.6 Cases selection .....	17
3.3 Model results.....	17
3.3.1 Mangrove coverage effect on wave attenuation.....	17
3.3.2 Wave attenuation spatial patterns with Sea Level Rise .....	19
3.3.3 Mangrove effect on floods.....	23
3.4 Discussion.....	24
3.4.1 Mangroves contributions to coastal protection .....	24
3.4.2 Implications of mangrove loss on coastal protection .....	25
3.4.3 It is not only mangroves, but mudflats and people .....	25
<b>4. Perceptions on mangroves contributions to people .....</b>	<b>27</b>
4.1 Study area, social and cultural features.....	28
4.2 Qualitative approach .....	31
4.3 Results .....	34
4.3.1 Percieved material contributions .....	35
4.3.2 Percieved non-material contributions .....	37
4.3.3 Percieved regulation contributions .....	38
4.3.4 Perceived mangroves drivers of change .....	40
4.3.4.1 Anthropogenic drivers.....	41

---

4.3.4.2 Natural drivers .....	41
4.3.5 Effects of mangrove loss on their NCPs.....	42
4.4 Discussion.....	45
4.4.1 Community perceptions of mangrove contributions to people .....	45
4.4.2 The highly dynamic protective capacity of mangroves .....	46
4.4.3 Changes on mangroves contributions and their implications on Ecosystem-based adaptation strategies .....	47
4.4.4 Community's symbolic relationship with mangroves .....	48
<b>5. The role of mangroves in reducing damage. An economic approach.....</b>	<b>50</b>
5.1 Economic features of Punta Soldado.....	51
5.2 Assessment of expected avoided damages.....	52
5.3 Results.....	55
5.3.1 Mangroves effect on wave attenuation and coastal flooding .....	55
5.3.2 Economic value of infrastructure and associated income.....	57
5.3.3 Damage reduction by mangroves .....	59
5.4 Discussion.....	59
5.4.1 Damage reduction by mangroves, mudflats and beaches .....	59
5.4.2 Process-based approaches vs benefit transfer .....	60
5.4.3 The economic value of related mangrove contributions to people.....	61
<b>6. The complexity of coastal protection in mangrove social-ecological systems .62</b>	
6.1 Mangrove social-ecological system .....	63
6.2 Dynamic nature of mangroves contribution to coastal protection .....	66
<b>7. Conclusions.....</b>	<b>70</b>

## List of Figures

	<b>Page.</b>
Figure 1. Schematic introduction and methods carried out for the evaluation of coastal protection in mangroves social-ecological systems. ....	4
Figure 2. Buenaventura Bay location in the Colombian Pacific Coast and mangroves coverage in 2020 from Global Mangrove Watch data (left). Zoom to Punta Soldado Island where channels' locations are indicated. ....	6
Figure 3. QQ plots of water level (left) and eastward currents velocity (right) that compares measurements in AWAC's position and the numerical model.....	9
Figure 4. QQ plots of significant wave height (left) and peak period (right) that compare measurements in AWAC's position and the numerical model. ....	10
Figure 5. Points of surveys of mangrove structure and root structure in Punta Soldado Island taken from secondary data and in situ field campaigns. ....	11
Figure 6. Scheme summarizing mangrove roots parameter estimation process considering species root types. ....	12
Figure 7. Mangrove area evolution from 1996 to 2019 considering GMW data (left), and coastline changes in Punta Soldado Island from 1997 to 2019 obtained through remote sensing analysis (right).....	14
Figure 8. Boxplots of the monthly multiyear mean of significant wave height, peak period, and wave direction from ERA 5, and relative sea level from Buenaventura tide gauge...	16
Figure 9. Peaks Over Threshold POT method applied to the significant wave height extreme events series extracted from ERA5 data. ....	16
Figure 10. RMS of the significant wave height spatial distribution near Punta Soldado Island. ....	18
Figure 11. Spatial distribution of the difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an indecent significant wave height of 1.0 m, wave direction WSW and RSL of zero. ....	18
Figure 12. Spatial distribution of the difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an indecent significant wave height of 1.0 m, wave direction W and RSL of zero. ....	19
Figure 13. Spatial distribution of the relative difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an indecent significant wave height of 1.75 m, wave direction W and RSL of zero. ...	19

Figure 14. Comparison of the spatial distribution of the mean absolute difference between the Hs for average RSL and 0.4m of temporal sea level rise, without vegetation and with 1996 mangroves distribution within Punta Soldado Island, for an incident significant wave height of 1.0 m and wave direction WSW. ....	20
Figure 15. RMS Significant wave height evolution within a transect in front of Punta Soldado Village during the high tide (top) and the low tide (bottom). ....	21
Figure 16. Cumulative mangrove's wave attenuation contribution in function of mangrove area.....	22
Figure 17. Water heads with and without vegetation for different wave and water level scenarios in front of Punta Soldado Village (left) and in Estero Bodega (right). ....	23
Figure 18. Aerial photograph of Punta Soldado village in february 2022 in low tide. Taken by the author. ....	29
Figure 19. Mangroves species in Punta Soldado Island. Credits: Elkin Caicedo, Deisy Montaña, Edwin Alomia and Ballantyne Puin .....	30
Figure 20. Evolution of Punta Soldado's mangrove social-ecological system. Created by the author. ....	30
Figure 21. Aerial images of mangroves regeneration area (left), dying mangrove area at the front of the island (middle) and signs of mangrove deforestation in the island (right). Taken by the author. ....	31
Figure 22. Schematic diagram of the qualitative approach methodology for the assessment of perceptions. ....	32
Figure 23. Perceived mangroves contributions to people identified in Punta Soldado. ...	34
Figure 24. Piangueras of Punta Soldado collecting piangua ( <i>Anadara sp</i> ). Credits: Corporación Social Manantial.....	35
Figure 25. Mangrove planting by the local group of mangrove's people. Photos taken by Jorge Luis Rocha .....	36
Figure 26. Mangrove wood to build houses in Punta Soldado. Photos by Jorge Luis Rocha.....	36
Figure 27. Fauna associated to mangroves ecosystem found in Punta Soldado. ....	39
Figure 28. Classification of mangroves drivers of change considering the eight proposed typologies. Created by the author. ....	40
Figure 29. Number of perceived mangroves' NCPs affected by the identified drivers of change. Created by the author. ....	43
Figure 30. Conceptual diagram of the process-based methodology for the assessment of avoided damage attributed to mangroves.....	53
Figure 31. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1 m coming from WSW. ....	56
Figure 32. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1 m coming from W.....	56
Figure 33. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1.7 m coming from WSW. ....	57
Figure 34. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1.7 m coming from W.....	57

Figure 35. Punta Soldado's mangrove social-ecological system based on IPBES Framework. ....	65
Figure 36. Causal diagrama of Punta Soldado's mangrove social-ecological system representing the complexity of interactions between the variables within the SES.....	67

## List of Tables

	<b>Pág.</b>
Table 3-1. Phase and amplitude of the 7 main tide constituents obtained from the Buenaventura tide-gauge time series. ....	8
Table 3-2. Mangrove stilt root parameters for Punta Soldado Island are estimated through the modified Ohira et al (2013) model classified per zones.....	13
Table 3-3. Mangrove area evolution in Punta Soldado Island calculated from the Global Mangrove Watch data .....	14
Table 3-4. Wave and RSL scenarios to be assessed for four scenarios of mangroves coverage (1996, 2007, 2015 and 2019) and one control scenario without vegetation.....	17
Table 4-1. Categories for the identification of Nature’s contributions to people (Díaz et al., 2018) perceived by the community of Punta Soldado with the thematic analysis method. ....	32
Table 4-2. Typologies created from the text to assess perceived drivers of change of the mangrove ecosystem in Punta Soldado. Created by the author. ....	34
Table 5-1. Inventory of affected infrastructure from extreme events. ....	58
Table 5-2. Present value of revenue per tourist per night in 10 hotels in Punta Soldado for the year 2023. ....	58



# 1. Introduction

Mangroves are coastal ecosystems that, together with local populations, constitute social-ecological systems (SES) where biophysical and socioeconomic factors interact continuously across various spatial and temporal scales (Dahdouh-Guebas et al., 2021). Ecosystem services (ES) defines as the contributions of nature to human wellbeing (Costanza et al., 1997; Millennium Ecosystem Assessment (Program), 2005) are an example of multiscale interactions in social-ecological systems, as the physical and biological structure of an ecosystem determines the ecological processes on which potential contributions to social systems depend (Liquete et al., 2013). Recently, the framework of Nature's Contributions to People (NCP) was proposed, this new approach extends the concept of ecosystem services recognizing the two-way interactions among the socio-economic and ecological dimensions; it also considers the knowledge of Local Communities and Indigenous People (LCIP) on the complexity of this interactions (Bongaarts, 2019; Díaz et al., 2018; Kelly-Quinn et al., 2022). These contributions are essential for providing livelihoods and supporting coastal communities (Ávila-Foucat & Espejel, 2020).

Several of mangrove's contributions to people have been identified in previous studies (Barbier et al., 2011; Bimrah et al., 2022), mangrove forests are recognized as support systems for marine life specially as breeding grounds for multiple species of fishes including sharks (Lee et al., 2014). They also contribute to nutrient cycling and carbon sequestration (Hutchison et al., 2014). Moreover, mangroves sustain coastal communities through wood extraction, recreational activities like tourism, and as a food source, and they represent significant cultural assets for local communities whose livelihoods depend on this ecosystem (Vo et al., 2012).

One of the most important characteristics of mangroves in many places of the world is their role as protective barriers against moderate wave action and flooding, which is fundamental for the defense of human settlements and the livelihoods that sustain them (Alongi, 2008; Barbier, 2016; Gijssman et al., 2021; Lee et al., 2014; Mazda et al., 1997). Therefore, mangrove forests have been cataloged as crucial ecosystems for the adaptation of local communities and coastal areas to climate change and climate variability (M. D. Spalding, Ruffo, et al., 2014). However, recent studies have found that the action of various climatic and oceanic forces (Goldberg et al., 2020) associated with climate variability events has led to the degradation of these ecosystems (Leal & Spalding, 2022; Rossi & Soares, 2017). The historical degradation of mangrove forests has resulted in a global loss of

approximately 1.04 million hectares between 1990 and 2020 (FAO, 2020), possibly affecting their ecological functions and, consequently, the contributions these ecosystems provide to the livelihoods of coastal communities on a global, regional, and local scale.

The recent accelerated changes in the climate and ocean systems have raised concerns about the impacts they may have on ecosystems' functions and coastal communities. Despite the capacity of coastal ecosystems to mitigate these impacts, the likelihood that extreme events will exceed their tolerance threshold is increasing (Refugio-Coronado et al., 2021). The degradation of coastal ecosystems such as mangroves due to anthropogenic and natural processes is a current reality, and greater damage is projected because of climate change (Vo et al., 2012). These degradation processes lead to changes in ecosystems and, consequently, in the NCPs they provide. Specifically, the degradation of mangrove ecosystems is expected to result in a progressive decline in their protective capacity against short-duration natural events, leading to immediate and significant impacts on coastlines, such as flooding and erosion (Barbier, 2016).

Thus, it is imperative to evaluate the state and trends of biophysical factors associated with these natural forces, as well as their interconnections with human well-being from the perspectives of the social and economic systems of coastal communities and their response to these forces (Barbier et al., 2011; Hill et al., 2021). According to (Bell & Lovelock, 2013) and (Osorio-Cano et al., 2019), the quantification and analysis that integrates the evaluation of the biophysical capacity of ecosystems to provide coastal protection, as well as the perceptions and benefits associated with this contribution, is of great importance for coastal zone planning and management. This is particularly important because it serves as a tool for decision-making, such as the formulation and execution of projects for the conservation and/or restoration of coastal ecosystems like mangroves.

The study of NCPs in marine-coastal systems has often been conducted in isolation, analyzing each component ignoring the high complexity of the social-ecological systems explained by the dynamic and multidimensional nature of these SES (Schlüter et al., 2020). (Glaeser et al., 2009) argued that the analysis of coastal SES has the potential to improve Integrated Coastal Zone Management as it facilitates interdisciplinary discussion for knowledge integration. In addition, (Ávila-Foucat & Espejel, 2020) point out that identifying and assessing changes in the provision of NCPs and their influence on community well-being is of utmost importance, as it generates transdisciplinary inputs for decision-making in coastal areas.

The Colombian Pacific Coast (CPC) is one of the most representative areas for mangroves globally, with an approximate extension of 198,800 hectares (INVEMAR, 2022). It is also one of the regions with the highest aboveground biomass associated with mangroves worldwide (Hutchison et al., 2014). Additionally, the CPC is home to coastal communities, primarily composed of Afro-Colombians and indigenous peoples, who benefit from the direct and indirect contributions generated by mangroves within the SES they form.

According to (Fuentes et al., 2022) and (Gallego Perez & Selvaraj, 2019), the central Pacific coast of Colombia is highly exposed and vulnerable to coastal erosion (associated with climate variability events), one of the main drivers of change in CPC mangroves and their ecosystem services (Sánchez-Núñez et al., 2019).

Given the high dependence of local communities in the CPC region on natural ecosystems, it is crucial to assess the effects of changes in mangrove areas related to climate variability on their protective capacity and the potential social and economic impacts within these social-ecological systems. One of the areas in the region where mangrove reduction has been observed is the barrier island of Punta Soldado, home to one of the Community Councils of Black Communities of the Colombian Pacific. This research aims to address the impacts associated with climate variability on the contributions of mangroves to the protection of the social-ecological mangrove system in Punta Soldado.

The objective of this master's thesis is to evaluate the impacts of climate variability events on the coastal protection contributions of the mangrove social-ecological system in Punta Soldado on the Colombian Pacific Coast, considering ecological, social, and economic perspectives. This thesis aims at meeting the following specific objectives: 1) To quantify the coastal protection function of mangrove ecosystems for various land cover scenarios and climate variability events in the case study; 2) To identify local community perceptions of the change in nature's contributions provided by mangroves due to climate variability events; 3) Assess the economic effects of the change in the coastal protection contribution of mangroves at the local level; 4) To analyze the relationships between the assessed components of the coastal protection contribution in the socio-ecological system. The latter is addressed in the document in five sections; in the first section, the framework of nature's contributions to people in social-ecological systems is presented as the conceptual framework of this research; The second section assesses the biophysical contributions of mangroves to coastal protection on Punta Soldado Island and examines the effects of climate variability on this function using a numerical modeling approach. The third section qualitatively explores local perceptions of mangroves' contributions to communities and the changes they have experienced. The fourth section evaluates the economic impacts of changes in mangroves' protective contributions in Punta Soldado by quantifying the avoided damages under different maritime climate scenarios. Finally, the fifth section presents an integrated analysis of the relationships among the previously assessed elements, highlighting the contribution of coastal protection within the mangrove social-ecological system (Figure 1).

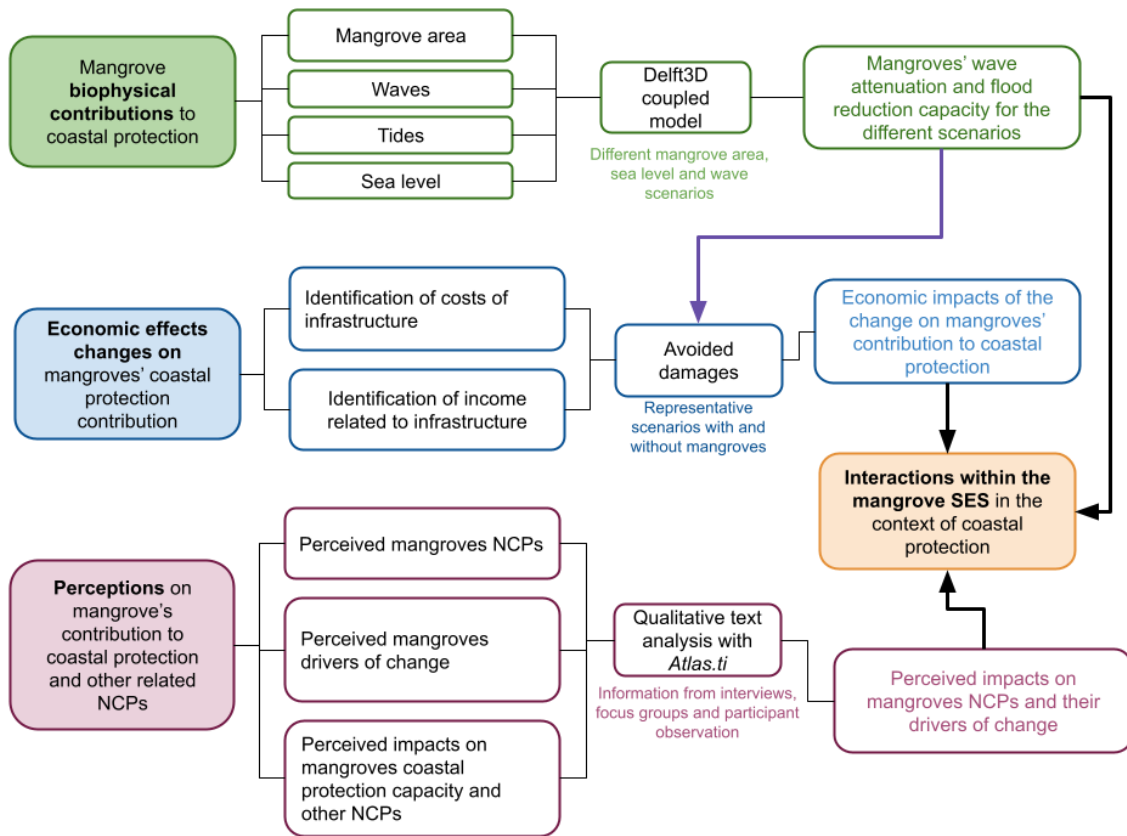


Figure 1. Schematic introduction and methods carried out for the evaluation of coastal protection in mangroves social-ecological systems.

## 2. Conceptual Framework

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has designed the frameworks of Social-Ecological Systems (SES) and Nature's Contributions to People (NCP) as tools that provide common terminology and structure to characterize and assess the relationships between people and nature (Díaz et al., 2015). This research employs the Social-Ecological Systems (SES) Framework to analyze the interactions between ecological, economic and social components within the mangrove ecosystem and the people. This is carried out by the assessment of the associated Nature's Contributions to People, that are the conduit between nature and people's well-being (Pascual et al., 2017).

### 2.1 Mangrove Social-Ecological Systems (SES)

The SES framework allows us to view the mangrove ecosystem not just as a collection of natural resources, but as part of a larger, dynamic system that includes human activities, governance structures, and social networks. This framework also allows for an integrated assessment of how various elements interact within the system, and how these interactions are influenced by both climate-related and anthropogenic drivers (Díaz et al., 2015). The SES framework is composed of several interrelated elements, each of which plays a critical role in the assessment of mangrove social-ecological systems.

- A. **Nature.** These systems include the natural capital inherent in the ecosystem, such as biodiversity, soil, and water resources. The health and sustainability of the natural systems are central to the well-being of the local communities.
- B. **Direct drivers.** These are the drivers that can directly affect the natural capital and can be both natural and anthropogenic. Natural drivers are those whose occurrence is beyond human control, such as climate and weather patterns or extreme events. Anthropogenic drivers are those that result from human direct actions.
- C. **Governance systems and other indirect drivers.** Refers to the way people organize themselves and their interactions with nature through the establishment of institutions, rules and decisions that may result in a direct effect on nature.
- D. **Anthropogenic assets.** Refers to building infrastructure, facilities, knowledge, technology and financial assets that facilitate people to get benefits from nature.

- E. **Nature's contributions to people.** All the contributions (material, non-material and regulating) that nature provides directly, indirectly or with the help of anthropogenic assets.
- F. **Human well-being.** The outcomes (positive and negative) of the interactions among the latter elements can be seen in the ecological health of the mangroves, the economic well-being of the communities, and the social cohesion within these groups.

This research assesses the natural system of mangrove forests, focusing on the direct drivers of change, with particular attention to climate-related factors. It examines the changes in Nature's Contributions to People, primarily coastal protection (regulation of hazards and extreme events), and the potential consequences for human well-being. Additionally, the study partially explores the anthropogenic assets, regulations, and stakeholders that can influence the generation of direct drivers of change in mangroves and their associated Nature's Contributions to People.

## 2.2 Nature's Contributions to People (NCP)

Complementing the SES framework, the Nature's Contributions to People (NCP) framework provides common terminology to determine the several ways in which nature and people interact to produce contributions (benefits or prejudice) to people, in this case mangroves and people in both directions (from mangroves to communities and from communities to mangroves) (Díaz et al., 2018). The NCP framework categorizes these contributions into three overlapping groups:

- **Material NCPs:** These refer to the tangible products and resources that directly sustain human physical existence and material goods. In the context of mangroves, material NCPs can include the timber, food, and medicinal resources provided by the mangroves (Barbier et al., 2011).
- **Non-Material NCPs:** Include the physical and psychological experiences nature provides for people such as cultural identity, spiritual fulfillment, aesthetic enjoyment, and recreational opportunities.
- **Regulating NCPs:** Regulating NCPs involve the ecosystem functions and processes that influence environmental conditions, thereby affecting the generation of both material and non-material contributions.
- **Cultural Context and Knowledge Systems:** The Nature's Contributions to People (NCP) Framework developed within the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) not only summarizes the relationships between people and nature as social-ecological systems (Díaz et al., 2015, 2018). It also emphasizes the importance of cultural context as a cross-cutting factor shaping people's perceptions of nature and good quality of life (Peterson et al., 2018),

highlighting the diversity of nature's benefits to people produced either on its own or by enhancing local anthropogenic assets (Kachler et al., 2023). The NCP's framework highlights the crucial role of indigenous and local knowledge in comprehending the contribution of nature to people (Hill et al., 2021; Kadykalo et al., 2019). This includes recognizing the relational values that people hold—how their relationships with nature contribute to their sense of identity, social cohesion, and overall well-being.

By integrating the SES and NCP frameworks, this research intends to provide a comprehensive understanding of the interdependencies between the mangrove ecosystems and the social systems they support, which are key for mangroves management strategies development.

## **2.3 Coastal Protection**

Coastal protection, also known as the reduction of coastal erosion and flooding, is one of the main contributions of mangroves to people, since they contribute to reducing the risk of such events that have the potential to generate significant economic and social impacts on coastal communities (Strain et al., 2022). The role of mangroves as natural protection systems consists of their ability to significantly attenuate the wave energy incident on the coasts (Lee et al., 2014) reducing the potential for wave erosion. Due to their structure associated with the presence of stilt roots and pneumatophores, they generate a drag force that dissipates wave energy and favors sediment deposition and stabilization (Sánchez-Núñez et al., 2019); they can also increase flow turbulence which induces additional hydrodynamic energy dissipation (Gijsman et al., 2021).

### **3. Mangroves biophysical contributions to protection**

Mangrove ecosystems consist of trees adapted to the intertidal fringe of tropical and subtropical coastal regions. Their vital ecological functions and ecosystem services, including acting as protective barriers against flooding and wave action, make them strategically valuable (Leal & Spalding, 2022). However, mangrove coverage worldwide has historically decreased due to human activities like land-use changes and overexploitation for timber, as well as natural climatic and oceanic forces (Goldberg et al., 2020).

As per (Ward et al., 2016), global mangrove communities are anticipated to be impacted by physical processes associated with climate change, such as sea level rise and an increase in the frequency and duration of storms. Mangroves' ecological functions, including coverage area, primary productivity, and sediment retention capacity, are some of the aspects potentially affected by climate change (Ward et al., 2016). In fact, (Goldberg et al., 2020) found that natural stressors have gained significance as ecosystem-altering factors. In certain regions, the amplified threat of mangrove loss due to natural factors has been observed for at least 30 years, owing to the impacts associated with climate variability phenomena like El Niño Southern Oscillation (ENSO) and the occurrence of hurricanes (Rossi & Soares, 2017).

The degradation of these ecosystems can lead to alterations in the provision of the protective contributions they offer to society at the global, regional, and local scales (Leal & Spalding, 2022). Consequently, not only the physical and biotic dimensions of the system are impacted, but also the social and economic dimensions of what constitutes the social-ecological system composed by the mangrove forest, the adjacent communities and the interactions among them (M. D. Spalding, Ruffo, et al., 2014).

Several authors have assessed the mechanisms through which mangroves contribute to coastal protection (Chen et al., 2024). Theoretical analyses and field observations have demonstrated that mangroves can damp ocean waves (Mazda et al., 1997; Mclvor et al., 2012; Quang Bao, 2011). The degree of wave dissipation by these ecosystems depends on several factors such as forest density, width, height, water level, wave height and current

wave interaction (Hu et al., 2014; van Hespén et al., 2023), as well as the drag coefficient given by the complex mangrove root systems characteristic of the different mangrove species (Wang et al., 2022). Numerical models have been developed to understand the mechanisms of the interaction between mangroves, waves and hydrodynamic (Chen et al., 2024) and have been refined in order to consider physical processes that are relevant for estimating the protective function of mangroves in the coasts around the world (Guannel et al., 2015). Mangrove's protective function has been broadly assessed in southeast Asia (Blankespoor et al., 2017; Himes-Cornell et al., 2018; Yanagisawa et al., 2010) and the Caribbean (Silver et al., 2019; Vanegas G et al., 2019), while the eastern tropical Pacific has been one of the less studied sites regarding this issue. (Hernández-Blanco et al., 2022) applied the INVEST model to estimate an index for coastal exposure with and without mangroves for the coasts of Guatemala and El Salvador (considering a resolution of 250 m). (Koch et al., 2009) and (Barbier et al., 2008) analyzed the nonlinearity of the coastal protection contributions given by mangroves, they found that wave attenuation increases non-linearly with the width of the mangrove forest in-land. This spatial variability as well as the temporal variability -due to climate and ocean dynamics- of the protection function of mangroves directly affects the economic value estimation of these contributions (Barbier et al., 2011; Menéndez et al., 2020).

Different approaches for estimating mangroves contributions to coastal protection have been proposed: the index-based through the InVEST model, the process-resolving methods that include analytical approximations and numerical modelling methods (World Bank Group, 2016). Process-resolving approaches to quantify the protective function of mangroves can provide more accurate inputs to economic valuation estimations such as the Expected Damage Function, which assumes the value of an ecosystem to reducing economic expected damage (Barbier, 2007).

The Colombian Pacific Coast stands as one of the most important regions globally for mangrove ecosystems, due to their great carbon storage potential (Hutchison et al., 2014) and their contributions to local communities' livelihoods, showcasing the critical ecological significance of these unique habitats (Selvaraj & Gallego Pérez, 2023). However, in recent years, the region has grappled with a pressing issue: coastal erosion; particularly in the central and southern sectors of the coast, this phenomenon has meant a significant environmental challenge (Fuentes et al., 2022), as well as the notable decline in mangrove populations within the zone (Uribe-Castañeda et al., 2020). Understanding the linkages between mangrove loss and their pivotal role in protecting the coast from erosion drivers becomes imperative for building effective conservation strategies.

This chapter provides a comprehensive overview of the role of mangrove forests in coastal protection in Punta Soldado Island, at the central Colombian Pacific Coast; the natural drivers of their degradation from a biophysical perspective and discusses the potential effects of these pressures on the provision of the coastal protection service by mangroves.

### 3.1 Study area and biophysical features

Buenaventura Bay is characterized by sediments from the Tertiary and Quaternary dominated by mud flats with accumulations of organic matter where riverine and fringe mangroves have developed (Cantera & Blanco, 2001). Punta Soldado is a barrier island located at the south of Buenaventura Bay's entrance where wave action has a direct impact on the front of the island (Figure 2 **Error! Reference source not found.**). The island is part of the Anchicayá River delta and has five main channels where brackish water flows as an effect of tides and river discharges. It has six main channels: Bodega, Bodeguita, Estero Hondo and Estero Fermina in the south zone, where the Community Council of Punta Soldado is established; and Estero Veneno and Estero Puteño in the north of the island where a military base is found.

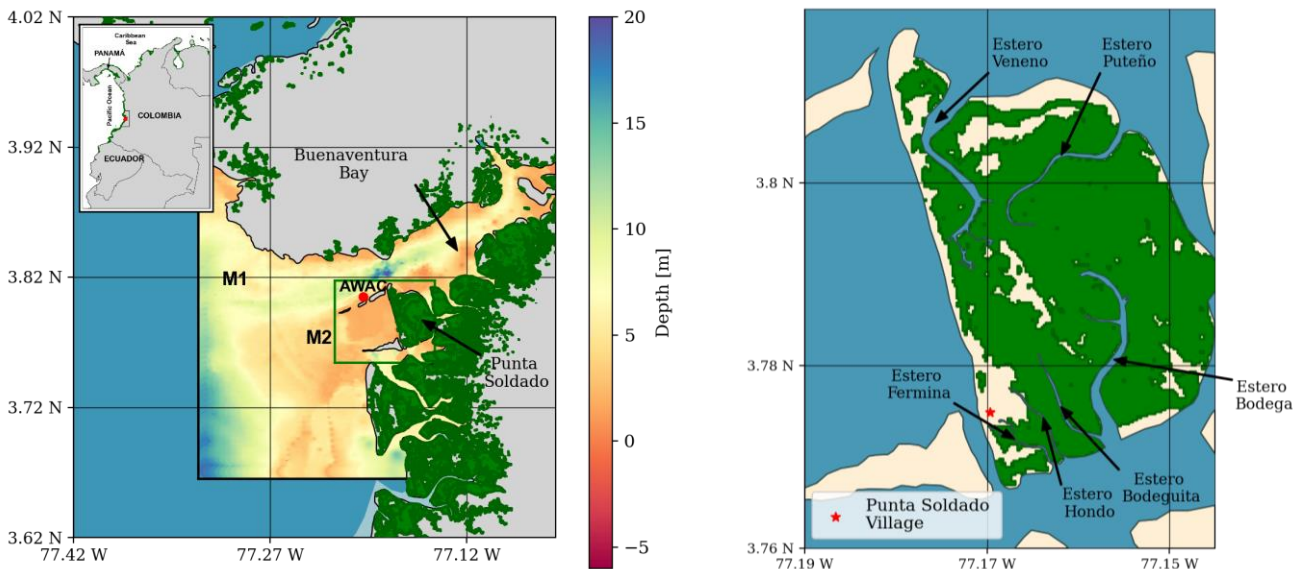


Figure 2. Buenaventura Bay location in the Colombian Pacific Coast and mangroves coverage in 2020 from Global Mangrove Watch data (left). Zoom to Punta Soldado Island where channels' locations are indicated.

Punta Soldado's mangroves have been catalogued as an inverted mangrove forest (Prahl et al., 1990) which is characterized by being established behind a barrier of sand or a beach that protects it from waves. The front of the island is dominated mostly by *Rhizophora sp*, from 20 to 35 m height; currently, the first line of mangroves is composed of dead mangrove followed by mature individuals of *Rhizophora sp* and *Mora oleifera* within the estuary. *Rhizophora sp*, *Pelliciera rhizophorae* and *Laguncularia racemosa* have heterogeneous distribution inland, the latter is most common in channel margins. The south zone between the South point and Estero Hondo is colonized by young individuals and seedlings of *Avicennia germinans* and *Laguncularia racemosa*.

### 3.2 Numerical model with vegetation

To assess mangroves forest function to coastal protection we implemented the numerical model Delft3D which integrates different modules to simulate a series of coastal processes including coastal, river and estuarine areas hydrodynamics, sediment transport and morphology as well as wave dynamics. The Delft3D-FLOW module solves 2D (depth-averaged) or 3D the Navier Stokes equations for an incompressible fluid, under the shallow water and Boussinesq assumptions resulting from tidal and wind forces, fresh-water river dischargers, stratified and density driven flows among others.

$$\nabla \cdot U = 0$$

$$\frac{\partial U}{\partial t} + (U \cdot \nabla)U = -\frac{1}{\rho_0} \nabla p + g + \nu \nabla^2 U + \nabla \cdot T^R \quad \text{Equation 3-1}$$

The Delft3D-WAVE module simulates the evolution of random, short-crested wind-generated waves in estuaries and tidal inlets with the third generation Simulating WAVes Nearshore (SAWN) model. The SWAN model is based on the discrete spectral action balance equation considering generation and dissipation processes. Waves can be simulated by neglecting current effects through the standalone module.

$$\frac{D}{Dt} N(\omega, \theta, \vec{x}, t) = S_{in} - S_{ds} + S_{nl} \quad \text{Equation 3-2}$$

The incorporation of SWAN in Delft3D-WAVE allows coupling with Delft3D-FLOW and Delft3D-MOR (Morphodynamics). Wave-current interactions can be modelled online or offline. Some research on the capabilities and limitations of SWAN can be found in (van der Westhuysen et al., 2007). The offline mode only considers the effect of currents on waves; while the online mode contemplates interactions in either way (effects of currents on waves, and effects of waves on currents). In this work, the online mode is used, so both water level and wave effects on mangrove forests can be evaluated.

Within the Delft3D FLOW-WAVE, mangroves effects on flux, turbulence and wave dissipation can be represented through the Rigid 3D Vegetation Module that incorporates mangroves drag forces to the momentum and turbulence equations. The drag forces depend on the number of stems per area as a function of height ( $n(z)$ ), the diameter of the stems ( $\phi(z)$ ), the drag coefficient ( $C_D$ ) and the number of individuals per square meter ( $\rho_0$ ). The influence of the vegetation upon the momentum equations is given by the vertical distribution of the friction force caused by cylindrical elements in oblique flow ( $F(z) = 12\rho_0 C_D \phi(z) \eta(z) u(z)$  Equation 3-3).

$$F(z) = \frac{1}{2} \rho_0 C_D \phi(z) \eta(z) |u(z)| u(z) \quad \text{Equation 3-3}$$

With  $u(z)$  the horizontal flow velocity profile.

### 3.2.1 Flow model

The model was set up with different sources of bathymetry including the GEBCO database (General Bathymetric Chart of the Oceans), bathymetric charts from DIMAR (Dirección General Marítima de Colombia) and field data for the nearshore from the island. A nested grid was implemented in the model, where the coarse grid (G1) of 100 m x 100 m cells covers the domain offshore the island; and a fine grid (G2) of 25 m x 25 m cells that covers the shallow region in front of the island and the transversal shoals (**Error! Reference source not found.**). For this case, a 2D depth-average simulation was carried out.

To study the dynamics of currents in the region, the Delft3D-FLOW model was previously implemented. Water-level open boundary conditions were prescribed at the grid's west and south edges. Water levels were governed by 7 astronomical tide constituents (M2, S2, N2, K2, K1, SSA and M4) obtained from the Buenaventura tide-gauge time series (from 1953 to 2014) as shown in Table 1. Within Buenaventura Bay, discharges from Anchicayá (989.2 m<sup>3</sup>/s) and Dagua (569.4 m<sup>3</sup>/s) rivers (Barbosa Hurtado, 2018) were considered.

Table 3-1. Phase and amplitude of the 7 main tide constituents obtained from the Buenaventura tide-gauge time series.

Astronomical Tide Constituent	Buenaventura tide-gauge	
	Amplitude	Phase
M2	1.560	100.7
N2	0.317	288.2
K2	0.113	190.9
K1	0.110	1.7
S2	0.403	104.6
SSA	0.063	174.5
M4	0.059	277.6

Calibration and validation of the Delft3D-FLOW was carried out comparing field data records with modeled data for the period October 1st to 7th of 2019. Velocity currents and water level variations were obtained through an Acoustic Doppler Current Profiler (ADCP) installed at the coordinates Lat: 3.802691, Lon: -77.199282 (Figure 2). Model parameters were adjusted for calibration such as the eddy viscosity ( $\nu_T = 5 \text{ m}^2/\text{s}$ ), the Manning coefficient ( $n = 0.03 \text{ s}/\text{m}^{1/3}$ ), and the boundary reflection parameter ( $\alpha = 3783 \text{ s}^2$ ). The model performance shows a good agreement for water levels (WL) with a  $R^2 = 0.97$  and average RMSE= 0.23 for the time-period. Although the agreement for velocities is less accurate,

with  $R^2=0.73$  and  $RMSE=0.28$  for Eastward velocities ( $V_x$ ), the temporal variability with high and low tide is in good agreement, also the positive value in the flow is in good agreement for statistical parameters,  $V_{x-FLOW}$   $RMSE=0.22$  and  $V_{x-FLOW}$   $R^2=0.94$ .

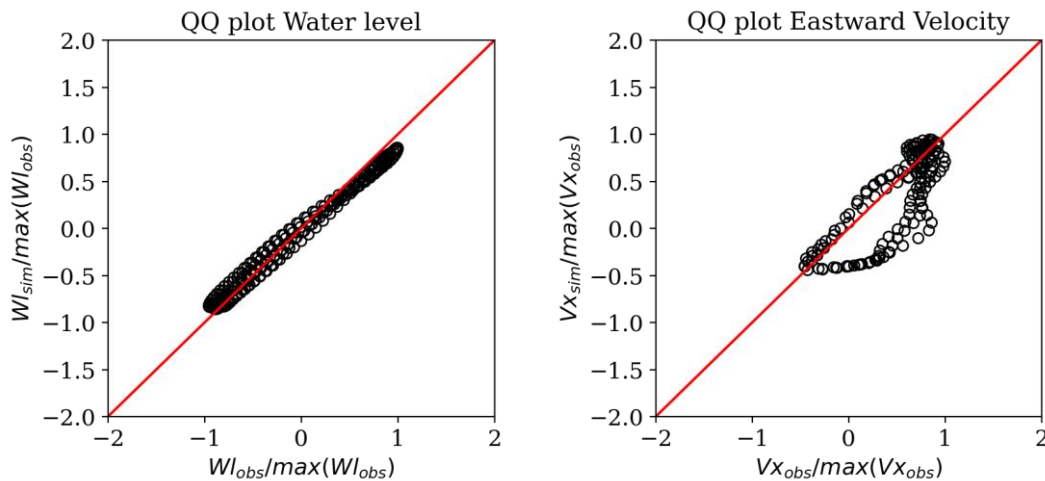


Figure 3. QQ plots of water level (left) and eastward currents velocity (right) that compares measurements in AWAC's position and the numerical model.

### 3.2.2 Wave model

The same nested grids were employed for the Delft3D-WAVE model set up. Incident waves at the south and west boundaries were specified from the database ERA-5 (<https://cds.climate.copernicus.eu/cdsapp#!/home>). Time-varying hourly descriptive parameters, wave height ( $H_s$ ), peak period ( $T_p$ ), and mean direction ( $D_m$ ) were used. Like the Delft3D-FLOW module's boundary conditions, wind velocities and roughness were uniform for the whole domain. Wave model parameters such as the bottom friction wave dissipation coefficient ( $C_{bottom}$ ) and the depth-induced breaking coefficients ( $\alpha$  y  $\gamma$ ). The best results were obtained with  $C_{bottom} = 0.035 \text{ m}^2/\text{s}^3$ ,  $\alpha = 1$  and  $\gamma = 0.73$ . Modelled wave data, ERA-5 records as well as the results with the ADCP's field data were compared in terms of the  $RMSE$  and  $R^2$ .

To consider the wave-current interaction effects on the coastal dynamics, the Delft3D-FLOW and Delft3D-WAVE models were coupled through the online mode. Simulations were carried out considering the calibration parameters exposed above for both waves and currents models. A 5-minute step was set up for models coupling with a time resolution of 15 minutes. The model performance shows a good agreement for significant wave height ( $H_s$ ) with a  $RMSE=0.08$  and  $R^2=0.40$  for the period where tendency and magnitude are well represented (Figure 4). In terms of the peak period ( $T_p$ ) model performance is given by the statistical parameters  $RMSE=1.2$  and  $R^2=0.8$ . It is important to note that this model

considered wave transformation processes such as refraction either by depth or currents, as well as shoaling.

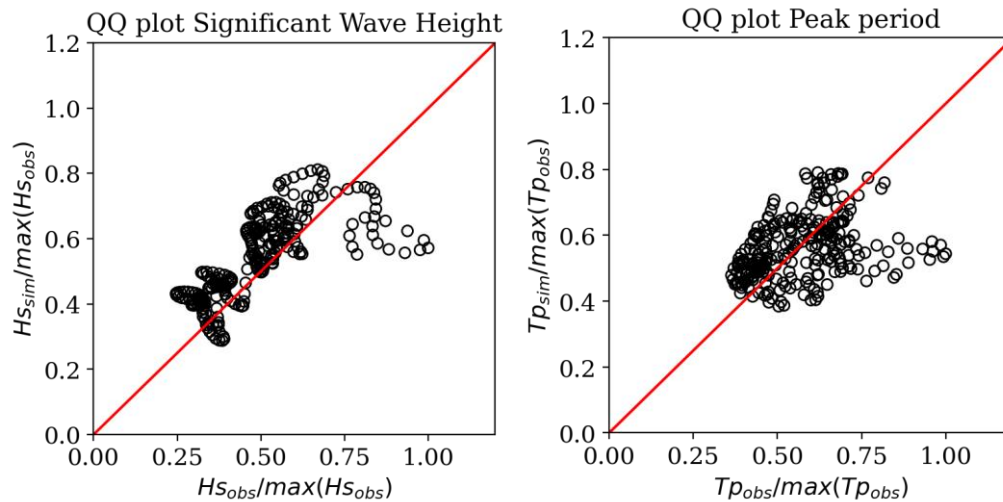


Figure 4. QQ plots of significant wave height (left) and peak period (right) that compare measurements in AWAC's position and the numerical model.

### 3.2.3 Rigid vegetation model

The vegetation module from Delft3D allows to set vegetation characteristics into the Delft3D FLOW-WAVE model to consider the effect of vegetation either on flux velocity, turbulence and significant wave height incidence on the shore. The vegetation integrated into the model is represented as cylindrical elements spatially and vertically distributed. Therefore, variables such as the number of individuals per area, abundance of species, tree height, diameter at breast height and roots parameters were spatially distributed in polygons within the island. Root parameters such as diameter and number of roots and stems were characterized as a function of height above ground, these parameters comprise the vertical plant structure (Vps).

The spatial information from the Global Mangrove Watch - GMW (Bunting et al., 2022) was used to integrate vegetation to the model. These data consist of the spatial coverage of mangrove from 1996, from 2007 to 2010, 2015 and from 2018 to 2020, with a spatial resolution of 30 m. Field data regarding structural parameters of mangroves and mangroves species zonation from 1990 to 2021 was collected from several written sources (Blanco & Cantera, 1999; Cantera & Blanco, 2001; Sánchez-Páez et al., 1997) and field campaigns previously executed by OCEANICOS research group in the island. Root parameters of mangroves on the island were measured in 2023 as well. These measurements included the characterization of stilt roots (number of primary and secondary roots; and their diameter on different heights above ground) from mangroves such as *Rhizophora sp.* Also, the height and perimeter of pencil roots from mangroves like *Avicennia germinans* were

measured. Figure 5 shows the sites where both primary and secondary information regarding mangrove structural and roots parameters were compiled.

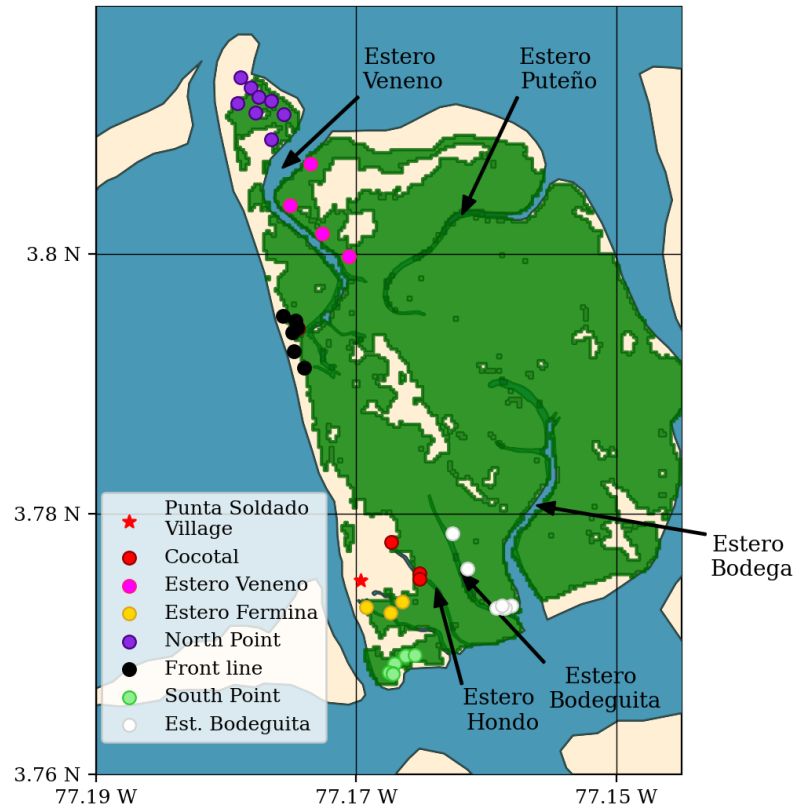


Figure 5. Points of surveys of mangrove structure and root structure in Punta Soldado Island taken from secondary data and in situ field campaigns.

Mangroves species spatial distribution within the island was estimated considering GMW, the Information System for Mangroves Management in Colombia - SIGMA (Rodríguez-Rodríguez et al., n.d.) patches, zonation from literature and collected field data. Through this estimation it was possible to classify the predominant type of roots present in each patch, defining the vertical plant structure (Vps).

Stilt roots parameters were estimated through an adaptation of the (Ohira et al., 2013) model to local mangroves characteristics. Thus, the number of roots ( $n$ ) is given by  $n = 3.15 (H_{R-max})^2 + 5.3(H_{R-max}) + 0.114$   $0.25 m < H_{R-max} < 2.70 m$  Equation 3-4.

$$n = 3.15 (H_{R-max})^2 + 5.3(H_{R-max}) + 0.114(0.25 m < H_{R-max} < 2.70 m) \quad \text{Equation 3-4}$$

Where  $H_{R-max}$  is the highest root height in meters, and it is a function of the diameter at breast height (DBH):

$$H_{R-max} = 7.56(DBH) + 0.500 \quad \text{Equation 3-5}$$

The average diameter of primary roots ( $\phi$ ) is function of the DBH and the average primary roots height ( $H_R$ )

$$\phi = 0.04(DBH) + 0.005(H_R) + 0.024 \quad \text{Equation 3-6}$$

The vertical plant structure (Vps) from *Avicennia germinans* - characterized by pencil roots - were established considering collected field data. Vps from single stem mangroves such as *Pelliciera rhizophorae* and *Mora Oleifera* were parameterized by their DBH and tree height. For instance, we have a mangrove patch where the *Rhizophora mangle* is dominant; this is a mangrove species with stilt roots, then the Vps i.e. the number and diameter of roots at 10 cm, 30 cm and 50 cm above ground were measured to determine the patch root parameters (diameter and number of roots) as a function of height above ground. Figure 6 summarizes the classification process through which Vps were estimated for each patch depending on the dominance of the mangrove species.

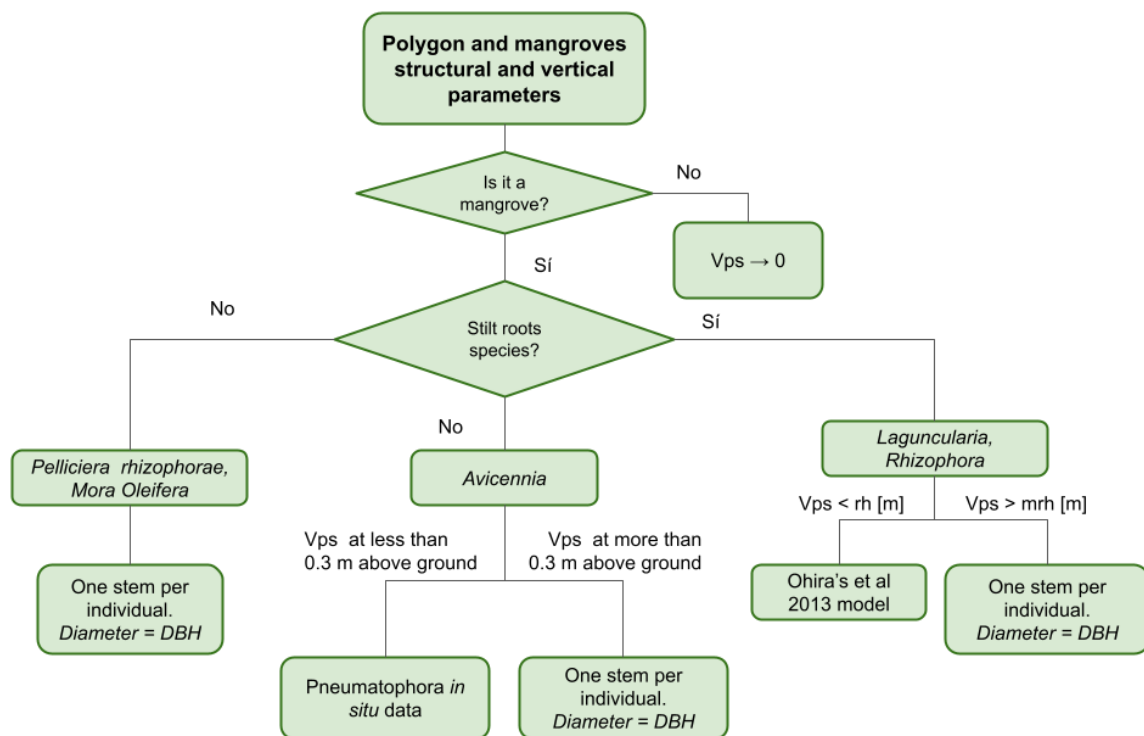


Figure 6. Scheme summarizing mangrove roots parameter estimation process considering species root types.

### 3.2.4 Mangroves area and parameters distribution

Mangroves in Punta Soldado can be classified in seven main zones according to literature descriptions, field observations and measurements. Considering a modified model from

(Ohira et al., 2013) for Punta Soldado, average stilt root parameters are shown in Table 3-2. In the table it is observed that the highest mangroves are found in the Estero Fermina with 18.58 m while the shortest are in the South Point with 4.3 m; the densest site is the South Point, while the site with the lowest density is the Cocotal. Also, root diameter is larger at Estero Fermina and Cocotal, while smaller roots are found at the South Point.

Table 3-2. Mangrove stilt root parameters for Punta Soldado Island are estimated through the modified Ohira et al (2013) model classified per zones.

Site	Height [m]	DAP [m]	H <sub>R-max</sub>	N	Root diameter [cm]	Density [ind/m <sup>2</sup> ]
Cocotal	15.380	18.403	2.901	42	4.466	0.088
Bodeguita	12.800	8.600	2.131	26	3.977	1.024
Estero Fermina	18.583	19.433	2.980	44	4.633	0.083
Estero Veneno	16.296	12.282	2.427	32	4.265	0.118
Frente	17.927	15.133	2.657	37	4.445	0.166
North Point	6.138	4.975	1.818	20	3.554	0.521
South Point	4.300	4.730	1.797	20	3.471	2.026

The mangrove area on Punta Soldado Island has decreased by approximately 37 hectares from 1996 to 2020 (Table 3-2), with the forest along the coastline being the most impacted, followed by the southern point (Figure 7). Between 1996 and 2010, there was a fringe of mangrove forest in front of Punta Soldado Village, but by 2020, mangroves had retreated approximately 466 meters, leaving fragmented patches along the village's coastline. Through field observations, we noted that the front-line mangroves are currently dead, likely due to sand sedimentation among their roots, which covers the pneumatophores of the trees and may obstruct their respiration. Mangrove forest degradation can be associated with coastal erosion processes assessed by remote sensing image analysis from 1997 to 2019. Punta Soldado's coastline has retreated 340 m in the south zone, and 145 m in the front line in the center of the island (Figure 7). Also, mangroves within the south zone have recovered naturally since 2019 which can be product of sedimentation processes occurring in this site of the island since, at least 2015.

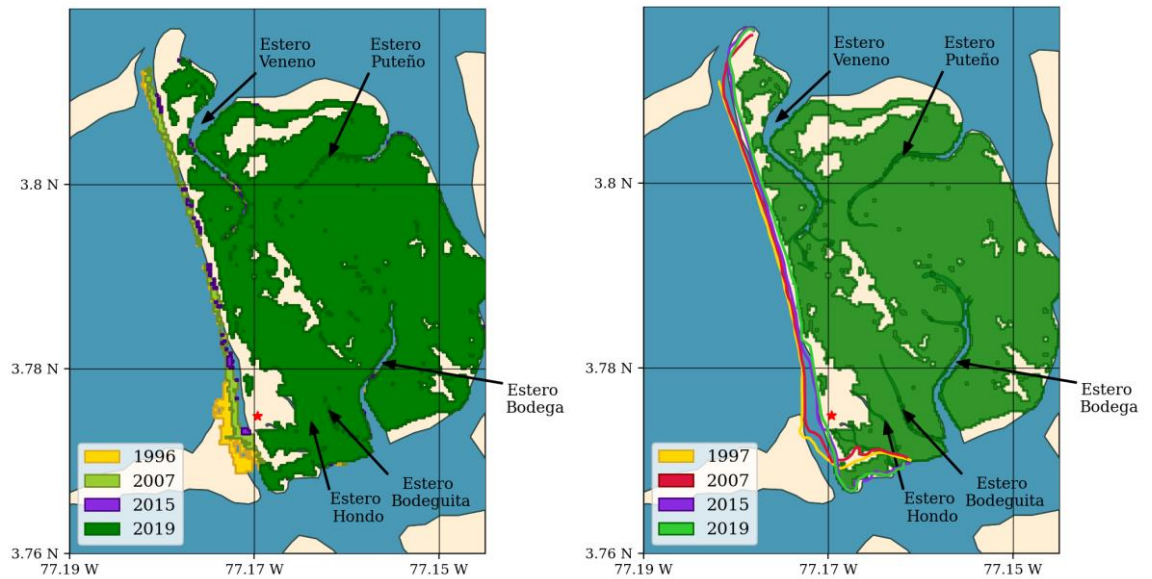


Figure 7. Mangrove area evolution from 1996 to 2019 considering GMW data (left), and coastline changes in Punta Soldado Island from 1997 to 2019 obtained through remote sensing analysis (right).

Table 3-3. Mangrove area evolution in Punta Soldado Island calculated from the Global Mangrove Watch data

Year	Area [ha]	Year	Area [ha]
1996	1025.81	2016	990.75
2007	1010.51	2017	990.00
2008	1009.17	2018	994.79
2009	1005.74	2019	994.789
2010	998.70	2020	987.26
2015	993.99		

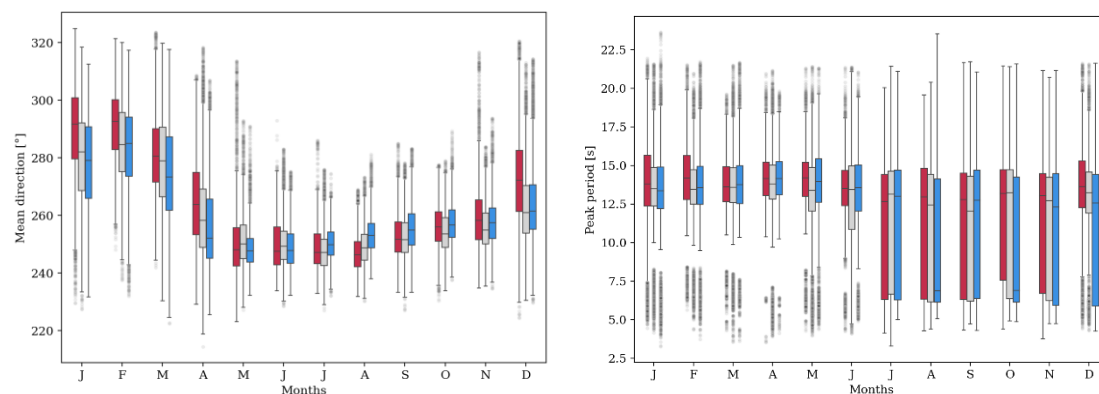
### 3.2.5 Waves and sea level variability

Mangroves protective capacity depends on multiple factors, including significant wave height, peak period and relative sea level (RSL) (van Hespen et al., 2023). A variability assessment was carried out considering Buenaventura's tide gauge registrations for sea level, and satellite data from ERA5 database from the European Center for Medium-Range Weather Forecasts for wave parameters (significant wave height, peak period and mean

direction). Figure 8 displays multiyear boxplots of wave parameters and relative sea levels monthly, differentiated by the ENSO phase. RSL has important fluctuations throughout the year, during the first quarter it tends to be up to 0.2 m less than the mean sea level of the year. Meanwhile, during the second half of the year RSL reaches 0.1 m more than the mean sea level. Throughout the whole El Niño phase characteristic year, RSL tends to be up to 20 cm higher than Neutral phases of ENSO, which is consistent with (Belliard et al., 2021) and (Muis et al., 2018). Extreme RSL during El Niño are related to anomalous ocean-atmosphere conditions that can induce changes in the intensity, frequency and track of storms (Muis et al., 2018), therefore ENSO driven extreme sea levels worsen flood risks on coastal ecosystems and society (Belliard et al., 2021).

Spread of the significant wave height and peak period are very broad and change throughout the year. Mean peak period tends to fluctuate from 12.5 to 15 seconds - suggesting the incidence of swell waves on the site - however their spread is broader in the second half of the year when sea waves tend to appear with peak periods from 6.5 to 9 seconds. Significant wave height is most of the time represented by waves between 0.6 to 0.8 m, nevertheless waves can reach up to 1.4 m specially in the second half of the year. During El Niño events, waves' incident direction shifts, originating more frequently from the west and northwest. This is consistent with previous assessments done by (Vos et al., 2023) and (Odériz et al., 2020) regarding the positive ENSO events effects on wave patterns in several sites of the Eastern Tropical Pacific.

From the latter analysis, wave scenarios can be extracted representing the mean conditions of significant wave height parameters and water level. However, it is necessary to consider the role of mangroves in extreme events to address their capacity for protecting coastal social-ecological systems



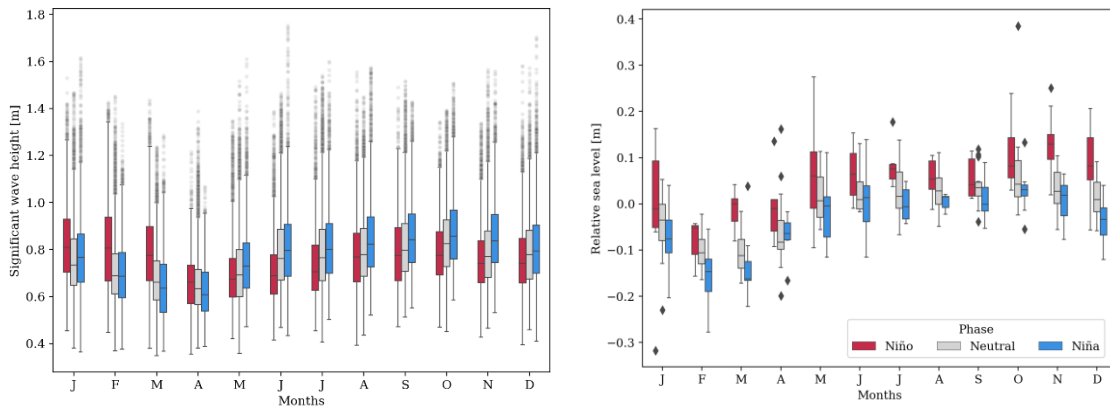


Figure 8. Boxplots of the monthly multiyear mean of significant wave height, peak period, and wave direction from ERA 5, and relative sea level from Buenaventura tide gauge.

We carried out the Peaks Over Threshold (POT) method in order to estimate significant wave height values for extreme events in multiple return periods. The POT method consists of defining a threshold and a time window to extract a series of extreme events, in this case, a threshold of 1.22 m and a time window of three days was selected considering the graphic method and that these events need to be completely independent and identically distributed. The POT extreme values are estimated considering the Generalized Pareto Distribution (Figure 9).

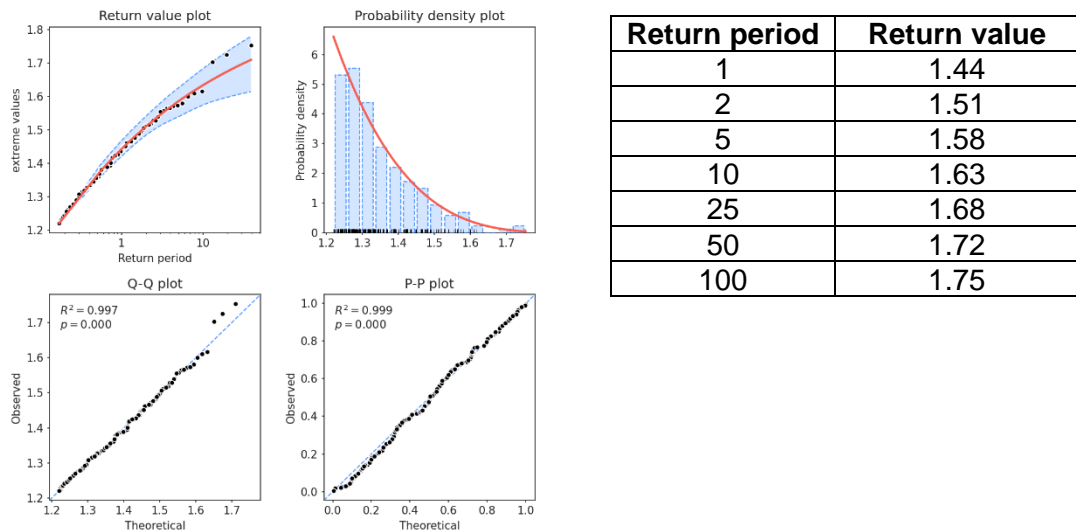


Figure 9. Peaks Over Threshold POT method applied to the significant wave height extreme events series extracted from ERA5 data.

### 3.2.6 Cases selection

Four scenarios of mangrove area distribution were selected, these correspond to 1996, 2007, 2015 and 2019 from the GMW data, considering that the greatest differences in mangrove area have been recorded between these years (Table 3-3). Wave and relative sea level scenarios were selected considering the most frequent wave parameters during neutral and El Niño phases; the average RSL condition and the temporal sea level rise related to El Niño events; and the significant wave height associated to the return period of 100 years estimated with the POT analysis (Table 3-4). Only the most frequent wave peak period was selected because this parameter is not a determining factor for mangrove's wave damping capacity (Maza et al., 2019).

Table 3-4. Wave and RSL scenarios to be assessed for four scenarios of mangroves coverage (1996, 2007, 2015 and 2019) and one control scenario without vegetation.

Water level [wl]	Wave direction [Dm]	Significant wave height [Hs]	Peak period [Tp]
0 cm	WSW (225°) W (270°)	1 m 1.75 m	13.2 s
40 cm	WSW (225°)	1 m	13.2 s

## 3.3 Model results

### 3.3.1 Mangrove coverage effect on wave attenuation

Figure 10 shows the root mean square (RMS) of the spatial distribution of the significant wave height during the high tide for each scenario on average RSL conditions. Wave direction has differential effects on significant wave height incidence at the front of the island. When waves come from the west, Hs is higher at the south with values between 0.4 and 0.6 m; waves coming from the southwest have a more homogeneous distribution along the coast front with greater Hs than the latter case (0.7 to 0.9 m). Furthermore, waves coming from the west may have a more important impact on Punta Soldado's village considering that Hs is greater in the south zone (up to 1.0 m) than the front and north of the island (up to 0.5 m).

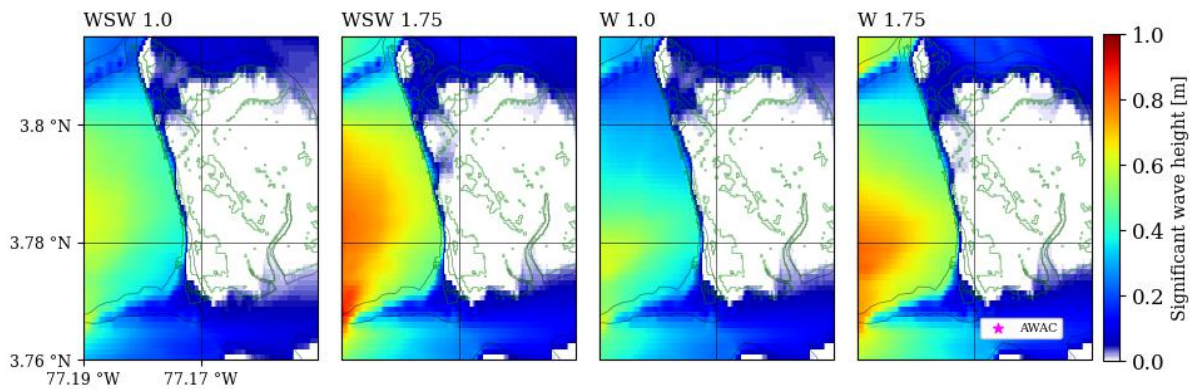


Figure 10. RMS of the significant wave height spatial distribution near Punta Soldado Island.

Significant wave heights in each scenario simulated without vegetation are compared to simulations considering the vegetation coverage from 1996, 2007, 2015 and 2019 through the Mean Absolute Difference (MAD) of wave attenuation rate. This assessment aims to evaluate mangroves' effects on wave damping for different incident wave directions and heights. Wave attenuation is estimated using (E. M. Horstman et al., 2014) approach, where  $H_s$  in each pixel is compared with  $H_s$  from pixels before waves pass through the mangrove forest. Mangrove's role on damping waves is different along the coast (Figure 11, Figure 12 and Figure 13); when the incident  $H_s$  is 1.0 m -either coming from west or southwest-mangroves at the front of Punta Soldado Village attenuate from 20% to 60% of the wave height for 1996, 2007 and 2015 forest spatial distribution. For the 2019 vegetation scenario, there is no difference in wave attenuation rate in this zone, possibly due to the lack of mangroves at the front of the village. Wave attenuation by mangroves is also observed in the north point for waves coming from the west and mangroves distribution from 1996. This attenuation has an extent of more than 200 m inland and may be linked to the continuity of the mangrove forest in this site.

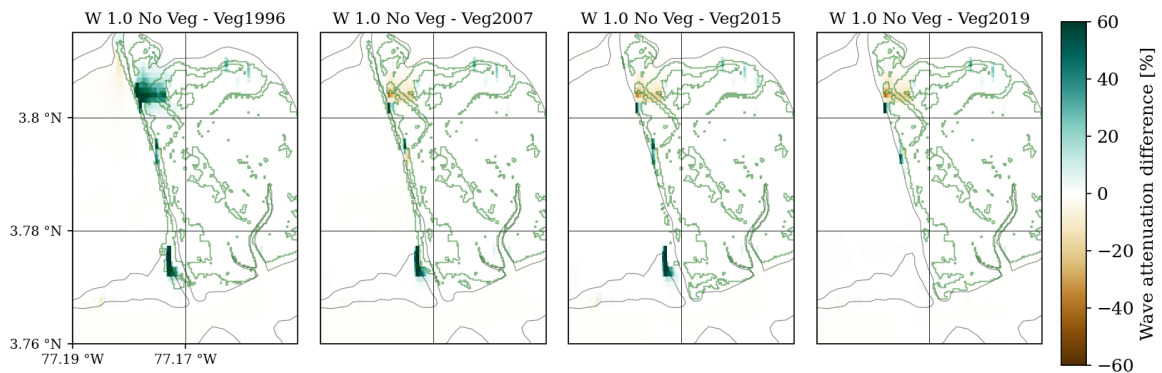


Figure 11. Spatial distribution of the difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an incident significant wave height of 1.0 m, wave direction WSW and RSL of zero.

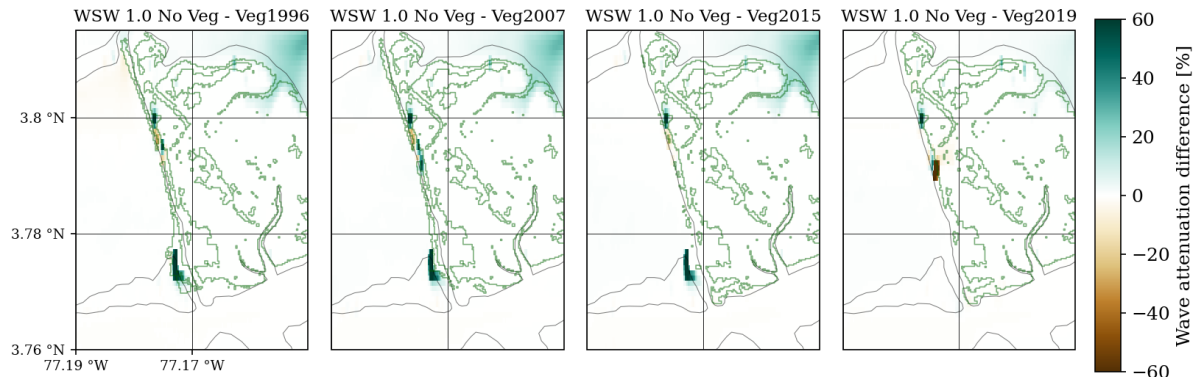


Figure 12. Spatial distribution of the difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an incident significant wave height of 1.0 m, wave direction W and RSL of zero.

In contrast to the simulations for a significant wave height of 1.0 m, when the incident significant wave height of a 100-year return period occurs, mangroves at the front of Punta Soldado Village do not significantly contribute to wave attenuation in any mangrove distribution scenario. However, in the northern front line of the island, fragmented wave attenuation offered by mangroves is 30% higher than in a scenario with no vegetation (Figure 13). Particularly, the 2019 coverage scenario shows a broader area of wave attenuation linked to mangroves, possibly because the mangrove area in this site increased by 3,600 m<sup>2</sup> compared to the 1996 coverage.

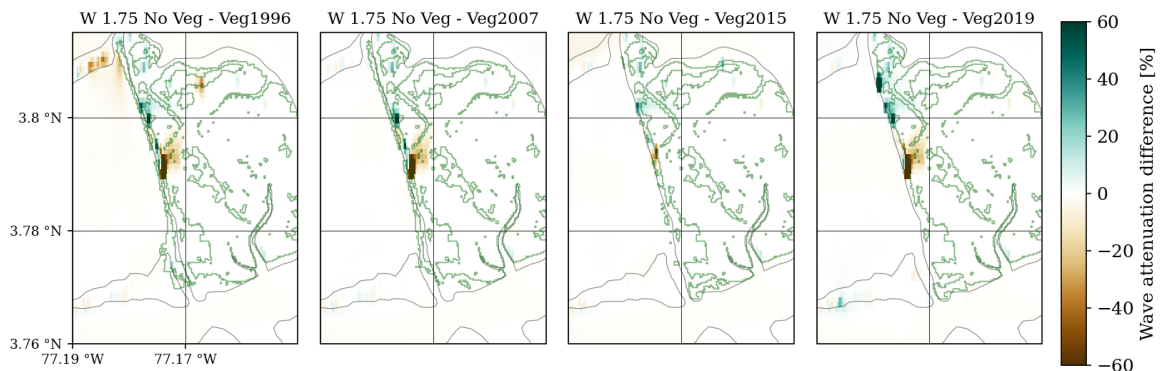


Figure 13. Spatial distribution of the relative difference between wave attenuation rate without mangroves and with different mangroves distribution within Punta Soldado Island, for an incident significant wave height of 1.75 m, wave direction W and RSL of zero.

### 3.3.2 Wave attenuation spatial patterns with Sea Level Rise

When the relative sea level rises to 0.4 m, the spatial distribution and magnitude of mangrove effects on waves change. Figure 14 displays the significant wave height differences between scenarios with no vegetation and the 1996 mangrove coverage for

average relative sea level (RSL) and a 0.4 m rise in RSL. With a 0.4 m rise in RSL, mangroves in front of Punta Soldado Village do not have a significant effect on wave attenuation compared to the 1996 mangrove coverage scenario. However, along the front line of the island, mangroves reduce significant wave height by 10 cm.

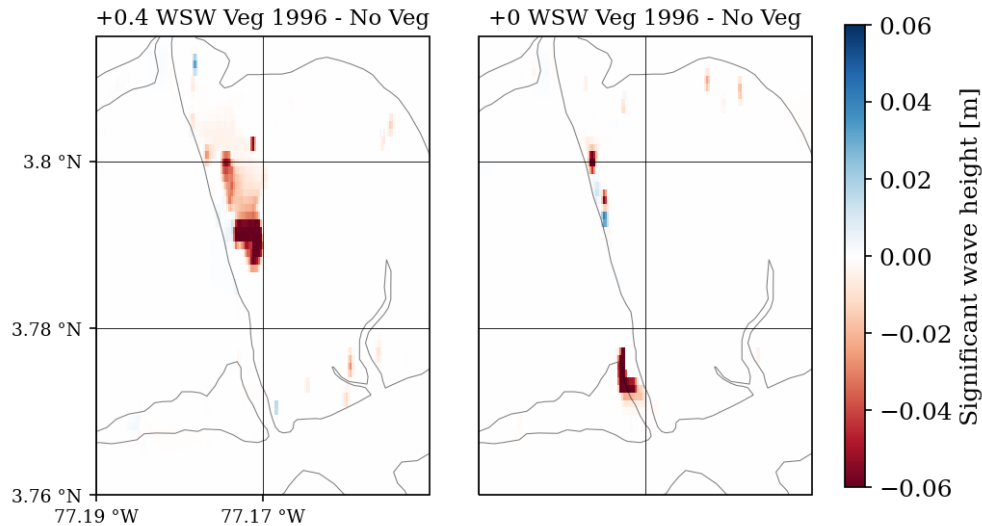


Figure 14. Comparison of the spatial distribution of the mean absolute difference between the Hs for average RSL and 0.4m of temporal sea level rise, without vegetation and with 1996 mangroves distribution within Punta Soldado Island, for an indecent significant wave height of 1.0 m and wave direction WSW.

Waves evolution in front of Punta Soldado village is assessed through the root mean square for waves in the high and low tide. During the high tide, incident waves in the surf zone have a significant wave height of up to 0.6 m, while during the low tide this magnitude reduces to 0.1 m. Figure 15 (top) shows that waves can approach the coast ~50 meters further when there are no mangroves in the front of the village and predominantly come from the west (270°) or the southwest (225°). Meanwhile, when waves come from the north-west (300°), these have the same approach whether there are mangroves on the profile or not. The latter indicates a potential threat of coastal erosion or damage depending on wave direction. On the other hand, Figure 15 (bottom) shows slight differences between the wave approach comparing the profiles with and without mangroves, however, the differences are of less than 10 cm.

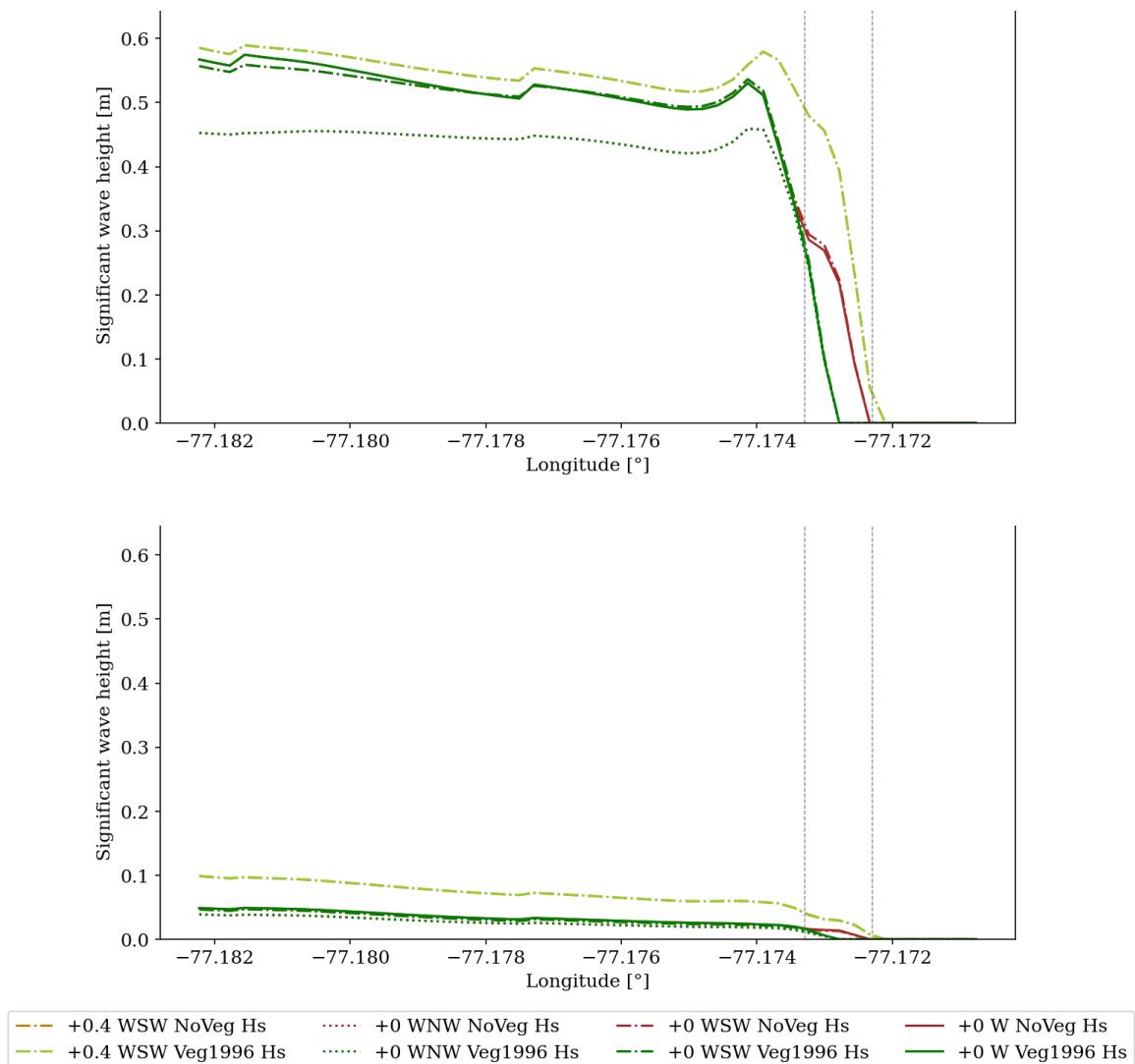


Figure 15. RMS Significant wave height evolution within a transect in front of Punta Soldado Village during the high tide (top) and the low tide (bottom).

The mangrove protection function for Punta Soldado was estimated by calculating the cumulative wave attenuation rate per hectare of mangrove for each simulated scenario (except those corresponding to 2019 mangrove coverage). This calculation considered the area where the community is located as well as the surrounding buffer zone. The mangrove area was divided into transects parallel to the coast, and wave attenuation was estimated for each transect, with the effect accumulating as the total mangrove area increased.

Figure 16 shows that in an average significant wave scenario, wave attenuation increases rapidly within the first 30 hectares, with an average reduction rate of 2 cm in wave height per hectare, reaching a maximum attenuation of 56 cm (or 60% of the incident wave height). Beyond 30 hectares, the attenuation rate decreases to less than 0.1 cm per hectare. The different scenarios indicate that broader mangrove areas (such as in 1996) exhibit higher

attenuation rates compared to the red mangroves in later years. This highlights the importance of preserving mangroves, particularly within the first 30 hectares closest to the coast, where they provide the greatest protective benefits.

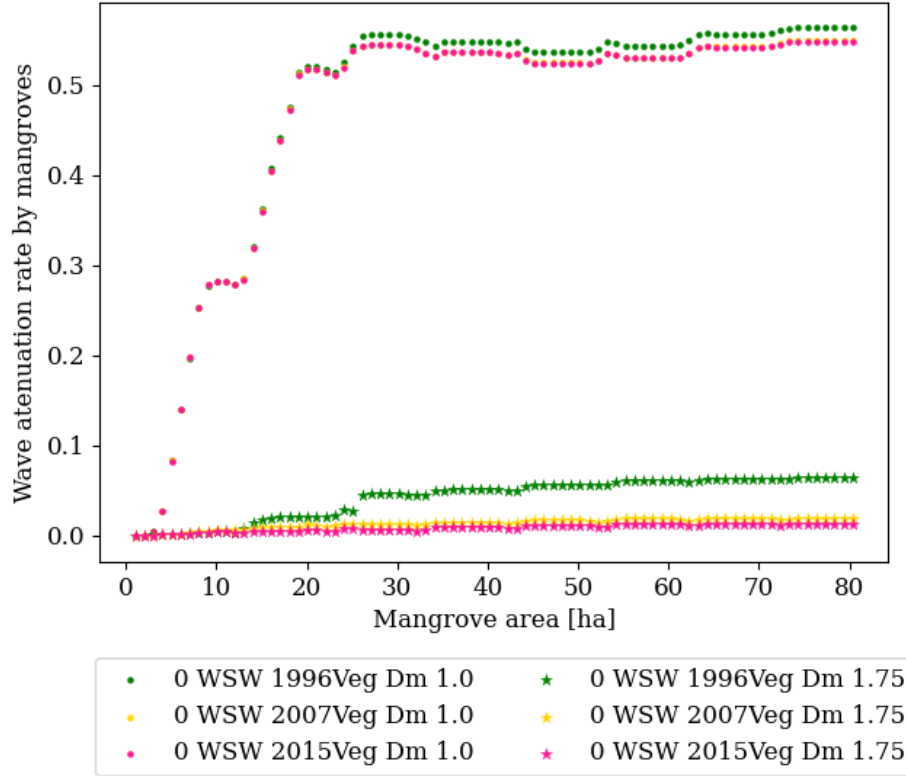


Figure 16. Cumulative mangrove's wave attenuation contribution in function of mangrove area.

The cumulative effect of mangroves on wave attenuation rate per hectare, considering the scenario with the most extensive mangrove area (1996) and an average significant wave height ( $H_s$ ), can be represented by the 4th order polynomial function with a  $R^2$  of 0.98 written in  $-8 \times 10^{-8}x^4 + 2 \times 10^{-5}x^3 - 0.0015x^2 + 0.0539x - 0.1236$  Equation 3-7.

$$-8 \times 10^{-8}x^4 + 2 \times 10^{-5}x^3 - 0.0015x^2 + 0.0539x - 0.1236 \quad \text{Equation 3-7}$$

In contrast, mangroves' attenuation capacity in extreme events (incident  $H_s$  of 1.75 m) reaches less than 10 cm, even for the 1996 mangrove coverage scenario. Moreover, mangroves cumulative attenuation rate is almost unnoticeable for the scenarios where mangrove coverage is reduced (2007 and 2015). The cumulative wave attenuation rate can be represented by  $-1 \times 10^{-8}x^4 + 2 \times 10^{-6}x^3 - 8 \times 10^{-5}x^2 + 0.0003x - 0.0027$  Equation 3-8 for 1996 mangrove coverage scenario and  $-2 \times 10^{-9}x^4 + 3 \times 10^{-7}x^3 - 2 \times 10^{-5}x^2 + 0.001x - 0.0024$  Equation 3-9 for 2007 and 2015 mangrove scenarios.

$$-1 \times 10^{-8}x^4 + 2 \times 10^{-6}x^3 - 8 \times 10^{-5}x^2 + 0.0003x - 0.0027 \quad \text{Equation 3-8}$$

$$-2 \times 10^{-9}x^4 + 3 \times 10^{-7}x^3 - 2 \times 10^{-5}x^2 + 0.001x - 0.0024 \quad \text{Equation 3-9}$$

### 3.3.3 Mangrove effect on floods

According to simulations results, tide transit along the coast profile is affected by the presence of mangroves and it differs within zones on the island. Figure 17 shows the evolution of head level in the vegetation scenarios considered, for the several wave scenarios simulated both in average RSL and the 0.4 sea level rise conditions for the front of Punta Soldado Village and the channel Estero Bodega. Simulations results suggest that in front of the Village, the presence of mangrove vegetation (from 1996, 2007 and 2015 distribution) leads to a lower water head specially with an incident  $H_s$  of 1 m coming from the west (W), in which an attenuation of the water head is up to 12 cm. Mangrove's role on reducing water head in this site, considering other wave and RSL scenarios is not shown as important as the latter, with attenuation values of less than 5 cm.

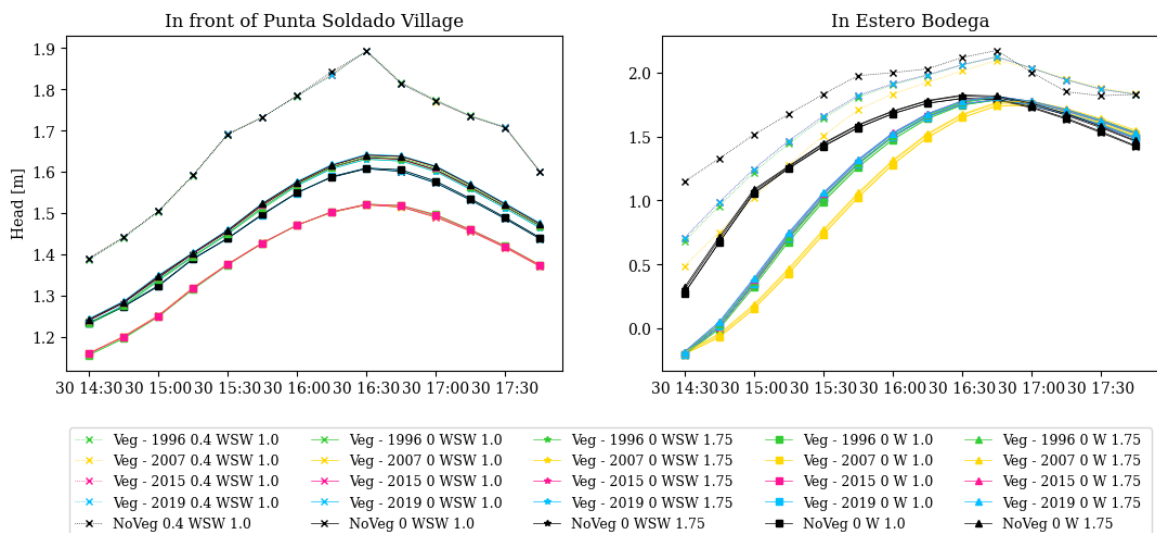


Figure 17. Water heads with and without vegetation for different wave and water level scenarios in front of Punta Soldado Village (left) and in Estero Bodega (right).

For Estero Bodega, the most significant water head levels are observed in no vegetation scenarios in the flow tide (from 14:30 to 16:30), which suggest mangroves have an important role in reducing the flow and ebb tide velocities (reduction of tide transit speed within the vegetation). Moreover, the vegetation area in the site for 2007 increased, which could explain the greater reduction of water level in every wave scenario compared to the other vegetation scenarios.

## 3.4 Discussion

### 3.4.1 Mangroves contributions to coastal protection

This chapter provides an overview of mangroves' role in coastal protection both from waves and flood hazards. This numerical modelling approach has revealed and quantified mangroves contributions to coastal protection, specifically, wave and flood attenuation depending on the incident wave and oceanographic conditions in the site, as well as different vegetation areas in a barrier island on the CPC. These conditions are given mainly by the incident significant wave height, wave direction and, to some degree, the relative sea level. In this site, mangroves have the capacity to attenuate up to 60% of incident wave height in an average scenario; this value is similar from mangroves located in other sites of the world and laboratory experiments, which range from a 13% to up to 77% of significant wave height attenuated by mangroves (Bryant et al., 2022; E. Horstman et al., 2012; Mclvor et al., 2012, 2020)(Bryant et al., 2022; E. Horstman et al., 2012; Mclvor et al., 2012). However, in extreme scenarios ( $H_s = 1.75\text{m}$ ), mangroves are not able to attenuate waves according to the obtained results, these are consistent with conceptual models from (van Hespen et al., 2023), (Gijsman et al., 2021), (Lee et al., 2014), and the review made by (Gedan et al., 2011) which stated that mangroves ecosystems may contribute to coastal protection on average scenarios, however, extreme conditions could exacerbate this ecological function. The latter are high energy disturbances that mangrove forest may not be able to put up to, depending on its characteristics such as tree density, stem and root diameter, bathymetry and incident wave height (Alongi, 2008). Such disturbances can also decrease functionality due to natural failure mechanisms related to tree mortality (Gijsman et al., 2021), observed within Punta Soldado Island and other coastal areas along the Colombian Pacific Coast.

Location with respect to settlements is one of the factors attributed to mangroves for them to provide coastal protection; when villages are situated behind mangrove areas, they tend to be better protected than those located close to or in front of them (Barbier et al., 2011; Lee et al., 2014). Moreover, according to the given results, mangroves capacity to attenuate waves also depends on their location along the coast. In this case, mangrove forest located in the south zone of Punta Soldado Island has a higher capacity to attenuate waves than those in the middle zone of the coast. This can be attributed to mangrove forest structure, incident wave height and relative sea level as have been analyzed in previous work (Hu et al., 2014; Mclvor et al., 2012; van Hespen et al., 2023). Mangrove forest located in the south point and in front of Punta Soldado village correspond those with the most abundant root system ( $n=44$ ) within the mangrove forest, this factor is determinant for coastal protection according to (Herison et al., 2023; E. Horstman et al., 2012; Mazda et al., 2006). Mangroves forest perpendicular thickness with respect to the coastline, is also one of the key features for coastal protection (Gijsman et al., 2021). According to (Kelty et al., 2022) thicker mangrove transects are capable of attenuating wave height better than those less thick; this supports our results, considering that mangroves transects at the south of the

coastline (~ 400 m thick) attenuate waves up to 20% more than transects at the middle and north of the coastline in an average scenario.

### **3.4.2 Implications of mangrove loss on coastal protection**

Mangrove area in Punta Soldado island has decreased since the 20th century both because of anthropogenic and natural pressures, as it is happening all over the world ([Goldberg et al., 2020](#)). The main anthropogenic pressure identified in the site is the intensive lodging carried out by adjacent communities resulting in forest fragmentation; these are some of the most common pressures for mangroves in Southeast Asia (Ilman et al., 2016; Richards & Friess, 2016) and globally (Bryan-Brown et al., 2020). Natural pressures, such as coastal erosion itself, changes in sediment composition and extreme events; identified as key factors of mangroves loss in (Aunurrahman et al., 2023; Goldberg et al., 2020); are also identified for Punta Soldado. A comparison of the areas where the wave attenuation rate attributed to mangroves exceeded 50% between the 1996 and 2019 coverage scenarios reveals a striking decline of nearly 90% in this vital coastal protection function. This means that 90% of the areas where mangroves significantly attenuated waves in 1996 no longer exhibit this protective benefit in the 2019 scenario. This reduction highlights the critical importance of mangroves in coastal defense considering the possible impact of their loss community's vulnerability to both average and extreme wave events (M. D. Spalding, McIvor, et al., 2014).

Our results suggest that coastal protection provided by mangroves is non-linear, not only due to their distribution along the coast but also because of the marginal effects of changes in mangrove area as stated in (Barbier et al., 2008) and (Koch et al., 2009). The wave attenuation rate in function of mangrove area is described by a 4th order polynomial function that tends to stabilize beyond an area threshold (30 ha in an average scenario). The wave attenuation rate function serves as a crucial tool in guiding decision-making processes aimed at restoring mangrove areas to optimize coastal protection benefits while minimizing costs. It is imperative to highlight that, according to the results, this function is different for every incident wave condition and the thickness of mangrove transects, reflecting the complex interconnections between coastal protection and marine climate variability. Thus, decision-makers and practitioners need to carefully consider the dynamic nature of environmental conditions and their influence on wave attenuation rates when proposing and designing strategies of Ecosystem-based Risk Reduction (Triyanti et al., 2017) and Ecosystem-based Adaptation (EbA) such as mangrove restoration for coastal protection.

### **3.4.3 It is not only mangroves, but mudflats and people**

The results of this chapter support mangrove recovery and restoration as management

measures for coastal protection, however, to enable this nature's contribution to people (better known as ecosystem services), it is important to acknowledge the broader picture, to propose effective solutions. In the first place, biophysical conditions for mangrove recovery need to be accomplished, (van Bijsterveldt et al., 2020) listed some of them: an available source of mangrove propagules (when natural regeneration is to be achieved), the restoration of hydrological connections to tidal flows, bed level is raised and the substrate is conducive enough for propagule to establish. For Punta Soldado and other barrier islands along the Colombian Pacific coast that have been affected by coastal erosion (Fuentes et al., 2022), the recovery of the hydrological conditions and mudflats are the main challenges for mangrove restoration within them (Lovelock et al., 2022a). Recent mechanisms have been proposed to assist mangrove establishment along vulnerable coastlines to enable the needed conditions for mangrove recovery such as permeable dams (Winterwerp et al., 2020), which philosophy is to build with nature, based on the rehabilitation of mangrove habitat through the re-establishment of the fine sediment dynamics.

Mangroves are ecosystems that provide multiple contributions to coastal communities in addition to coastal protection (Leal & Spalding, 2022). Fisheries support, tourism, habitat sustenance, provision of raw materials, supporting identities and recreation are some of the contributions of mangroves reported in literature (Bimrah et al., 2022; Vo et al., 2012). Understanding and addressing people's perceptions, beliefs, and values regarding mangroves and their NCPs are essential for developing coastal management strategies, considering that local communities' perceptions can significantly influence the success or failure of mangrove conservation and restoration efforts (Elwell et al., 2018; Quevedo et al., 2020). Therefore, a comprehensive approach that integrates ecological considerations with socio-cultural aspects is necessary for effective mangrove conservation and restoration in the coastal areas of Punta Soldado. Furthermore, sustainable mangrove restoration requires multi-stakeholder involvement and capacity building in order to match restoration opportunities with prospective supporters and investors (Lovelock et al., 2022a). To achieve this, more information regarding the economic benefits and costs to carry out the solutions must be generated for a data-based decision making process (Gatt et al., 2022); the results provided by this chapter are a clear base for economic valuation through the cost replacement or the avoided damage approaches. The following chapters will address some of the social and economic perspectives regarding mangroves contributions to protection of this social-ecological system.

## 4. Perceptions on mangroves contributions to people

Mangrove forests have been recognized as ecosystems that provide multiple benefits to coastal communities (Hutchison & Spalding, 2014) such as food, fiber, timber and protection from storm surges (Golebie et al., 2022). However, global mangrove cover has decreased in the last decades because of both natural and anthropogenic drivers (Kochoni et al., 2023a). Mangroves degradation not only could affect their contribution of coastal protection, but other regulation, material or non-material contributions (Owuor et al., 2019).

Culture is one of the central factors that define the linkages between people and nature (Díaz et al., 2018); it influences local knowledge, experiences and values regarding mangroves which in turn are reflected in the communities' perceptions of these ecosystems (Mitra, 2020). Perceptions can impact decisions on different aspects of ecosystem or resource management (Pascual et al., 2017) and can determine decisions regarding conservation or restoration of these ecosystems (Audu, 2022). Previous studies have assessed local perceptions of mangrove NCP's, often referred to as ecosystem services (ES). Most of the research has been conducted across diverse regions specially Africa (Zanzibar, Kenya, Tanzania and Côte d'Ivoire) (Afonso et al., 2022; Kochoni et al., 2023a; Nyangoko et al., 2022a, 2022b), Asia (Su & Gasparatos, 2023), and in some countries of Latin America such as Ecuador (Villanueva et al., 2023), Brasil (Queiroz et al., 2017) and French Guiana (Scemama et al., 2022). Several Nature's Contributions to People (NCPs) associated with mangrove ecosystems have been identified in these studies. Material contributions, such as fishery resources, are the most recognized by local communities, particularly in areas where livelihoods depend directly on mangrove products (Kochoni et al., 2023a; Mohamed et al., 2024; Nyangoko et al., 2022a, 2022b; Roy et al., 2020). Additionally, communities acknowledge coastal protection as a significant regulating contribution, especially in the context of climate adaptation. Although non-material contributions are less studied within ecosystem services, (Queiroz et al., 2017) and (Reyes-Arroyo et al., 2021) highlight the important role of mangroves in local value systems, where they hold cultural significance for the communities.

Despite the attention given in previous literature, various gaps have been identified in the study of local perceptions of mangroves' Nature's Contributions to People (NCPs). The first gap is the study of changes in these perceptions over time, especially in response to environmental changes such as mangrove decline or climate change (Nyangoko et al.,

2022a). Additionally, the understanding of how communities perceive mangroves' protective capacity in the context of climate variability or change remains underexplored. Moreover, perceptions of mangroves' NCPs and their changes are context-dependent and may vary subtly across different geographic regions due to their unique physical-biotic and socio-cultural contexts. Addressing these gaps could aid in developing effective adaptation and conservation strategies in each specific geographical context (Queiroz et al., 2017).

The Colombian Pacific Coast is predominantly inhabited by Afro-Colombian communities (comprising between 92% and 96% of the population), who have distinct cultural practices and organizational models compared to other regions of the country (Olaya Requene, 2022). Specifically, the local communities in this region are ethnic groups that have developed a deep connection between their collective identity and nature (Hoffmann, 2007; Restrepo, 2016). This connection is closely linked to the historical processes of occupation along the Pacific Coast, particularly in areas near strategic ecosystems such as mangroves (Bravo Pazmiño, 1998). In spite that local communities of the CPC have a strong relationship with mangrove forest, perceptions on NCP's provided by mangroves in this region haven't previously been assessed.

Understanding local perceptions of mangrove ecosystem services is crucial for several reasons. First, perceptions often influence behavior, which in turn affects the success of conservation and restoration initiatives. If local communities perceive mangroves as valuable and worth protecting, they are more likely to engage in conservation efforts and support sustainable management practices. Conversely, if these ecosystems are undervalued or seen as expendable, conservation strategies are less likely to succeed. Furthermore, perceptions of the protective role of mangroves against coastal hazards are particularly important, as these can directly influence local resilience to climate change and natural disasters.

In this chapter, the perceptions of the local community of Punta Soldado regarding mangroves' contributions to people, their drivers of change and the consequences of these changes perceived by the community are assessed through a qualitative approach. Particular attention is given to the community's perception of mangroves protective capacity and its linkages with drivers of change and the synergies with other NCPs.

## **4.1 Study area, social and cultural features**

Punta Soldado island is a rural area of Buenaventura in the central Colombian Pacific Coast (CPC), a region distinguished by its great biodiversity and culture. Currently, the island is occupied by three black communities: Las Contreras, Firme Bonito and Punta Soldado; the latter is the community with which this study was carried out (Figure 18). Punta Soldado Village is inhabited by approximately 400 afro-colombian people represented by the

Community Council of the black community of Punta Soldado<sup>1</sup>; it also has been populated since 1915 by people from other sites of the CPC such as Guapi, Timbiquí, Cajambre and the municipality of Buenaventura. The main economic activities within the community of Punta Soldado are artisanal fishing, mollusks collecting and coconut agriculture; these activities complemented by subsistence agriculture also provide livelihood opportunities in the community for daily living.



Figure 18. Aerial photograph of Punta Soldado village in February 2022 in low tide. Taken by the author.

According to mangrove coverage area data from the [Global Mangrove Watch](#) (GMW), Punta Soldado island had an area of approximately 950 hectares of mangrove forest in 2020, which comprised 6 species such as *Rhizophora mangle*, *Avicennia germinans*, *Mora oleifera*, *Laguncularia racemosa* and *Pelliciera rhizophorae* locally known as “Mangle rojo”, “Comedero” or “Pela Ojo”, “Nato”, “Mangle blanco” and “Piñuelo” respectively (Figure 19). The mangroves of the island are characterised by their robust appearance with trees of up to 35 m height and extremely dense roots; mangroves also have formed channels that connect the village with the Pacific Ocean and the Buenaventura Bay, these are locally known as esteros and have their own names (Figure 2), where the Estero Fermina, Estero Hondo, Estero de la Planta, Bodega and Bodeguita are the closest channels to the village and are recognized by the community.

---

<sup>1</sup> Community Councils in Colombia were established in Law 70 of 1993. The Community Councils represent a legal figure for black communities that have collectively occupied “empty lands” to have a territory and therefore the rights to use these lands according to the community's rules and traditions.

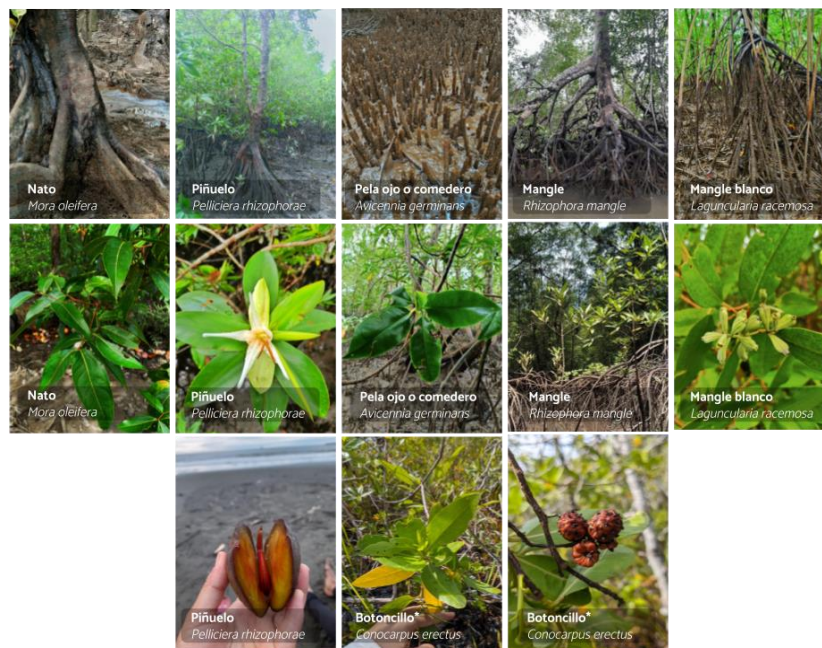


Figure 19. Mangroves species in Punta Soldado Island. Credits: Elkin Caicedo, Deisy Montaño, Edwin Alomia and Ballantyne Puin

In Punta Soldado, both the coastline and mangrove forest area have changed over time due to erosion processes linked to extreme sea level and wave events. Figure 20 shows through satellite imagery that the coastline in front of Punta Soldado Village has retreated approximately 500 m from 1983 to 2020. Moreover, data from the Global Mangrove Watch suggest that mangrove coverage area in the island has reduced to 75 hectares from 1996 to 2020. This reduction is spatially noticed mainly in the southern part of the island at the seaside, coinciding with the main changes on the coastline.



Figure 20. Evolution of Punta Soldado's mangrove social-ecological system. Created by the author.

Satellite and aerial imagery suggest that Punta Soldado Village experienced significant impacts from coastal erosion in the last four decades evidenced by the changes on the

village's infrastructure (Valderrama, 2023). Particularly, in 1996 the village was composed of two populated units, the largest in the front of the island and close to the beach; and another behind the mangrove forest and a channel formed within it. These two populated units were separated by a channel that could only be crossed by a bridge of concrete. By 2001, the area where the populated unit in front of the beach was settled was totally inundated by the sea; the mangrove forest within this area and the channel separating the two units had also disappeared and the bridge was partially destroyed. By 2020, mangroves and some infrastructure (including the bridge) in front of the remaining village disappeared leaving behind a coast fringe of approximately 20 m in the high tide, and a village with almost 110 houses. In field campaigns it has been observed that currently the beach in front of the village has naturally been restored with a coast fringe of approximately 70 m, and a natural regeneration process of *Avicennia germinans* has been observed at the south of the island as well (Figure 21). A dead mangrove fringe is observed in the seaward from the midst to the north of the island, also mangroves in the inner island remain robust, however, near the Estero Bodega and Bodeguita are signs of mangrove deforestation.



Figure 21. Aerial images of mangroves regeneration area (left), dying mangrove area at the front of the island (middle) and signs of mangrove deforestation in the island (right). Taken by the author.

## 4.2 Qualitative approach

This research is based on a qualitative approach that allows to capture trends regarding the intangible beliefs, values and perceptions of people (*Qualitative and Quantitative Research Techniques for Humanitarian Needs Assessment*, 2012). Perceptions on mangroves benefits and damages to the community, the drivers of change on mangrove forest and their effects on mangroves contributions to people were explored considering the methodology outlined in Figure 22. The information was collected using empirical techniques with two collective semi-structured interviews (the community council leaders and the piangueras<sup>2</sup> group) and 10 individual semi-structured interviews to representative members of the community (a fisherman, a cooker, a seeder, the oldest adult, a

---

<sup>2</sup> Group of people, mainly women, who traditionally dedicate themselves to the collection of mollusks within the mangrove forest specially *Anadara tuberculosa* and *Anadara similis* (Delgado et al., 2010).

shopkeeper, a housekeeper, a young woman, a young man and a coconut farm keeper). Participant observation was also carried out to explore in more detail some of the identified perceptions within the community. Field work was developed in three field campaigns in Punta Soldado Village with a duration of 6 days on average in 2022 and 2023. Focus groups meetings and interviews were recorded with the previous consent of the participants to digitally transcript them. The transcriptions were analyzed through content analysis techniques using the Atlas.ti software to categorize them where the methods of thematic analysis and type-building approach were applied.

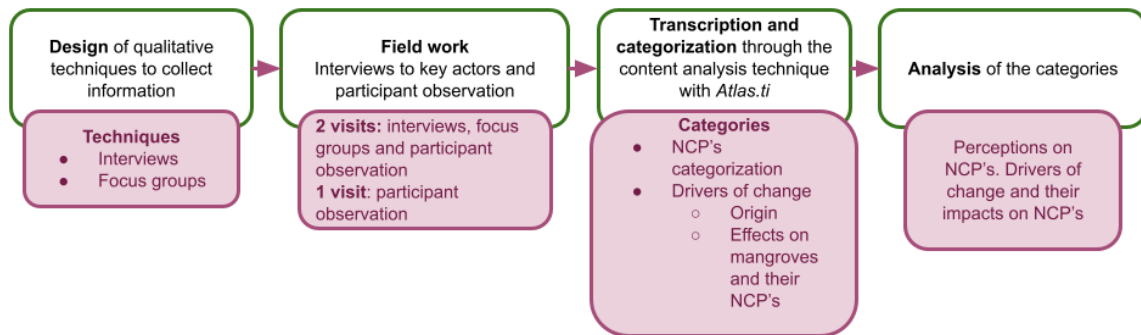


Figure 22. Schematic diagram of the qualitative approach methodology for the assessment of perceptions.

The thematic analysis consists of a content-reductive analysis (Lamnek, 1993) through the categorization of texts either creating categories inductively using the data or creating the categories deductively based on a theoretical framework (Kuckartz, 2014). This method was applied to identify mangroves contributions to people that the community of Punta Soldado perceives according to the IPBES framework proposed by (Díaz et al., 2018). Thus, the categorization in this case was carried out deductively considering the categories and subcategories indicated in Table 4-1.

Table 4-1. Categories for the identification of Nature's contributions to people (Díaz et al., 2018) perceived by the community of Punta Soldado with the thematic analysis method.

Topic	Categories	Subcategories
Nature's Contributions to		Formation, protection and decontamination of soils and sediments
		Habitat creation and maintenance
		Pollination and dispersal of seeds and other propagules

People (NCP)  Classification from <a href="#">Díaz et al (2018)</a>	Regulating	Regulation of air quality
		Regulation of climate
		Regulation of detrimental organisms and biological processes
		Regulation of freshwater and coastal water quality
		Regulation of hazards and extreme events
	Material	Energy
		Food and feed
		Materials, companionship and labor
		Medicinal, biochemical and genetic resources
	Non-material	Learning and inspiration
		Physical and psychological experiences
		Supporting identities
		Maintenance of options

The perceived drivers of change on the mangrove forest were assessed by applying the type-building text analysis method that consists on creating typologies in which the information can be classified considering multi-dimensional patterns (Kuckartz, 2014). For this case, eight typologies were developed to classify mangroves drivers of change by their origin and the type of effects they have on mangroves and their NCPs, i.e. if they are positive (that contribute to the recovery or regeneration of mangroves and enhance their NCPs) or negative (that contribute to the degradation or loss of mangroves and to diminish their NCPs) changes and if they have a slow or fast effect on the ecosystem and the contributions it provides. The Table 4-2 shows how these typologies are classified considering the previously explained factors. For example, extreme events are natural drivers of change that have had a negative and fast effect on mangroves, then this is a Type 8 driver of change.

Table 4-2. Typologies created from the text to assess perceived drivers of change of the mangrove ecosystem in Punta Soldado. Created by the author.

	Effects on mangroves and their NCPs			
Origin of the driver	positive and slow effect	negative and slow effect	positive and fast effect	negative and fast effect
Anthropogenic	Type 1	Type 2	Type 3	Type 4
Natural	Type 5	Type 6	Type 7	Type 8

Finally, the perceived effects on mangroves NCP's were subclassified considering the categories proposed by (Díaz et al., 2018) in order to obtain the number of NCP's that have changed over time according to the community's perceptions.

### 4.3 Results

Sixteen of the eighteen NCPs in the classification stated by (Díaz et al., 2018) were identified for the mangrove social-ecological system of Punta Soldado, through the categorization of 46 emergent subcategories of perceived mangroves contributions (Figure 23). Of all the identified NCPs, 48% were classified within the non-material NCPs, where the contributions that the mangroves provide to identity support are highlighted. Material contributions, such as the provision of labor and resources for food and materials, were also notably recognized, suggesting mangroves practical importance to the community's livelihood. Regulation contributions, particularly those associated with the mangroves' role in habitat maintenance, climate and natural hazards regulation were acknowledged as well.

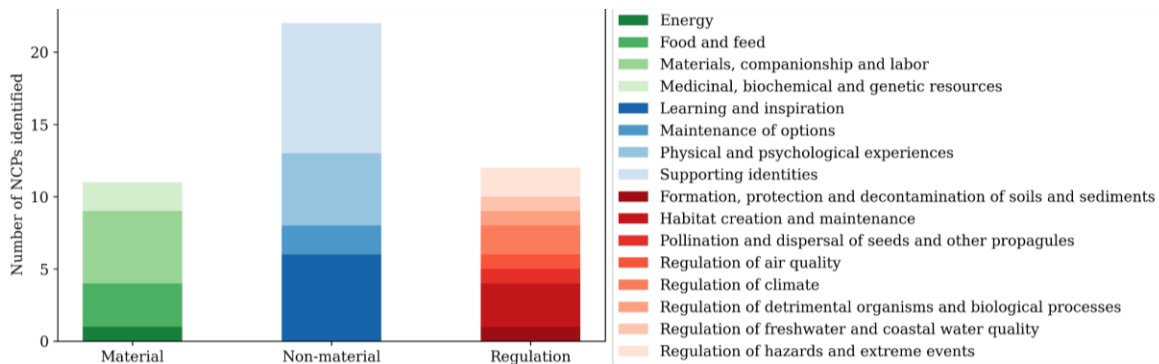


Figure 23. Perceived mangroves contributions to people identified in Punta Soldado.

### 4.3.1 Percieved material contributions

Among the material contributions of mangroves, the provision of food, materials and labor stand out. The mangrove forest is recognized as a place where a variety of species of fish, crustaceans, and mollusks can be obtained, serving as both sustenance and potential income through commercialization. In particular, the mollusks *Anadara tuberculosa* and *Anadara similis*, locally known as *piangua*, are traditionally harvested by women in the community (Figure 24), a practice reported in other mangrove areas of the Colombia's Pacific coast (Bravo Pazmiño, 1998). This activity - locally called *pianguar* or *conchar* - not only provides food for their families but also a means of income, suggesting that mangroves play a significant role in fostering local women's economic independence as stated by (Caicedo, 2019).



Figure 24. Piangueras of Punta Soldado collecting piangua (*Anadara sp.*). Credits: Corporación Social Manantial

Additionally, the mangrove forest provides labor opportunities in tourism, as it is one of the main attractions on the island. The local environmental authority Corporación Autónoma Regional del Valle del Cauca (CVC) has created temporary jobs for community members in environmental management projects and mangrove restoration and conservation as well. These jobs involve mangrove sowing activities, such as collecting propagules, developing and maintaining nurseries, planting saplings, and environmental monitoring tasks, all of which are reported by the community as sources of labor linked directly to the mangrove ecosystem.



Figure 25. Mangrove planting by the local group of mangrove's people. Photos taken by Jorge Luis Rocha

The wood and firewood from mangroves are used by community households for building their homes and as an energy source for cooking, respectively. The wood from the *Mangle* (*Rhizophora mangle*) and *Nato* (*Mora oleifera*) is commonly employed for the construction of walls and floors, as well as for the stilts (elevated poles) that raise the houses about 30 to 50 cm above the ground observed in the field and documented by multiple authors including (Prah et al., 1990). Mangrove lodging by external actors -from neighboring communities and the municipality of Buenaventura- for wood commercialization has been another contribution recognized through the interviews and conversations with several community members.



Figure 26. Mangrove wood to build houses in Punta Soldado. Photos by Jorge Luis Rocha

Medicinal plants linked to the mangrove ecosystem are identified, such as root-associated algae of the genus *Bostrychia* and termites (*Isoptera*), are known to the community for their wound-healing properties. Furthermore, the estuarine channels between mangrove strips

have historically functioned as waterways, facilitating access for tourist and community boats, especially when the mangrove strip in front of the settlement was intact (until 1997).

### 4.3.2 Perceived non-material contributions

Plenty of non-material contributions from the mangrove ecosystem are recognized for their role in supporting identities and maintaining options, offering a range of physical and psychological experiences—both positive and negative—as well as serving as a source of inspiration and learning opportunities. Interviews and observations suggest that mangroves serve as a foundation for environmental education through the continuous knowledge transmission among diverse community groups, including children, youth and adults regarding the ecosystem. Conservation programs led by environmental authorities, activists and academia incorporate activities aimed at enhancing and creating knowledge about the mangrove ecosystem and its ecological functions. The variety of economic and non-economic activities within the mangroves contribute to experiential learning regarding natural processes linked to these environments as well; moreover, interactions with the ecosystem have fostered traditional and ancestral knowledge for various purposes, such as methods to avoid or treat environmental hazards like animal stings or physical injuries, as well as for improving productive activities. Enhancements in piangua harvesting techniques and the creation of products derived from the diverse species of fauna and flora found within the ecosystem are examples of such knowledge. The mangrove forest is also recognized as an ecosystem of interest for collaborative development of scientific knowledge through participatory action research implemented by some of the scientists visiting the island. The groups of piangüeras and sowers identify themselves and are recognized by the community as groups that are tightly connected to the mangrove forest, then mangroves contribute to support the identity of these groups not only within the community but to other actors that have worked in the island, especially the local environmental authority and NGOs.

Mangroves are recognized as places where people experience a diversity of physical and psychological sensations that can be both beneficial and detrimental to their well-being. Many recreational activities take place here, with community members traditionally swimming and enjoying the channels formed within the forest. Described as marvelous sites, mangroves attract touristic activities organised by local groups, including bird-watching routes and piangua collecting, which are part of a community-based ecotourism experience. The mangrove forest is described as a provider of freshness, peace and serenity where troubles are forgotten, and life prospers; this perception is echoed in sensations expressed in local testimonies such as: *“In the mangrove we feel freshness. That’s why here, people hardly ever fall seriously ill”* and *“Because of the oxygen, here you feel the heat, but once you go deeper inside (the mangrove forest), it’s like, wow, it’s like entering another world, it’s so refreshing”* – Nancy Caicedo (Piangüera).

Several detrimental experiences linked to the interactions among the community with mangrove features are identified in the SES. The mangrove forest is qualified as an area that presents plenty of challenges for access and mobility requiring specific attire to prevent accidents and move safely. These challenges arise from the ecosystem's characteristic features, such as mudflats where individuals can easily sink, and the complex roots system, locally called '*el raicero*', represent obstacles for mobility. Sometimes, people attempt to move by climbing onto the roots; however, this can lead to a risk of accidents, as some roots may be weakened and could break underweight, causing falls of up to 2.5 meters. These conditions demand preventive strategies for those engaged in activities like mangrove monitoring, piangua harvesting, and mangrove planting. Mangroves are also associated with harmful animals found within the forest such as sandflies, mosquitoes, stingrays, toadfish and snakes, which can lead to injuries with risk of infection.

During wave extreme and coastal flooding events, the destructive potential of dead mangrove trunks and branches has reshaped the lives of the community. These events have not only damaged property but also represented serious safety risks, as described by community members: "*Huge waves... and I don't know where all those logs came from, but they smashed into the houses with the sea pounding 'boom and boom', it was extremely tough*". Such experiences etch in the community's memories, perception of risk and their interactions with the mangrove environment. The latter is evidenced by the testimonies that relate to the need they had to cut dead mangrove trunks to prevent household damage "*I had a talk with my cousin. I told him, 'Cousin, look at the sea, it's coming. Start cutting down the trees. The ones that are close to the houses, start cutting them down'*" – Vicente Góngora.

### 4.3.3 Percieved regulation contributions

The thematic analysis indicated that the regulation contributions represent 27% of all the mangroves NCPs perceived by the community. Eight of the ten regulation NCPs from the IPBES framework were identified in the interviews. Mangroves are recognized for sustaining and creating habitats for various species crucial to the community's economy and subsistence, including fish and crustaceans like *jaiba* (*Callinectes sp.*), "*tasqueros*" crabs (*Goniopsis cruentata*) and molluscs like *piangua* and "*piacuil*". Mangroves are also habitat for terrestrial mammals like the mangrove deer (*Odocoileus sp.*) and the silky anteater (*Ciclopes dorsalis*). Alligators locally called "*tulisios*" and some snakes are also reptiles that are recognized to live within mangroves. Birds and shorebirds have been permanently observed within the mangrove forest, some of these species are the Yellow-backed Oriole (*Icterus chrysater*), the Slaty-Tailed Trogon (*Trogon massena*) the Little blue Heron (*Egretta caerulea*) and the Humboldt's Sapphire (*Chrysuronia humboldtii*).



Figure 27. Fauna associated to mangroves ecosystem found in Punta Soldado.

Climate and air quality regulation from mangroves are perceived by the community. According to the testimony's mangroves provide oxygen, regulate the temperature and generate shade from the sun. Also, the mangrove forest is identified due to its purer air compared to the villages or the municipality's: *"Once you're in the mangrove, it's like, oh, you breathe something different from when you're in the village. It has this, it's fresh. Fresh"*. The regulation of coastal water quality is also recognized as a gift from mangroves that is linked to the maintenance of fishes and crustaceans.

The propagules from the different mangrove species are recognized by the members of the community and their dispersion is highlighted as key for the mangrove ecosystem maintenance through time. The mangrove forest also fosters species that may be detrimental to humans, for instance, the sandflies and mosquitoes are known as vectors of diseases like malaria, dengue and yellow fever. This is a negative contribution for those who carry out activities near the mangroves, however, it could be a positive contribution for the people in the village considering that these species tend not to establish within it.

Mangroves are conceived as key elements for soil structure maintenance due to their complex root system that helps "tie" the soil and protect it from erosion. Mangroves are considered as protective barriers against waves, according to some of the interviewees, they are the village's walls and barriers that attenuate average wave and tides events: *"... when the waves are small, they protect us. If the mangroves weren't there, the wave would pass straight through and hit harder... the sticks (the mangroves) fell while holding back the force of the waters"*; *"Who knows, without the mangroves the sea and water would flood the town. With the "puja" (spring tide), we are left unprotected"*. Plenty of testimonies indicate that mangroves' protective capacity against waves is limited, particularly, it is perceived that mangroves are not capable of attenuating extreme wave events considering

their experience in the past decades. Moreover, there is the perception that only God can protect them from the damages these events can cause as expressed in some statements full of helplessness: *"Ah, I don't know. Because there's nothing that can stop the sea, only God, because when it (the sea) gets furious, there's nothing that can stop it."*, *"The mangroves are always protecting us. They help to protect. But against the sea, who can? Who will be able to tackle it?"*.

While living mangroves are recognized for their role in coastal protection, dead mangroves can represent significant risks during adverse wave events. Interviewees noted that when dead mangroves were positioned in front of the village, they lacked the strength to withstand extreme waves. Consequently, they would fall and could be dragged by waves and tides into houses with enough force to cause damage to the infrastructure or even injure the inhabitants. In response to these experiences, some testimonies highlighted that community members would proactively remove dead mangrove trunks during extreme events to prevent damage to households: *"So we had to find a way to divert them (the trunks) so that the sea could take them away, cut them with an axe at low tide and divert them. That same tree could knock down your house and it could take your life. We looked for the chainsaw. Recently we had one, or the axe, we had to cut them and move them. We looked for the long ones, because... that's not going to withstand a fierce sea"*.

#### 4.3.4 Perceived mangroves drivers of change

Fourteen drivers influencing changes in mangroves have been identified and categorized in eight typologies as was explained in the methodology section.

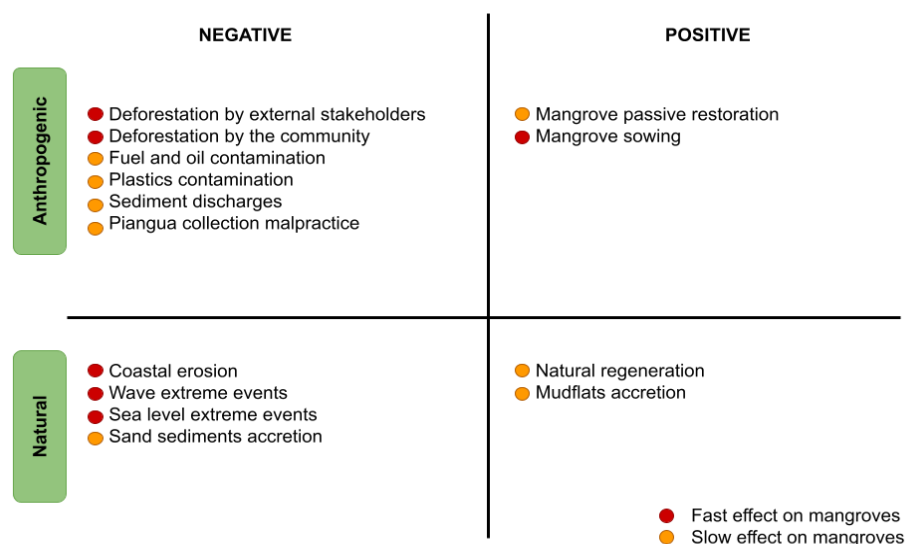


Figure 28. Classification of mangroves drivers of change considering the eight proposed typologies. Created by the author.

#### 4.3.4.1 Anthropogenic drivers

Negative Effects. Most of the identified anthropogenic drivers with negative effects are characterized by their perceived fast and slow impact on the mangrove ecosystem. Fast impact drivers include deforestation due to indiscriminate logging by both local and external actors, who exploit mangrove wood because of its structural favorable characteristics. Mangrove logging has been ongoing for years, however, recent increases in wood demand for construction purposes in Buenaventura have intensified these activities (Figuerola et al., 2011). Contamination from chainsaw oil used during logging operations has been recognized as another driver of change with medium to long term effects on mangroves' extent. According to some interviewees, oil contamination has directly affected piangua populations, impacting the work and livelihoods of the piangueras. Additionally, the piangueras report that women from other communities engage in malpractices while collecting piangua, such as cutting branches and stems, which further degrades the mangroves. Plastic pollution is also recognized as a significant driver of change for mangroves, impeding their respiration and other ecological processes. Sediment discharges from the Bajo Anchicayá Hydroelectric Plant and the dredging of the Buenaventura Harbour Channel are described as drivers of change to the mangrove ecosystem as well, considering the tight relationship between sediments and mangroves.

Positive Effects. Fewer positive anthropogenic influences on mangroves are acknowledged and reported to be evident over a medium or long term. These involve restoration projects such as mangrove sowing, which have been led by the group of piangueras and sowers through the intervention of CVC, the local environmental authority. Mangrove sowing is particularly challenging considering the high dynamics of the territory and the complexity of the sowing techniques that need to be performed, however the most challenging factor reported by the community is the forest degradation by logging that has detrimental effects on the mangrove sowing plots. The protective local rules that limit mangrove cutting mechanisms to cutting aim at the natural recovery and preservation of mangrove areas are identified drivers of change with positive effects on mangrove ecosystems.

#### 4.3.4.2 Natural drivers

Negative Effects. Natural drivers that rapidly change mangroves are predominantly related to natural hazards such as coastal erosion and extreme wave and sea level events, which can immediately affect large areas of mangrove forests. Local stories about changes in the coastline and mangroves over time have revealed connections between them. For instance, the community reports significant changes in the mangrove area in front of the village throughout the years. Periods such as 1983-85, 1996-98, 2001-2007, and 2019 remain vivid in the memory of the community's eldest members due to the events that took place. Interviewees recall that from 1996 to 1998, part of the mangroves in front of the current village settlement were impacted by extreme waves during the October Spring tide

season, locally known as "la puja," which destroyed some mangrove trees and degraded others. This period coincides with the 1997 El Niño event reported by NOAA, which caused a 0.45 m sea level rise, creating extreme oceanic and coastal conditions that the social-ecological system had to face. From 2000 until 2019, the mangrove forest in front of the village gradually degraded and died due to the action of waves and tidal effects, as reported by community members. Natural sediment transport around the island, influenced by coastal and river dynamics, has changed the type of sediments within the mangrove forest over time. Some interviewees indicate that fine sediment like mud allows mangroves to settle, while other types of sediment, like sand, can harm mangroves because they are more likely to reach high temperatures, affecting mangrove roots.

Positive Effects. Positive natural influences generally occur slowly. These include natural fine sediment accumulation processes that help in building up mudflats and therefore supporting mangrove natural expansion over time. According to testimonies, field observations and aerial images it was possible to detect that from 2019 until 2024 the south point of the island in the right margin of the Anchicayá River has been regenerating with mudflats and some new mangrove areas of *Avicennia germinans* ("pela ojo" or "mangle negro") and *Laguncularia racemosa* ("mangle blanco").

Most of the negative drivers of change have a fast effect on mangroves' area and are related to natural hazards exacerbated by anthropogenic drivers such as deforestation and contamination. Positive drivers may have medium- to long-term effects on mangrove forest areas and are influenced by natural dynamics and the social governance of the ecosystem. These effects are shaped by conservation and restoration efforts carried out by the local community and supported by external institutions, such as the local environmental authority and other stakeholders interested in coastal ecosystem conservation. This analysis suggests that the mangrove area is likely to decrease over time, which aligns with observations from the Global Mangrove Watch that show a reduction in mangrove extents over the years from 1996 to 2020 in Punta Soldado Island. The predominance of negative and fast-acting natural drivers coupled with the slow but persistently negative anthropogenic impacts suggests an ongoing threat to mangrove ecosystems. In contrast, the positive contributions, whether natural or anthropogenic, tend to take effect more gradually, which may not be sufficient to counteract the rapid losses unless they are enforced by more immediate conservation efforts.

#### **4.3.5 Effects of mangrove loss on their NCPs**

Observations and interviews have highlighted several consequences of mangrove loss and degradation on the NCPs related to mangroves in Punta Soldado. The impacts extend across plenty of dimensions, affecting the community's economic activities, the ecosystems ecological balance, local infrastructure, health, recreational spaces and cultural identity. Figure 29 shows that, according to the community's perceptions, the identified drivers of change affect several Materials, companionship and labor contributions. Non-material

contributions are perceived to be highly affected by drivers of change, especially the one's related to supporting identities, physical and psychological experiences and the maintenance of options. From the regulation NCPs only the contribution of regulating hazards and extreme events were perceived to be affected by the drivers of change. The perceived effects of these drivers are described as follows:

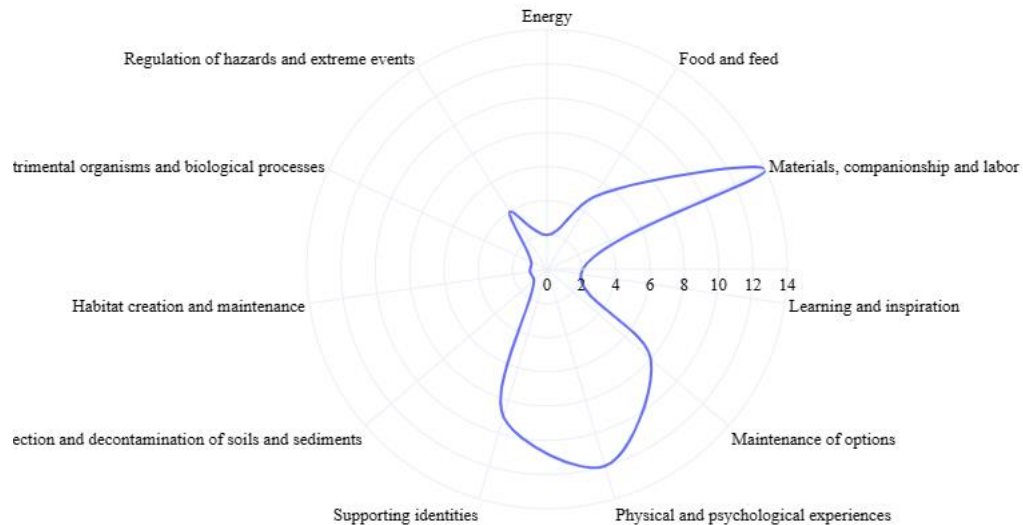


Figure 29. Number of perceived mangroves' NCPs affected by the identified drivers of change. Created by the author.

#### *Impacts on labor and economic activities*

The loss of more than 70 hectares of mangrove over time has significantly increased the effort required for traditional activities like piangua collection and artisanal wood harvesting for fuel. This area of mangroves was in front of the current village and was therefore the closest to the household. Consequently, these changes have led to increased distances to the mangrove areas where these activities can be carried out, as well as decreased accessibility, particularly since waterways previously supported by mangrove channels are now tide dependent. The loss of mangroves correlates with a decrease in local fauna, such as fish and piangua, which affects food availability and income sources, directly impacting the livelihoods of piangueras and fishermen.

#### *Habitat maintenance changes*

The disappearance of mangroves has led to the loss of critical habitats for various species such as shorebirds and mammals, directly threatening biodiversity. This degradation also affects the availability of essential natural resources, such as fish, crustaceans, and mollusks, which are integral to both the local diet and economy. Additionally, the decline in

biodiversity has diminished the region's natural beauty and appeal, directly impacting ecotourism—another source of income for the community.

#### *Reduced coastal protective capacity*

As mentioned above, extreme wave and tide events have been perceived as drivers of loss and degradation of the mangrove ecosystem. However, mangroves are recognized also as natural barriers against some of those events, thus, their degradation leaves the community more vulnerable to flooding and storms. The loss of some of the local infrastructure such as communitarian accommodation for tourism, the bridge, houses, the school and the church; is attributed both to mangroves loss and beach retreatment. This highlights how mangrove degradation and loss have affected their role as protective barriers for the community.

#### *Effects of changing landscape on health and recreation*

According to the identified perspectives, the proliferation of disease vectors like mosquitoes and sandflies has increased due to the changing landscape, particularly due to decreased mangrove areas to which these species are related to. The increasing disease vectors within the village have directly increased diseases such as malaria in the community members. However, the loss of mangroves and therefore the transformation of the physical landscape has created new recreational spaces such as beaches while simultaneously reducing traditional spaces within the mangrove ecosystem that were used for swimming or playing.

#### *Impacts on traditions and risk perception*

The disappearance of mangroves directly affects traditional practices and the cultural fabric, leading to psychological distress and a sense of loss among community members. Traditional activities such as piangua harvesting, fishing, and the use of mangrove wood for artisanal purposes are not only economic activities but cultural traditions passed down through generations. Therefore, mangrove loss threatens these traditions, knowledge and skills eroding the cultural identity and heritage that define the community. Moreover, mangroves ecosystem degradation has heightened the community's perception of risk, particularly regarding extreme weather events and coastal erosion. The threat of storms and flooding strengthened by the loss of mangroves as protective barriers, fosters a constant sense of anxiety and helplessness among the community. These feelings are exacerbated by the visual and emotional impact of seeing once-healthy mangrove forests reduced to dead trunks. The statement, "*The mangroves are always protecting us. They help to protect. But against the sea, who can? Who will be able to tackle it?*" evidences their struggle with the sense of vulnerability and the diminishing hope for effective protection against natural forces. Furthermore, the disruption of recreational spaces and the natural beauty provided by mangroves has diminished the community's positive psychological experiences, considering that mangroves offer places of peace and reflection, contributing to mental well-being.

## **4.4 Discussion**

### **4.4.1 Community perceptions of mangrove contributions to people**

Material contributions of mangroves have been reported to be the most important and recognized by communities' due to their role in sustaining communities livelihoods through fisheries, timber collection and mollusks harvesting, the latter especially important for women (Afonso et al., 2022). However, this chapter reveals that in the case study of Punta Soldado, non-material contributions of mangroves are the most recognized by the local community. These include the significance of mangroves in supporting local identities and providing spaces for learning, inspiration, and intergenerational knowledge transmission. This finding aligns with (Martín-López et al., 2012) who suggest that in rural areas non-material contributions to people tend to be valued more highly than material and regulating contributions. Also, this is supported by (Reyes-Arroyo et al., 2021) and (Queiroz et al., 2017) who studied the socio-cultural value of mangroves in Mexico and Brazil respectively, and emphasized that non-material contributions of mangroves are deeply rooted in the community's identity and traditional knowledge, further reinforcing the intrinsic connection between communities and these ecosystems. Contributions related to the maintenance of options provided by mangroves – such as the opportunity of new generations for both enjoying the ecosystem or making use of it as a source of labor- were also recognized by the community, aligning with the findings of (Quevedo & Kohsaka, 2024) in their systematic review of cultural services from mangroves. Moreover, the perception of mangroves as key elements for the community's well-being through psychological experiences such as the sense of freshness and peace has been broadly identified in coastal areas where local communities that rely on mangroves resources for their livelihoods (Su & Gasparatos, 2023). This connection could be associated with the closeness of the community from mangroves which can promote stress reduction due to the basic psychological need of nature relatedness from humans (Ke et al., 2022).

Furthermore, in this chapter material contributions are also recognized by the local community because of their role in food, materials and labor provisioning, where the provision of fish and mollusks and the collection of firewood and timber were identified as some of the contributions from mangroves. In fact, (Gnansounou et al., 2022), found that fish provision and timber collection are the most important contributions of mangroves to local communities because these materials are essential for local consumption and livelihoods.

Regulating contributions like habitat maintenance, climate regulation, regulation of hazards and extreme events among other were identified through the focus groups and interviews, which concords with the findings of (Nyangoko et al., 2021) who suggest that communities

close to mangrove forest tend to be aware of the regulating contributions that mangroves provide to people, especially those regarding to climate and hazards regulation.

#### **4.4.2 The highly dynamic protective capacity of mangroves**

Although the community identified mangroves as ecosystems which contribute to coastal protection by reducing flooding and wave strength, one of the most intriguing findings is the highly dynamic nature of the protective contributions of mangroves perceived by the community. According to the community's testimonies, the protective capacity of mangroves is significantly dependent on the state of the mangrove ecosystem itself. This perception aligns with the understanding that a healthy, dense mangrove forest offers more robust protection against environmental hazards compared to a degraded one (Kelty et al., 2022; M. Spalding, McIvor, et al., 2014).

According to (Damastuti & de Groot, 2019) and (Nyangoko et al., 2021) the incidence of coastal hazard makes coastal communities value mangroves as protective features of the coast, particularly when they have lived both in presence or absence of mangroves. These studies have involved communities where mangrove rehabilitation has taken place in contrast with Punta Soldado where the degradation of mangroves has been visually evident throughout the past decades. In this chapter it is identified that the community recognizes that, as mangroves degrade—due to factors such as deforestation, pollution, or overharvesting—their capacity to protect against waves, sea level rise, and extreme weather events diminish. This finding is echoed in previous research by (Kochoni et al., 2023a).

Moreover, the protective effectiveness of mangroves is also perceived to be contingent on the environmental conditions of the sea, particularly the intensity of waves and the level of the sea. During periods of extreme waves or higher sea levels, even healthy mangrove ecosystems may struggle to provide adequate protection. This dynamic understanding of mangrove protection highlights the community's awareness of the complex interplay between ecosystem health and external environmental factors. It also highlights the need for adaptive management strategies that can respond to both ecological changes within the mangrove forests and changing sea conditions.

This duality and dynamic perception of mangrove protection are reflected in other studies, such as those by (Afonso et al., 2022), who noted that communities in São Tomé Island appreciated the protective role of mangroves but also recognized that this role is not static and can be compromised by both internal degradation and external environmental pressures. This understanding by the community suggests that conservation efforts must not only focus on maintaining or restoring mangrove health but also consider broader environmental factors, including wave action and sea level changes, in planning and implementing ecosystem-based adaptation strategies.

#### **4.4.3 Changes on mangroves contributions and their implications on Ecosystem-based adaptation strategies**

Eight types of mangroves' drivers of change were identified in this chapter, either natural and anthropogenic drivers were acknowledged by the community where the demand of mangrove products (timber and firewood) was one of the drivers of degradation of the ecosystem as noted by (Friess et al., 2019); this direct drivers can be derived from the lack of enforcement of laws and regulations (even informal rules) regarding mangrove protection (Mwansasu, 2016). As found in southeast Asia by (Islam et al., 2018) unsustainable exploitation practices on mangrove products harvesting, such as piangua, were also identified as a cause of degradation of both mangroves and this material contribution. The focus groups also highlighted the importance of developing agreements that enforce the existing harvesting rules with the neighboring communities to preserve this product as a source of food and income in the long term which is one of the key challenges on mangroves governance (Hicks & Cinner, 2014; Mshale et al., 2017).

The influence of wave and sea level extreme events as well as coastal erosion are perceived by the community as natural mangrove drivers of change which have degraded the ecosystem until the point of total loss at the front of the village from 1996 to 2019. This responds to the fact that in spite mangroves may function as coastal protection, they also suffer damage carrying out this task (Islam et al., 2018); which can harm coastal communities by damaging houses, infrastructure and even source of labor (Mallick et al., 2021; Nyangoko et al., 2022b). Similar to the findings in this chapter, (Nyangoko et al., 2022b) found that local communities perceived significant changes in the regulating contributions provided by mangroves, such as coastal protection and flood control due to changes in this ecosystem area. These perceptions reinforce the critical role that mangroves play in community adaptation strategies, particularly in regions vulnerable to climate variability and climate change (Kochoni et al., 2023a).

As (Damastuti & de Groot, 2019) stated, mangrove restoration and conservation activities and programs are positive drivers of change of mangroves and their NCPs, enhancing not only mangroves ecosystem but also providing income and the opportunity to improve community's livelihoods related to mangroves. Given the capacity of mangroves to contribute to mitigate the influence of waves in the coastal zone, Ecosystem Based Adaptation (EbA) has been proposed as a conservation and adaptation measure in different coastal zones around the world with the purpose to protect or restore NCP's and then minimize people's vulnerability to climate variability events (Munang et al., 2013; Nyangoko et al., 2021; Vignola et al., 2009). Nevertheless, the success of these strategies are highly dependent on the socio-cultural dimension of NCP's associated with the symbolic relationship of people with mangroves (Queiroz et al., 2017) as well as appropriate rehabilitation and restoration techniques that ensure the successful enhancement of mangroves contributions to people (Waryszak et al., 2021). Therefore, transdisciplinary

interventions that address the specific needs and challenges of the specific context are needed.

#### **4.4.4 Community's symbolic relationship with mangroves**

The community's symbolic relationship with mangroves is deeply intertwined with their understanding of coastal protection and their perception of risk. Mangroves are not merely viewed as natural resources; they are seen as the village's protective walls, embodying a sense of safety and resilience against the forces of nature. The complex root systems of mangroves, which "tie" the soil and protect it from erosion, are perceived as vital for maintaining the integrity of the land on which the community lives. As many community members express, mangroves serve as crucial barriers that attenuate the impact of average wave and tide events, safeguarding the village.

This perception of mangroves as protective barriers is consistent with findings from other studies, such as those by (Badola et al., 2012; Badola & Hussain, 2005; Reyes-Arroyo et al., 2021) who have identified that local communities from Mexico and India are aware and value the protective roles of mangrove. Similar to the community in Punta Soldado, the communities studied by (Reyes-Arroyo et al., 2021) regard mangroves as essential not only for their physical protection but also for their cultural and spiritual significance. However, while mangroves are recognized as barriers for protection, there is a growing awareness among the community that their protective capacity is limited, particularly against extreme wave events. This is consistent with the statements from (Lee et al., 2014; Mitra, 2020) who conceptualized the limitations of mangroves in the face of severe storms, leading to a reliance on divine protection or external interventions. The community's experience with increasingly severe storms and higher sea levels has led to a sense of helplessness, where the limits of mangrove protection are acknowledged. This perception underscores the importance of understanding that the effectiveness of mangroves as protective barriers is dynamic and heavily dependent on the health of the mangrove ecosystem and the environmental conditions of the sea (Nyangoko et al., 2022a).

Furthermore, the degradation of mangroves—manifested in the presence of dead mangrove trunks—poses additional risks during adverse wave extreme events. Dead mangroves, once vital protectors, become potential hazards that can cause significant damage to infrastructure and threaten lives. The community's proactive measures to remove these dead trunks during extreme events highlight their adaptive strategies in managing these risks, even as they contend with the diminishing protective role of the mangroves. This adaptive behavior is also noted in Malaysia, where local populations take direct action to mitigate risks posed by degraded mangrove ecosystems (Abd Rahman & Asmawi, 2016).

The loss of mangroves not only heightens the community's vulnerability to natural disasters but also erodes the cultural and psychological foundations that have long supported their resilience. As mangrove ecosystems degrade, the community's sense of security

diminishes, and with it, their cultural practices and traditions that are deeply tied to the health of these ecosystems. The symbolic role of mangroves in the community's identity and their practical role in coastal protection are thus inseparable, making the conservation of these ecosystems critical not just for physical protection but for maintaining the cultural and psychological well-being of the community. This is in line with the observations made by (Afonso et al., 2022; Kochoni et al., 2023b), who emphasize that in many communities, the degradation of mangroves leads to a loss of cultural identity and an increased sense of vulnerability, further complicating efforts to manage coastal risks effectively.

In this chapter, the perceptions of the Punta Soldado community regarding the contributions of mangroves to people are explored. The results show that the community places significant value on both the material and non-material contributions of mangroves, recognizing their importance for livelihoods, such as through fishing and mollusk collection, while also acknowledging their cultural and identity-supporting roles. Mangroves are perceived not only as sources of food, timber, and labor but also as spaces of psychological well-being, offering a sense of peace, freshness, and identity for the community. The community's understanding of mangroves as protective barriers against coastal hazards reflects their deep connection to the ecosystem, but this protective role is seen as limited in the face of extreme events, reinforcing the need for conservation and adaptive management strategies.

Additionally, mangroves drivers of change are perceived to be both natural and anthropogenic, such as deforestation, pollution, and coastal erosion. According to the community, these drivers have led to a decrease in mangrove coverage, diminishing their protective capacity and affecting the community's economic and cultural practices. It was possible to acknowledge that effective governance and restoration initiatives may contribute to maintaining the ecosystem and their contributions to people. The community's insights provide context for developing EbA strategies that consider the ecological functions of mangroves and the socio-cultural dimensions of their contributions to people; however the economic dimension needs to be considered as well.

## **5. The role of mangroves in reducing damage. An economic approach**

Mangroves are vital ecosystems for coastal protection, particularly due to their ecological function of damping waves and reducing flooding. Additionally, local perceptions of this protective role and other associated NCPs are reported to be highly significant for the livelihoods of local communities. A key aspect of highlighting the benefits of mangrove protection and restoration, particularly regarding their protective contributions, is the ability to quantify these benefits in monetary terms. This is relevant to propose strategies for conservation and restoration of mangroves ecosystems such as Nature-Based Solutions (NbS) or Ecosystem-Based Adaptation (EbA). Economic valuation is an approach that intends to estimate quantitative values to the contributions that nature provides to people (Costanza, 2020). The economic value of mangroves contributions to people has been studied by several authors mainly for land-use decision making (Barbier et al., 2011; Vo et al., 2012) and integrated coastal areas and ecosystems management (Menéndez et al., 2018; Narayanan et al., 2023).

Among other NCPs provided by mangroves, economic estimates regarding the coastal protection contribution of mangroves to coastal communities have been carried out previously by a few authors. (Barbier, 2016) conducted a review of the different methods for estimating the economic value of this contribution where it was found that the most commonly used method is the avoided cost method, which estimates the costs of building artificial barriers that fulfill the mangroves' role as a defense mechanism against erosion and flooding. (Sathirathai & Barbier, 2001) applied this method in a coastal area of Thailand, where the authors calculated that the present value of the contribution of mangroves for coastal protection and stabilization is \$12,263 USD/ha. Recently, the expected damage function approach has been used, which estimates the value of protection provided by ecosystems in terms of the reduction of expected damage associated with a specific event (Barbier, 2015). The benefit transfer method is one of the methodologies that has gained significant attraction recently. It involves taking the economic value estimates from one site and transferring them to a site with similar characteristics (Richardson et al., 2015). However, due to the limits and the large number of assumptions that have to be taken into account to use this methodology, there have been discussions about its inaccuracy for estimating the economic value of the coastal protection contribution and other contributions in general (Barbier, 2016; Himes-Cornell et al., 2018).

Previous studies, such as those by (Barbier et al., 2008, 2011) and (Koch et al., 2009), have identified the challenges in capturing the dynamic and non-linear nature of mangroves contribution to protection. This chapter contributes to addressing this issue by examining how changes in mangrove coverage and the intensity of wave events—both average and extreme—affect the effectiveness of mangroves in coastal protection. Additionally, the chapter discusses the integration of these protective contributions into broader ecosystem-based adaptation (EbA) strategies, considering that there has been limited integration of mangrove valuation within comprehensive coastal management frameworks (Marois & Mitsch, 2015). By exploring how varying scenarios of mangrove areas and wave conditions influence their protective capacity, this chapter provides some insights that can enhance the incorporation of mangrove into EbA strategies for coastal management.

## 5.1 Economic features of Punta Soldado

Punta Soldado village is located at the south of Buenaventura Bay's mouth and currently is inhabited by approximately 400 people identified as afro-colombians who have been settled in Punta Soldado island since 1915 (Mosquera Torres & Aprile Gniset, 2018). Most of the population of the community are fishermen, who are mainly men that have carried out this practice as a source of income while some women collect mollusks and other resources from the beach and mangroves. Some members of the community dedicate themselves to agriculture of coconut and banana and subsistence crops, as well as the collection of non-wood resources from the forest such as medicinal plants and fruits. Tourism has also been another important activity in the community as an alternative source of income since the 80's, however due to coastal erosion and extreme events this activity was officially suspended from 1996 to 2021 (Consejo Comunitario de la Comunidad Negra de Punta Soldado et al., 2023).

Currently, the community has approximately 100 houses mostly made of mangrove wood (*Rhizophora sp* or *Mora oleífera*) or other terrestrial trees such as Machare (*Symphonia globulifera*). Water is sourced from rain and from a well located in the beachfront area, while drinking water is obtained through filters or by purchasing bottled water. They are supplied with electricity through a hybrid system of solar and fuel source, which has allowed them to have energy 24 hours a day. This system was provided by USAID with the support of CELSIA (Energy Enterprise in Colombia). In the village there is a school made of wood with three classrooms where primary and high school classes are taught; the community also has an events hall, an office, a library and a health center made of brick and cement, the latter with adequate facilities but with insufficient health personnel to attend to the people who come to it. A plastic waste collection center was built as part of an initiative to promote the collection of plastic waste on the beach as well as the recovery of plastic waste within the community. There is a park in the central area of the village next to a satellite internet station managed by one of the community members. In the area behind the village there

are three tourist cabins, and two hotels made of wood to cater for the flow of tourists that may visit the community.

Years before, the community of Punta Soldado was known as a satellite village whose exclusive economy of fisheries and mollusk collection resulted in its dynamic growth. Between 1994 and 1995 more than 150 houses made of wood were inhabited by almost 600 people in the village (Mosquera Torres & Aprile Gniset, 2018). The population of the community was situated in two different areas, most of the population was in the beach area near the sea and some people lived in the forested area behind the mangroves and a natural channel (estuary). According to newspaper files from the period, the community was connected by a concrete bridge of approximately 300 meters across the channel. In the beach area were located among 135 houses, the school, the community lounge and ten hotels with 10 to 15 rooms; while in the forested area the coconut and other kinds of crops were grown and approximately 25 houses were settled.

Due to the extensive beach where most of the community was situated, as well as the proximity to the Port of Buenaventura, Punta Soldado, along with other beaches to the north of the Bay, was one of the most visited tourist destinations in the area to enjoy the beaches and the seasoning of the town's cooks who sold food to tourists. Thus, Punta Soldado was a community specialized in sun and beach tourism that provided income for the different members of the community. However, coastal erosion and wave extreme events from the 1997 and 1998 destroyed a great part of the village that was settled in the beach area affecting houses, the hotels and a third part of the bridge which was left functioning as a dock for the fishermen and other boatmen of the community.

## **5.2 Assessment of expected avoided damages**

Economic values of mangroves contributions to coastal protection are based on different approaches that have been separated into two main categories: index-based and process-resolving (World Bank Group, 2016). Process-resolving approaches enable a refined quantification of coastal processes, such as sediment transport and wave-vegetation and flow-vegetation interactions along the coast (Chen et al., 2024). These methods allow for more accurate estimates of the role of mangroves in wave attenuation and the reduction of erosion and coastal flooding. These approaches can be divided into analytical and numerical modeling. Analytical approaches to coastal processes are based on semi-empirical formulations and require low computational capabilities, while numerical models solve coastal processes with higher accuracy, but have a higher computational capacity (World Bank Group, 2016). The use of these approaches depends on the scale of analysis and the availability of data. In any case, they serve as inputs for the economic valuation of mangroves' contributions to coastal protection through various methods, such as estimating expected avoided damages, avoided costs, or replacement costs. The expected avoided damage approximation is one of the most promising valuation techniques where it is

assumed that the mangrove forest produces a non-marketed contribution or service such as protection of economic activity, property and even human lives that in turn benefit people by limiting damages (Barbier, 2016).

The expected avoided damage attributable to mangroves in Punta Soldado is estimated considering a process-based approach, inspired by the five step methodology proposed by (Barbier, 2016). The methodology consisted of the integration of biophysical and economic assessments (Figure 30); where the quantification of the biophysical contribution of mangroves to coastal protection - i.e. reducing significant wave height and flood level – is the input to estimate the economic damages reduction due to mangroves.

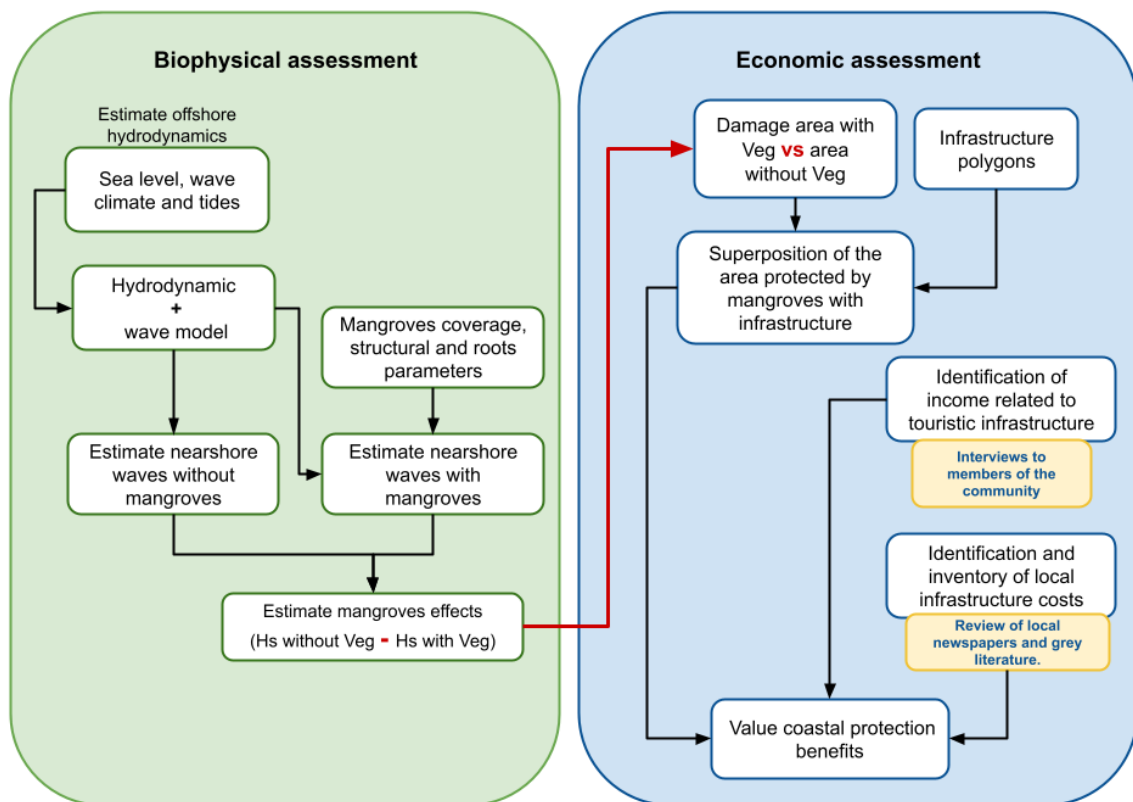


Figure 30. Conceptual diagram of the process-based methodology for the assessment of avoided damage attributed to mangroves.

- Estimate Offshore Hydrodynamics.** As described in Section 3 regarding mangroves biophysical contributions to coastal protection, an analysis of the oceanographic conditions such as sea level and discrete wave parameters was carried out for the region of Buenaventura Bay. This assessment included the estimation of wave parameters (significant wave height - Hs, peak period - Tp and

mean direction -  $D_m$ ) in both average and extreme conditions determined by the evaluation of the joint probability between significant wave height and the peak period. Also, the Peak Over Threshold method was employed for estimating the magnitude of extreme events for several return periods. The wave parameters data was obtained from the database ERA-5 (<https://cds.climate.copernicus.eu/cdsapp#!/home>); tides data were taken from the Buenaventura tide-gauge time series. These analyses allowed us to determine the extreme and average scenarios to evaluate.

Table 5-0. Evaluated events of significant wave, wave direction and peak period.

Wave Direction [ $D_m$ ]	Significant wave height [ $H_s$ ]	Peak period [ $T_p$ ]
WSW (225°)	1 m	13.2 s
WSW (225°)	1.75 m	13.2 s
W (270°)	1 m	13.2 s
W (270°)	1.75 m	13.2 s

- b. **Estimate Nearshore Hydrodynamics.** To determine the nearshore processes, such as nearshore waves, currents and water level; the Delft3D model was implemented using the coupled scheme of waves (Delft3D-WAVES) and currents (Delft3D-FLOW) modules. The coupling model allows considering wave-current interactions which make them more accurate than separated models. The model was forced with the average and extreme sea level and wave scenarios obtained from the data analyzed in the previous step.
- c. **Estimate the Effects of Mangroves on Hydrodynamics.** The interaction between waves and flow with partially submerged structures such as mangroves was assessed using the vegetation module of Delft3D that allows to set vegetation characteristics into the Delft3D FLOW-WAVE model. Thus, considering the effect of vegetation on waves dissipation, flux velocity and turbulence onshore. In this case, four different mangrove forest areas from the Global Mangrove Watch - GMW (Bunting et al., 2022) were considered to quantify their effect on coastal processes such as wave dissipation and flood reduction. To address the contribution of mangroves to these processes the mangrove forest scenarios from 1996, 2007 and 2015 were compared to scenarios without vegetation and the same physical parameters. This comparison consisted in calculating the difference between the significant wave height in the scenarios with and without mangroves.
- d. **Determining the areas protected by mangroves.** The comparison of flooding areas with and without mangroves allowed us to identify the infrastructure that would be protected by these ecosystems. Polygons representing infrastructure are

superimposed with the areas protected by mangroves. The identification of the infrastructure situated on the area of interest was carried out through the review of newspaper files and grey literature such as reports and bachelor's monographies; also interviews with elder people from the community were used to validate the collected information.

e. **Assess Expected and Avoided Damages (Value Coastal Protection Benefits).**

The economic valuation of coastal protection benefits was conducted by comparing expected damage in 1996 scenario with a scenario without mangroves, considering both average and extreme wave and sea level conditions. This involved estimating the economic value of properties and infrastructure located within the flooding areas identified through modeling. Additionally, we estimated the income associated with economic activities linked to this infrastructure, specifically tourism-related activities, considering 15% of hotel occupation through the years and the average night cost for staying in the community. The value of the island's infrastructure was obtained by reviewing technical documents, previous studies and newspaper archives; in addition, these values were validated with community eldest members.

The expected avoided damage due to the presence of mangroves was calculated by multiplying the values estimated above, the probability of occurrence of the associated climate variability event and the ratio indicating the percentage of significant wave height dissipated due to the presence of mangroves.

$$\text{Expected avoided damage} = V_{\text{damage}} \times P_{\text{event}} \times R_{\text{attenuation}} \quad \text{Equation 5 – 1}$$

Where  $V_{\text{damage}}$  is the value of the estimated damage or loss, that would occur without the presence of mangroves.  $P_{\text{event}}$  is the probability of the associated climate variability event. And  $R_{\text{attenuation}}$  is the ratio of the significant wave height attenuation (or dissipated) by mangroves.

## 5.3 Results

### 5.3.1 Mangroves effect on wave attenuation and coastal flooding

To assess the impact of mangroves on reducing coastal flooding in the area where the community of Punta Soldado is located, Figure 31, Figure 32, Figure 33 and Figure 34 illustrate the difference on the spatial distribution of wave attenuation rate with and without vegetation. Each figure considered different incident significant wave heights (1 and 1.75 meters) and mean wave direction (270° and 225°). As shown, the maps were overlaid with

the locations of infrastructure, including those established in 1996 when the village was distributed between the beach and the forested area.

Figure 31 and Figure 32 show that in scenarios where waves approach from the southwest (WSW) and west (W) with an average significant wave height of 1 m, the mangrove coverages from 1996, 2007, and 2015 contribute to attenuating 60% of the significant wave height in the outer zone of the town. In contrast, in the scenario without mangroves at the front of the village (on 2019), waves are observed to flood the entire outer zone of the town.

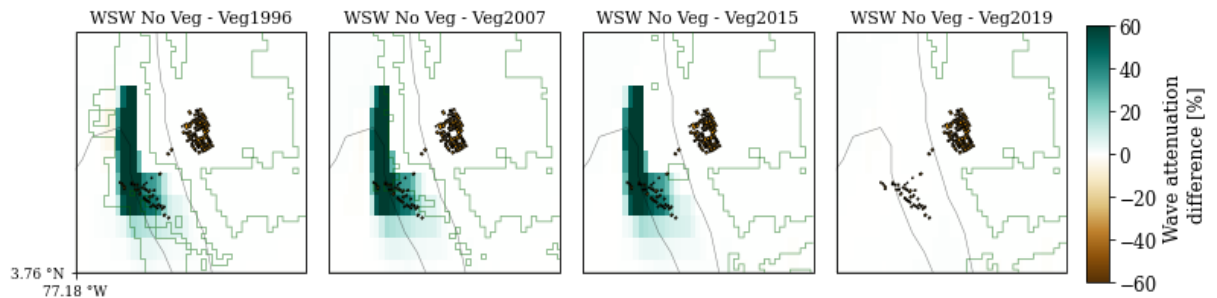


Figure 31. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1 m coming from WSW.

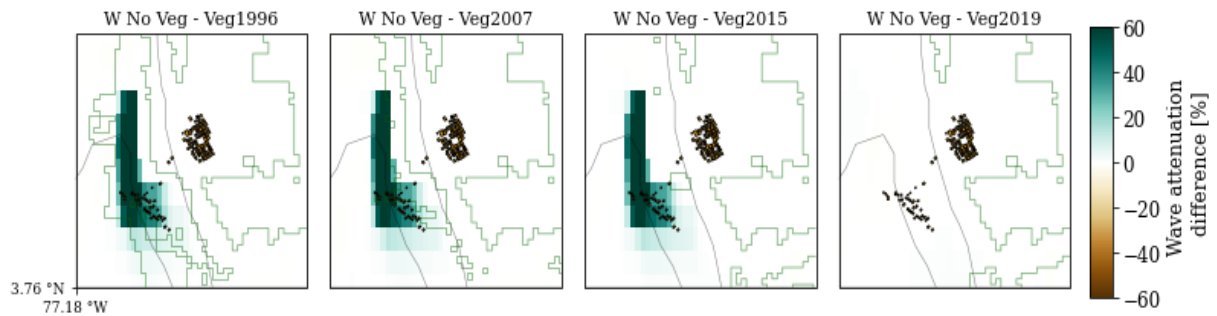


Figure 32. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1 m coming from W.

As shown in Figure 33 and Figure 34, when the incident significant wave height is 1.75 m, both for the scenarios where waves come from W or WSW, a protection effect provided by the mangroves to the infrastructure of the community is not perceived. i.e. in all the coverage scenarios evaluated waves reach the whole village located in the beach area. This result suggests the limitation of mangroves to reduce damage in coastal areas depending on the oceanic climate and then, the incident significant wave height. This limitation is also reflected in the testimonies of the community mentioned in the last chapter, where they indicate that *"when the sea is rough there is no one who can stop it"*.

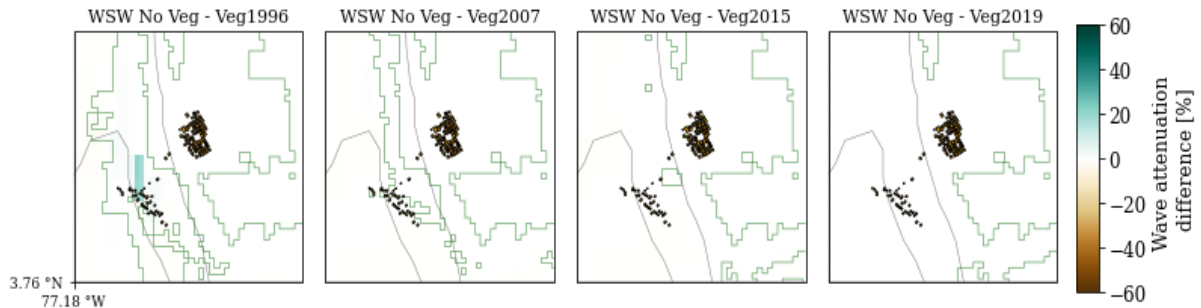


Figure 33. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1.7 m coming from WSW.

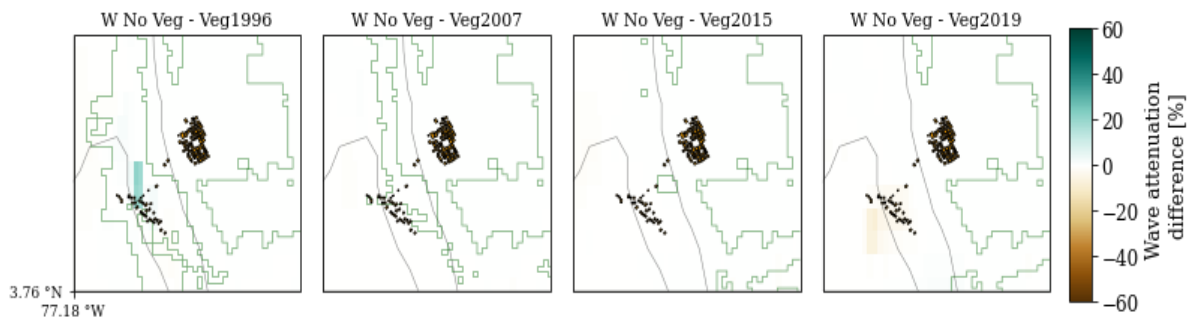


Figure 34. Significant wave height spatial distribution near Punta Soldado village in the scenario of incident significant wave height of 1.7 m coming from W.

### 5.3.2 Economic value of infrastructure and associated income

In the results from the latter section was possible to observe that mangroves had a protective effect on the part of the village of Punta Soldado that was settled at the beach. Various infrastructure was in this area, including wooden houses, hotels, and the bridge that connected the two areas of the village, the school and the community lounge.

By 2017, a wooden house in the community was estimated to cost 7 million COP (1,750 USD) according to (Lozano Montoya & Restrepo Cárdenas, 2019), which is consistent with estimates of mangrove wood for construction from (Palacios & Cantera, 2017). The community also reported the estimated value of the concrete bridge that connected the beach area to the interior of the village, as well as the school. Considering the approach of (Palacios & Cantera, 2017), the cost of construction of a hotel was estimated considering an area of 130 m<sup>2</sup> of each of the ten hotels reported in the newspaper files. In Table 5-1. Inventory of affected infrastructure from extreme events. the present value by 2023 of the features inventoried in the beach area of Punta Soldado is reported.

Table 5-1. Inventory of affected infrastructure from extreme events.

Infrastructure	Present Value (COP)	Present Value (USD)
Wooden houses	\$1,241,476,900	\$USD 310,369.23
School	\$63,613,761	\$USD 15,903.44
Community lounge	\$468,957,666	\$USD 117,239.42
Concrete bridge	\$1,540,802,365	\$USD 385,200.59
Hotels	\$175,859,637	\$USD 43,964.91
<b>TOTAL</b>	<b>\$3,490,710,329</b>	<b>\$USD 872,677.58</b>

As reported by (Mosquera Torres & Aprile Gniset, 2018), Punta Soldado was one of the most important villages for tourism in Buenaventura being an important source of income for the community. The income associated with tourist occupancy in hotels and the feeding of tourists was estimated considering an annual occupancy of 10% of the capacity given by the hotels located in the beach area. The present value of revenue per tourist per overnight stay is listed in Table 5-2. Present value of revenue per tourist per night in 10 hotels in Punta Soldado for the year 2023. By considering the deflation of these revenues in previous years and the tourist occupancy defined above, the total annual revenue flow is estimated from 1997 to 2023 (26 years), where a total of \$13,255'844,644 COP (\$3'313,961 USD) is accounted as income from tourism. It should be noted that other factors that may affect the price of food and accommodation are not considered.

Table 5-2. Present value of revenue per tourist per night in 10 hotels in Punta Soldado for the year 2023.

Concept	Present value per person	Annual revenue for 2023
Accommodation	\$30,000 (8 USD)	\$306,600,000 (76,650 USD)
Breakfast	\$15,000 (4 USD)	\$153,300,000 (38,325 USD)
Lunch	\$25,000 (6 USD)	\$255,500,000 (63,875 USD)
Dinner	\$15,000 (4 USD)	\$153,300,000 (38,325 USD)
<b>TOTAL</b>	<b>\$85,000 (21.25 USD)</b>	<b>\$868,700,000 (217,175 USD)</b>

### 5.3.3 Damage reduction by mangroves

Considering the value of the infrastructure located in the area and the areas where wave attenuation by mangroves is observed, the mangroves contribution to damage reduction is calculated for the scenarios evaluated with Equation 5-1.

For the scenarios with a significant wave height of 1 m, the ratio of the attenuation rate between the scenarios with and without mangroves is 60%, with a probability of occurrence of 86%.

$$\begin{aligned} \text{Expected avoided damage}_{H_S \rightarrow 1m} &= 17,196,554,973 \times 0.86 \times 0.6 \\ \text{Expected avoided damage}_{H_S \rightarrow 1m} &= \$8,873,422,366 \text{ COP} \end{aligned}$$

On the other hand, the extreme events scenarios with a significant wave height of 1.75 m, the ration of the attenuation rate between the scenarios with and without mangroves - considering the coverage area of 1996 – is 20%, with a probability of occurrence of 1%.

$$\begin{aligned} \text{Expected avoided damage}_{H_S \rightarrow 1.75m \text{ in } 1996} &= 17,196,554,973 \times 0.01 \times 0.2 \\ \text{Expected avoided damage}_{H_S \rightarrow 1.75 \text{ in } 1996} &= \$34,393,109 \text{ COP} \end{aligned}$$

In the case of extreme events, with a significant wave height of 1.75 m considering the coverage area of 2007, 2015 and 2019; the ratio of the attenuation rate between the scenarios with and without mangroves is 0%. Therefore, the damage reduction due to mangroves is zero for these cases.

$$\begin{aligned} \text{Expected avoided damage}_{H_S \rightarrow 1.75m} &= 17,196,554,973 \times 0.01 \times 0 \\ \text{Expected avoided damage}_{H_S \rightarrow 1.75m} &= \$0 \text{ COP} \end{aligned}$$

## 5.4 Discussion

### 5.4.1 Damage reduction by mangroves, mudflats and beaches

According to the obtained results, mangroves in Punta Soldado Island have the capacity of mitigating coastal damage, especially under moderate wave conditions through the reduction of significant wave height, thereby protecting the coastal area from flooding. This aligns with studies like those of (Zamboni et al., 2022), which demonstrate the potential economic losses due to shoreline erosion in Brazil, highlighting that maintaining mangrove coverage is essential to avoid costly damage and restoration efforts. However, during extreme events, the protective capacity of mangroves diminishes as stated by (Lee et al.,

2014), which indicates a need for comprehensive coastal management that integrates mangroves with other protective features.

(Marois & Mitsch, 2015) further emphasize that while mangroves are recognized for their role in mitigating storm surges and tsunamis and protecting communities (Menéndez et al., 2018), their valuation is often done in isolation from other coastal protection measures, potentially leading to suboptimal policy decisions. Beaches and mudflats can complement mangroves in coastal protection strategies, especially where mangrove efficacy is reduced. This is consistent with findings by (K G & Bhaskaran, 2017), who demonstrated that integrating specific slope profiles can significantly enhance protection against hazards, reducing wave height due to their effects on wave shoaling, refraction and reflection. However, unlike mangroves, these kinds of features alone do not offer the same range of contributions to people.

According to chapter two, mangroves can be also vulnerable to climate hazards, moreover, even if they stand still from extreme events, they are not capable of bringing protection from this type of event. Thus, (Morris et al., 2020) highlighted the importance of the diversification of coastal defense features to enhance coastal preparedness and reduce communities' vulnerability to extreme events. Hybrid defenses can be used to overcome some of the limitations of soft approaches (such as mangroves and beaches) in higher-intensity hazard conditions by combining dynamic (that is, the 'green' structure) with static (that is, the 'gray' structure) components that work together.

#### **5.4.2 Process-based approaches vs benefit transfer**

In this chapter, the economic value of mangroves contributions to protection has been estimated through a process-based approach which is considered as one of the most accurate approaches to estimate monetary quantities regarding damage reduction attributed to mangroves. In this case, we could assess the contributions of mangroves to coastal protection in different maritime climate conditions which let us acknowledge the limitations of mangroves on wave attenuation; this would not be possible if we estimated the economic value of protection by using the benefit transfer method, that only considers the mangrove area.

Benefit transfer is one of the most used methods for economic valuation of mangrove ecosystem services (Boyer & Polasky, 2004; Himes-Cornell et al., 2018) instead of process-based methods that can account for local variation in characteristic of storms, mangrove area, topography and bathymetry (Menéndez et al., 2018). Moreover, the economic valuation of the protective function of mangroves hasn't been addressed in other places of the Colombia's Pacific coast, (Rao et al., 2015) assessed the shoreline protection values by ecosystems like mangroves, coral reefs and mangroves through the benefit transfer method and found that coastal protection by mangrove in the Colombian Pacific today have a value of approximately \$8,500 USD/ha/year, this result differ from our findings which

estimate approximately \$2,800 US/ha/year using the avoided damage approach; which is consistent with the statement of (Himes-Cornell et al., 2018) regarding the differences on of economic value of mangroves contributions to protection by using the benefit transfer method.

### **5.4.3 The economic value of related mangrove contributions to people**

Beyond their protective capacity, mangroves provide substantial economic benefits related to material contributions such as piangua (*Anadara tuberculosa* and *Anadara similis*) harvesting and timber, as well as other regulating contributions like blue carbon sequestration as identified in the previous chapter. This synergies have been reported by (Sievers et al., 2023) who found that there is a correlation between mangroves coastal protection contribution with fisheries production. (Bimrah et al., 2022) also quantified the correlation between several NCPs provided by mangroves. They stated that mangroves protective contributions have a correlation of more than 0.6 with several contributions such as habitat maintenance, food and feed (mollusks and crustaceans); materials, companionship and labor (timber products and firewood); carbon sequestration, physical and psychological experiences (tourism and recreation), inspiration and learning, and climate regulation.

Some of these contributions can be easily valued considering that they can be related to a market, nevertheless, a high proportion of mangrove uses and benefits are not marketable, mainly the non-material (such as the sense of freshness and peace or the supporting identities contribution) and regulating (climate regulation) contributions therefore their full value cannot be captured through economic systems; however they play an important role in supporting local communities (Afonso et al., 2022; Glaser, 2003).

The analysis carried out in this chapter demonstrates that mangroves in Punta Soldado islan reduce damage from moderate wave conditions, providing measurable economic benefits through avoided damages to infrastructure. However, when mangrove coverage is absent at the front of the village, coastal protection benefits are lost, regardless of whether the conditions are average or extreme. During extreme events, the protective capacity of mangroves diminishes, but the absence of these ecosystems leads to even greater vulnerabilities for the community. In addition to coastal protection, mangroves contribute to local livelihoods through fisheries and timber further enhancing their economic value. These findings highlight the need for integrated coastal defense strategies that incorporate mangroves as a critical component of community resilience, while acknowledging the importance of hybrid solutions in scenarios where natural protection alone is insufficient.

## 6. The complexity of coastal protection in mangrove social-ecological systems

The different analysis carried out could provide an overview of the multiple dimensions that can be considered when evaluating the impacts of climate related issues on coastal strategic ecosystems such as mangroves. Through the numerical modelling approach, it was possible to determine that changes on the natural system represented by the mangrove forest area have impacts on their capacity of protection against waves. However, this capacity is not only dependent on mangroves' features, but also on the characteristics of the oceanographic variables such as the incident wave height and the relative sea level which are linked to macro-climatic phenomena mainly the El Niño Southern Oscillation (Aramburo et al., 2022). These results are coherent with the testimonies of local community representatives who indicate that mangrove forests have a limited capacity to protect them against coastal hazards, considering mangroves as natural barriers that are also fragile when sea conditions are extreme (high waves and a spring high tide for example); this is consistent with the conceptual models from (Lee et al., 2014; van Hespen et al., 2023). It was possible to identify that, for the local community of Punta Soldado, mangroves not only serve as coastal protection mechanisms but also, they are key for community's livelihoods as providers of food and labour mainly for women through the collection and commercialization of the *Anadara similis* and *Anadara tuberculosa* (piangua). Mangroves are also important for supporting the identity of the community through the sense of belonging they provide as well. Moreover, both anthropogenic and natural drivers of change of the mangrove social-ecological system were identified by the local community; coastal erosion, extreme events and mangrove lodging are some of the drivers highlighted. The assessment of the role of mangroves in avoiding damages on infrastructure, household and economic activities like tourism indicated that the loss of this ecosystem, especially in front of village or local infrastructure, can produce damages on the infrastructure and the loss of income related to touristic activities of approximately 8,873,422,366 COP (2'218355 USD). In this section the integrative assessment of the mangrove social-ecological system is presented as well as the complex relationships among mangroves and people in the lenses of the coastal protection contribution.

## 6.1 Mangrove social-ecological system

Considering the conceptual framework proposed by IPBES, previous sections have addressed key elements that compose the mangrove social-ecological system of Punta Soldado in regard of their contributions to coastal protection and other associated NCPs. The integrative analysis of the mangrove SES has allowed for a deeper understanding of the complex interactions between these elements, particularly in how they collectively support the system's capacity for coastal protection. Drawing on the key findings from previous analyses, the elements of the mangrove SES of Punta Soldado are described below highlighting their roles and interactions.

- a. Nature.** Mangrove forests are the foundation of the system that is characterized by several features composing them, such as mudflats, biodiversity and the different mangrove species within them (*Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans*, *Mora oleifera* and *Pelliciera rizophorae*). The mangrove forest in Punta Soldado has been capable of attenuating waves and reducing flooding transit on average conditions. However, diverse drivers of change have triggered mangroves degradation diminishing these ecological functions in the island similarly to other mangroves SES in the world (Chen et al., 2024; Goldberg et al., 2020; P et al., 2024).
- b. Drivers of change.** Both anthropogenic and natural drivers of change on Punta Soldado's mangrove SES are identified. Some of the anthropogenic drivers perceived by the community are mangrove logging for timber and restoration efforts, the first one having a negative and fast effect on the ecosystem (promoting degradation) and the second one having a positive and slow effect on the ecosystem (promoting ecological restoration). Coastal erosion and wave or sea level extreme events are some of the natural drivers identified by the community; these are controlled by climate variability and have a direct negative effect on mangroves and the related communities.
- c. Mangroves' contributions to people.** Mangroves at Punta Soldado provide multiple contributions to the local community and beyond. These contributions are diverse, and they are categorized into material, non-material, and regulating services: The mangroves provide *material contributions* referred to the tangible resources such as timber and mollusks, which are crucial for the local economy. These resources are harvested using traditional knowledge and techniques passed down through generations. Regarding the *non-material contributions*, the cultural and spiritual significance of mangroves to the local community is profound because these ecosystems are integral to the community's cultural identity and heritage, offering a sense of place and belonging. In the *Regulating contributions* perhaps most importantly, mangroves act as natural barriers, protecting the coastline from erosion, storm surges, and other extreme weather events. This protective function

is vital for maintaining the physical integrity of the coastal landscape and ensuring the safety of the community.

- d. **Benefits to people's well-being.** In Punta Soldado Island, some of the mangrove contributions provide various benefits to local well-being. They partially mitigate damage to economic activities, households, and infrastructure, and they also supply food and income to local communities through the co-production of material, labor, and companionship contributions. Physical and psychological benefits, such as a sense of freshness, recreational opportunities, and the support of local identity and sense of place, directly enhance the well-being of local people
- e. **Anthropogenic assets.** The capacity of mangroves to provide NCPs and benefits for people's well-being is also related to the assets that communities must co-produce them. In the case of Punta Soldado, local knowledge is key for the co-production of food by piangua harvesting. It is important to mention that, the piangueras of Punta Soldado have acquired technical and local knowledge to successfully restore different species of mangroves such as *Rhizophora mangle*, *Moral oleifera* and *Pelliciera rizophorae* (Viveros Duiza, 2021); this can also enhance mangrove features such as density and coverage area which are crucial for coastal protection and other regulating NCPs provided by mangroves. Additionally, financial resources from the environmental authorities and non-profit organizations projects support the community's ability to engage with and benefit from mangroves.
- f. **Governance and institutions.** The area where the local community is established is an ethnic territory known in Colombia as a collective territory that is organized as the Community Council of the black community of Punta Soldado represented by a "board" where the president and legal representative are the head. Thus, the governance of mangroves ecosystems in Punta Soldado operates at the intersection of formal legal frameworks and informal community-based rules. The Community Council is the main authority within the community and establishes the rules for resource use, interaction among members of the community, with external actors and other related rules. Also, national and regional law (Law 2243 for mangroves protection and the Protected Forest Reserve of the Anchicayá Basin), enforced by other actors like the Environmental authority Corporación Autónoma Regional del Valle del Cauca, CVC are other institutions for natural resources conservation and sustainable management in the region. They have been supporting the local community on the development of conservation and restoration programs in the island since 2015 jointly with two groups from the Community Council: The Sowers Group (conformed by men and women) and the Piangueras Group (conformed only by women): the latter group has remained active with restoration efforts that have been improved with the experienced gained on the last nine years. However, the local community expressed that there is an important challenge in the management of the mangrove forest that is the indiscriminate lodging that - according to testimonies - is carried out by external actors from neighboring communities and the municipality of Buenaventura. Therefore, the lack

of enforcement by local authorities or the community itself of mangrove conservation indirectly threatens the mangrove social-ecological system of Punta Soldado.

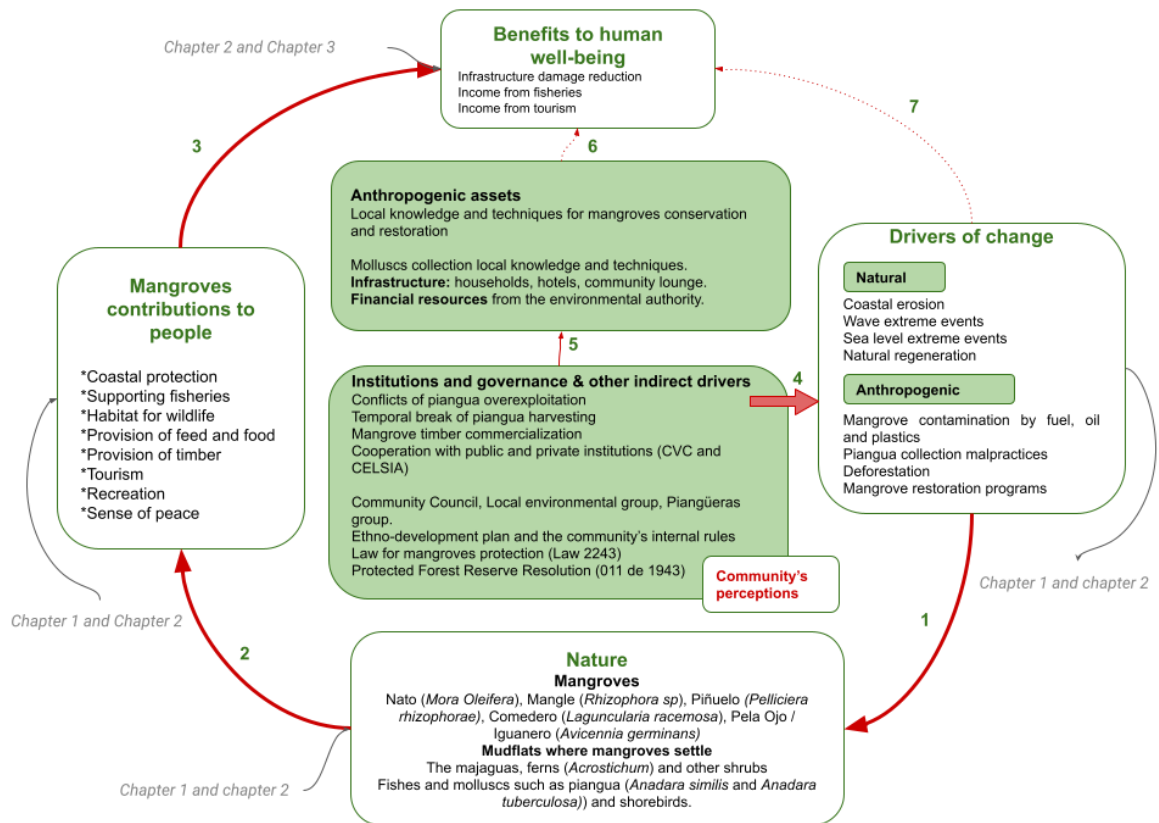


Figure 35. Punta Soldado's mangrove social-ecological system based on IPBES Framework.

As illustrated in Figure 35, the elements within the mangrove social-ecological system (SES) of Punta Soldado are highly interconnected, meaning that changes in one element can trigger a series of responses across the entire system. For instance, alterations in the mangrove forest area, whether due to natural regeneration or degradation from activities like logging, can directly influence the ecosystem's capacity to provide coastal protection. This, in turn, can affect the community in economic terms by altering their income from tourism or by the damage resulting from extreme wave or sea level events, which are dependent on the mangrove ecosystem to some degree.

Furthermore, the interactions between anthropogenic assets, such as local knowledge and infrastructure, and natural components like mangrove species and biodiversity, highlight the system's dynamic nature. For example, effective mangrove restoration techniques, supported by financial resources from environmental authorities, can enhance the resilience of the mangroves (López-Portillo et al., 2017; Lovelock et al., 2022b; Vardi

Venkateswarlu et al., 2023), leading to improved coastal protection and a reduction in infrastructure damage during extreme weather events. In contrast, negative drivers such as piangua overexploitation or coastal erosion can weaken the system, reducing both the ecological functions of the mangroves and the associated socio-economic benefits.

As an envelope of the mangrove SES of Punta Soldado, the intrinsic values and perceptions of the local community shape and are shaped by the interactions within the SES because, as they have stated, mangroves are more than just source of food, labor and material – they are considered life itself. Mangroves also support the identity of the community – “*if the mangrove is gone, we are gone*” – therefore, any alteration to the system not only impacts its ecological and economic functions but also threatens the identity support system that is intrinsically linked to mangroves. This highlights the importance of holistic management approaches that consider the full spectrum of interactions within the mangrove SES to sustain its contributions to coastal protection, community well-being and cultural identity (Dahdouh-Guebas et al., 2021; Suarez et al., 2022).

## 6.2 Dynamic nature of mangroves contribution to coastal protection

Social-ecological systems are dynamic systems which change over time, involving complex, nonlinear behaviors and interactions (Thelen & Smith, 2007). Thus, the role of mangroves in coastal protection is dynamic and multifaceted, in which a wide range of interactions occur between ecological, social, and economic dimensions within the SES. The causal diagram is a graphical model used to represent and analyze causal relationships between several variables that integrate a system (Staplin et al., 2017); it serves as a tool to visualize how changes in one element within the mangroves SES can ripple through and affect other components, possibly influencing the overall capacity of mangroves to protect the coast, especially under climate variability related pressures.

The causal diagram in Figure 36 provides a comprehensive view of the dynamic relationships within the mangrove SES, particularly in the context of coastal protection. By integrating results from the different methodological approaches applied in this research - both qualitative and quantitative - the causal diagram offers insights into how different variables interact to influence the system's ability to provide coastal protection.

The variables that integrate the causal diagram are presented with different colors that represent the element of the SES to which they belong. Mangrove's contributions to people are presented in different shades of purple depending on the category of contribution they belong to according to the NCP framework, among these are the provision of piangua, fish, tourism generation, support of identity, physical and psychological experiences, and sense of belonging and of course coastal protection which is the focus of this analysis. The variables representing the natural system elements within the SES are represented in green

and include areas of mudflats, beaches and mangroves which are habitat for birds. Natural drivers of mangrove change and their contributions to people are shown in orange, while anthropogenic drivers are shown in red; these include variables associated with coastal processes such as significant wave height and sea level; anthropogenic drivers include production practices, mangrove lodging and effective restoration and conservation measures. Variables related to decision-making, institutions and anthropogenic assets are presented in olive and include community governance (through formal and informal rules), environmental enforcement by environmental authorities and technical capacities for mangrove restoration. The blue color shows the explanatory variables of the economic dimension represented in the element of people's well-being.

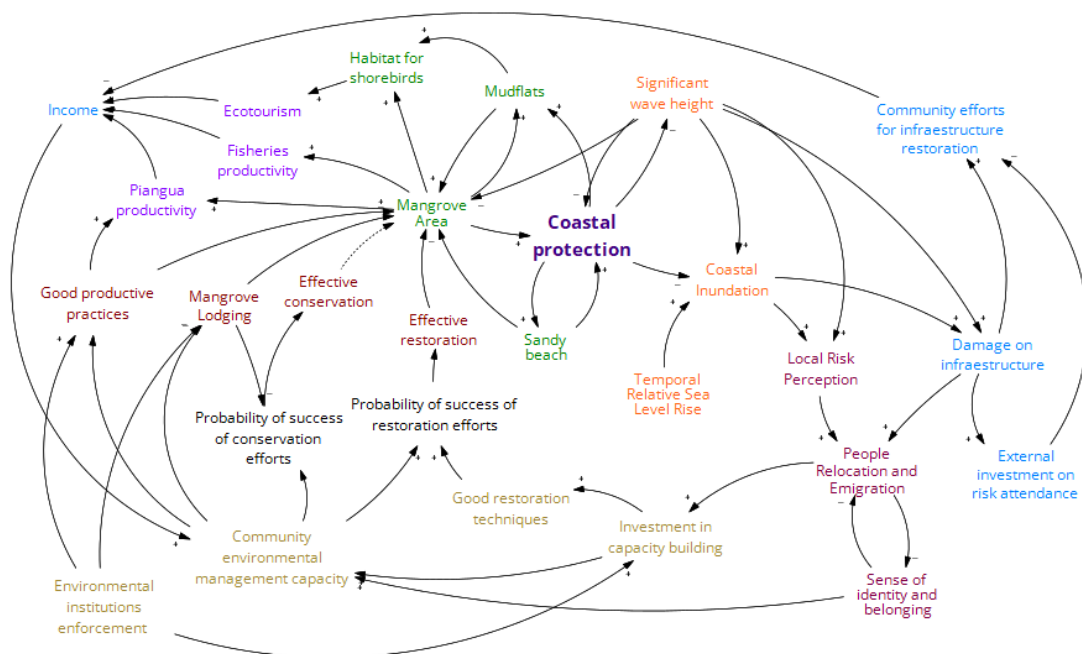


Figure 36. Causal diagrama of Punta Soldado's mangrove social-ecological system representing the complexity of interactions between the variables within the SES.

According to the assessment of the biophysical contributions of mangroves to coastal protection, it was evidenced that this contribution is dependent on the mangrove area - with a direct relationship- and the physical processes related to maritime climate described by variables such as significant wave height and sea level, both of which have a direct relationship with coastal inundation. These physical variables have an indirect relationship with coastal protection for the studied mangrove SES i.e. When the significant wave height or sea level are higher, coastal protection is reduced. When there is coastal protection, the formation of beaches and mudflats is commonly promoted due to the attenuation of waves that can result in sedimentation processes (Gijsman et al., 2021). The formation of mudflats is a forerunner of mangroves' establishment which can result in mangrove area increases;

however, the formation of sandy beaches is not favorable for mangrove establishment, but they can be alternative mechanisms for coastal protection instead of mangroves.

Mangrove areas can be directly affected by both anthropogenic and natural drivers such as extreme wave events and mangrove lodging that lead to degradation and even destruction of the forest; or effective mangrove restoration and conservation efforts that promote mangrove areas to increase. The reduction of mangrove lodging, and the enhanced probability of success of conservation or restoration efforts are dependent on the community environmental management capacities. If the community has a high capacity of management of the mangrove ecosystem, it may reduce mangrove lodging by reducing in turn mangrove decrease; also, these capacities can lead to better productive practices and more effective restoration and conservation efforts that might increase mangrove area.

Considering the perceptions of the local community, good productive practices are linked to the provision of materials and goods by mangroves for instance if there are better productive practices there may be an enhanced production of piangua and fisheries, generating direct income to the local community benefiting their well-being. Ecotourism is another source of income product of the contribution of mangroves as habitat for wildlife especially shorebirds that are an attractive feature for tourists.

Community environmental management capacity depends on the investment on capacity building by institutional enforcement or because of people relocation and other adaptation strategies established. This investment would not only improve the community's capacity to manage the mangrove ecosystem but would reinforce good restoration techniques that together can result in more effective restoration and hence increase in mangrove areas. Despite investment in capacity building is crucial, the sense of identity and belonging of the community would support the willingness of their members to act on environmental management strategies (Queiroz et al., 2017). Nevertheless, people relocation and emigration from the island due to the increasing local risk perception<sup>3</sup> have the potential to erode the sense of identity and belonging within the community which in turn make a positive feedback loop.

Local risk perception increased is driven by extreme waves and sea level events that can cause coastal inundation. This kind of event can also cause damage on local infrastructure as addressed on the section regarding mangrove's role on damage reduction; thus, the greater the coastal protection, less the coastal inundation and less damage on infrastructure. This damage can result in community efforts to restore the damaged infrastructure, and the loss of income related to that infrastructure.

This causal diagram of the mangrove SES in Punta Soldado reveals the intricate web of interactions between the dimensions that collectively shape the system's capacity for coastal protection. These dimensions are deeply intertwined, demonstrating how tangible

---

<sup>3</sup> Risk perception involves people's judgements and responses when evaluating hazards (Slovic, 1987), they also refer to the instinctive and intuitive reactions to danger (Slovic & Peters, 2006).

elements such as mangrove area, infrastructure, and income are closely linked to intangible aspects like community identity and sense of belonging.

The complexity of the mangrove SES is evident in how changes in one element can cascade through the system, affecting not only the physical environment but also the socio-economic well-being and cultural identity of the community. For instance, the effectiveness of coastal protection is not merely a function of ecological health but also depends on community governance, environmental management capacities, and the intrinsic values that drive local conservation efforts. Moreover, it is important to recognize the limits that the mangrove SES has for providing coastal protection in extreme events; considering the threat of a changing climate it may be useful to address complementary strategies for coastal protection through the reinforced protection of the mangrove SES by implementing hybrid strategies or multi-ecosystem strategies for adaptation (Winterwerp et al., 2020).

For practitioners, researchers, and policymakers, this analysis serves as a call to watch the broader picture when proposing Nature-Based Solutions (NbS) or Ecosystem-Based Adaptation (EbA) strategies. It is crucial to consider the full spectrum of interactions within the mangrove SES to ensure that these strategies are not only effective in conserving mangroves but also in preserving the well-being and cultural heritage of the communities that depend on them. Only by embracing this complexity can we develop solutions that are sustainable and resilient in the face of ongoing environmental and socio-economic challenges.

## 7. Conclusions

This thesis provides a comprehensive understanding of the complex interactions within the mangrove social-ecological system (SES) in Punta Soldado. These interactions are proof of the multifaceted role mangroves play in coastal protection and their significance to the local community.

1. **Quantification of Coastal Protection Function:** Through numerical modeling, it found that the coastal protection function of mangroves is sensitive to both ecological changes, such as variations in mangrove coverage, and oceanographic conditions, particularly incident wave height and sea level. The findings demonstrate that mangroves can effectively reduce wave heights and provide coastal protection under average climate conditions. However, the protection they offer is reduced during extreme climate events, which can lead to increased significant wave heights and relative sea levels. This highlights the limitations of mangroves in mitigating coastal hazards during extreme weather events, and therefore the need to consider additional or hybrid solutions for climate resilience.
2. **Local Community Perceptions:** The community of Punta Soldado acknowledges the protective role of mangroves but also recognizes their vulnerability to extreme conditions aligning to the biophysical assessment carried out. Moreover, beyond coastal protection, mangroves contribute to the livelihoods of the local population, particularly women, through the harvesting of shellfish species like *Anadara similis* and *Anadara tuberculosa*. Mangroves also serve as a source of cultural identity and a sense of belonging. Thus, mangroves are key ecosystems in supporting both the material and non-material aspects of the community, as reflected in the Nature's Contributions to People (NCP) framework.
3. **Economic Effects of Changes in Coastal Protection:** The economic assessment reveals that the loss of mangrove ecosystems, particularly those located directly in front of the village or local infrastructure, results in significant economic damage. The potential loss of income from tourism activities, alongside damage to infrastructure, is estimated at approximately 8,873,422,366 COP (2,218,355 USD). These economic impacts reinforce the need for robust conservation and restoration efforts to safeguard the socio-economic stability of the community.
4. **Interconnectedness in the Mangrove SES:** The relationships between ecological, socio-economic, and cultural components of the mangrove SES show that changes in one aspect can ripple across the entire system. For instance, the degradation of mangroves not only affects the physical environment but also undermines economic

---

opportunities, cultural identity, and community resilience. Effective coastal protection is thus dependent on an integrated approach that considers ecological health, community governance, and conservation efforts rooted in local values and knowledge. Furthermore, addressing the limits of mangrove protection during extreme events necessitates exploring complementary adaptation strategies, such as hybrid or multi-ecosystem approaches.

Policymakers and practitioners should recognize that while community-led conservation efforts are invaluable, they must be complemented by broader, more integrated strategies that can address the impacts of extreme climate variability. This may involve combining Nature-based solutions with engineered solutions or policy interventions that enhance the capacity of mangroves to continue delivering regulation contributions, such as coastal protection, even under adverse conditions.

Moreover, it is crucial to ensure that such strategies do not undermine the material and non-material contributions that mangroves provide to the community. The preservation of livelihoods, cultural identity, and community well-being should be a core consideration in any conservation plan. By integrating local knowledge and practices with scientific and technical solutions, a more holistic approach to mangrove conservation and coastal protection can be achieved, one that supports both the ecological integrity of the mangrove system and the socio-economic stability of the community.

# A. Appendix: Qualitative data collection instruments

## Taller de Contribuciones de la Naturaleza Asociadas a los Manglares en Punta Soldado

### Objetivo general

Identificar las percepciones asociadas a las contribuciones que generan los manglares sobre el bienestar de la comunidad de Punta Soldado

### Objetivos específicos

- Conocer las percepciones de la comunidad sobre la importancia de los SE de los manglares, haciendo énfasis en el Servicio de Protección costera (su evolución espacio temporal).
- Reconocer las percepciones de la comunidad sobre los factores de degradación de los manglares en la isla de Punta Soldado

### Materiales

- Mapa plastificado de la isla (coberturas diferentes de manglar)
- Fotos (plastificadas) de los manglares de PS (del drone, del manglar muerto y en regeneración)
- Post its, marcadores, lapiceros de colores, cartulinas
- Imágenes (plastificadas) de las especies de mangle que se encuentran en PS, de actividades económicas e infraestructura de la isla.
- Refrigerios (cuadrar con Doña Gladys)

### Grupos focales

Se propone realizar la actividad de manera separada con los grupos focales listados a continuación, que permitan obtener las percepciones discriminadas por grupos diferenciados evitando sesgos asociados a relaciones de poder u otro tipo de influencias dentro de los grupos.

- Piangueras (Guillermina, Nancy y Luz Dary)
- Consejo comunitario de Punta Soldado
- Jóvenes

- Grupo de adultos mayores
- Agencia comunitaria
- Pescadores

### Desarrollo del taller

<b>Primer momento: Los regalos de la naturaleza</b>	
<b>Objetivo</b>	Identificar los SE que reconoce la comunidad en general
<b>Método</b>	Conversación participativa / dibujos
<b>Duración</b>	10 - 15 minutos
<b>Preguntas orientadoras</b>	<p>¿En Punta Soldado la naturaleza nos da regalos?</p> <p>¿Qué partes / elementos de la naturaleza nos dan regalos? ¿Dónde podemos encontrarlos?</p> <p>¿Cuáles son los regalos que nos da la naturaleza?</p>
<b>Materiales</b>	<p>Tablero portátil / Pliego de cartulina</p> <p>Marcadores</p> <p>Pos-its</p>
<b>Desarrollo de la actividad</b>	<p>En esta actividad, los participantes realizarán una identificarán los servicios ecosistémicos que reconocen en la isla, así como los elementos de la naturaleza que proveen esos servicios ecosistémicos.</p> <p>En primer lugar, se realizará una breve presentación de cada participante del taller (nombre, ocupación principal en la isla, su pasatiempo favorito).</p> <p>Se tendrá un tablero / pliego de cartulina en el que se va a encontrar una tabla donde se puedan enumerar los servicios ecosistémicos que da la naturaleza y cuáles. Se les pedirá a los participantes que nos cuenten cuáles son los “regalos que les da la naturaleza”. Posteriormente, si no lo mencionan, se les preguntará qué partes de la naturaleza les dan regalos y cómo se benefician de ellos.</p> <p>Finalmente, con la ayuda de fotografías y un mapa de la isla, identificarán dónde se encuentran esos elementos que les dan regalos y serán demarcados con post-its.</p>

Regalos de la naturaleza	Elementos que nos dan regalos	Beneficios	¿Dónde podemos encontrarlos?

<b>Segundo momento: Los regalos de los manglares</b>	
<b>Objetivo</b>	Identificar los SE de los manglares que son reconocidos por la comunidad y su importancia
<b>Método</b>	Conversación participativa / Dibujos
<b>Duración</b>	10-15 minutos
<b>Preguntas orientadoras</b>	<p>¿Qué hace a los manglares especiales?</p> <p>¿Cuáles son los regalos que nos dan los manglares? ¿Qué importancia le daría a cada uno de esos regalos?</p> <p>¿Qué nos dan y que nos quitan los manglares?</p> <p>¿Qué actividades hacemos en torno a los manglares?</p> <p>¿Esos regalos han aumentado o disminuido en el tiempo?</p>
<b>Materiales</b>	<p>Mapa de Punta Soldado, Foto aérea del pueblo y de los manglares muertos y en regeneración. Marcadores</p> <p>Lista de los SE de los manglares (para el facilitador) - para complementar (explicar sobre los servicios que no son percibidos por ellos, si creen que es es verdad y qué tan importante sería)</p>
<b>Desarrollo de la actividad</b>	<p>En esta actividad los participantes escribirán en post-its los regalos que le dan los manglares, así como los perjuicios que identifican de estos ecosistemas.</p> <p>Posteriormente, se realizará una lluvia de ideas sobre las actividades que se llevan a cabo en el manglar y con ayuda del mapa, las personas ubicarán las zonas específicas en las que realizan dichas actividades.</p>

**Entrevista semiestructurada****Percepciones sobre los regalos de los manglares a la comunidad de Punta Soldado**

Lo invitamos a responder las siguientes preguntas, que ayudarán a entender la importancia que tienen y han tenido los manglares sobre el bienestar de la comunidad de Punta Soldado. Esta encuesta es anónima y los datos que nos proporcione serán utilizados única y exclusivamente para los propósitos de esta investigación. Agradecemos su disposición y tiempo.

Nombre \_\_\_\_\_

Género \_\_\_ (F, M, Otro)

Edad \_\_\_\_

¿Usted nació en Punta Soldado?

Sí \_\_\_\_, No \_\_\_\_

Si no, ¿cuántos años tenía cuando llegó a la isla? \_\_\_\_\_

¿Qué son los manglares para usted?

---

¿Usted vivió o presenció algún evento que generó la pérdida de los manglares en la isla?

---

¿Cuál cree que fue la causa de la pérdida / degradación de los manglares? ¿qué hizo que los manglares murieran?

---

¿Qué siente cuando ve los manglares muertos?

---

¿Cómo perder esos manglares afectó sus actividades diarias?

- Trabajo

\_\_\_\_\_

- La casa

\_\_\_\_\_

- Comida

\_\_\_\_\_

- Diversión / recreación / jugar

\_\_\_\_\_

- Seguridad
- 

¿Por qué cree que los manglares de la Punta Sur se están recuperando actualmente?

¿Qué siente al ver los nuevos manglares?

¿Los manglares son importantes para usted? ¿por qué?

---

Si está de acuerdo con que los manglares nos protegen de las olas y/o de las inundaciones ¿Cómo cree que nos protegen? (que los protegían) ¿cuándo dejaron de protegerlos?

---

Si no está de acuerdo con que los manglares nos protegen de las olas y/o de las inundaciones ¿por qué cree que no los protegen?

---

### **Comparación de imágenes**

¿En cuál imagen/escenario cree que la comunidad está menos expuesta a las olas y las inundaciones? ¿Cuál escogería si usted pudiera cambiarlo?



¿Mayor densidad (más tupido) es mejor?

---

¿Usted cree que podría vivir en Punta Soldado sin manglares? ¿Por qué?

---

¿Qué estrategia o elementos cree que puede reemplazar a los manglares para proteger a la comunidad del mar (las olas y las inundaciones)?

---

¿Usted por qué cree que es importante que los manglares protegen la playa/costa además del beneficio de la comunidad?

---

Ocupación principal

---

Ocupación(es) adicionales

---

Ingresos diarios (aproximadamente)

---

Estado Civil

- Soltero/a
- Casada
- Unión libre
- Otro

Número de hijos \_\_\_\_\_

¿Cuál es su rol dentro de la comunidad? (¿pertenece a alguna cooperativa, asociación, grupo dentro de la comunidad?, ¿cuál?)

---

## References

- Abd Rahman, M. A., & Asmawi, M. Z. (2016). MANGROVES DEGRADATION: A LOCAL PERSPECTIVE ON ITS AWARENESS. *PLANNING MALAYSIA*, 4. <https://doi.org/10.21837/pm.v14i4.162>
- Afonso, F., Félix, P. M., Chainho, P., Heumüller, J. A., de Lima, R. F., Ribeiro, F., & Brito, A. C. (2022). Community perceptions about mangrove ecosystem services and threats. *Regional Studies in Marine Science*, 49. Scopus. <https://doi.org/10.1016/j.rsma.2021.102114>
- Alongi, D. M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science*, 76(1), 1–13. <https://doi.org/10.1016/j.ecss.2007.08.024>
- Aramburo, D., Montoya, R. D., & Osorio, A. F. (2022). Impact of the ENSO phenomenon on wave variability in the Pacific Ocean for wind sea and swell waves. *Dynamics of Atmospheres and Oceans*, 100, 101328. <https://doi.org/10.1016/j.dynatmoce.2022.101328>
- Audu, S. I. (2022). *Perceptions of mangrove ecosystem services and conservation priorities by decision-makers and key stakeholders in Nigeria*. [https://commons.wmu.se/cgi/viewcontent.cgi?article=3107&context=all\\_dissertations](https://commons.wmu.se/cgi/viewcontent.cgi?article=3107&context=all_dissertations)
- Aunurrahman, A., Anggoro, S., Muskananfolo, M. R., & Saputra, S. W. (2023). Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery. *Biodiversitas Journal of Biological Diversity*, 24(11). <https://doi.org/10.13057/biodiv/d241134>
- Ávila-Foucat, S., & Espejel, I. (2020). *Resiliencia de socioecosistemas costeros*. Universidad Nacional Autónoma de México. Instituto de Investigaciones Económicas. [https://www.pensalatitec.iiec.unam.mx/sites/iiec.unam.mx/files/libros\\_electronicos/RSC\\_SAT\\_0.pdf](https://www.pensalatitec.iiec.unam.mx/sites/iiec.unam.mx/files/libros_electronicos/RSC_SAT_0.pdf)
- Badola, R., Barthwal, S., & Hussain, S. A. (2012). Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India. *Estuarine, Coastal and Shelf Science*, 96(1), 188–196. Scopus. <https://doi.org/10.1016/j.ecss.2011.11.016>

- Badola, R., & Hussain, S. A. (2005). Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. *Environmental Conservation*, 32(1), 85–92. Scopus. <https://doi.org/10.1017/S0376892905001967>
- Barbier, E. B. (2007). Valuing ecosystem services as productive inputs. *Economic Policy*, 22(49), 178–229. <https://doi.org/10.1111/j.1468-0327.2007.00174.x>
- Barbier, E. B. (2015). Valuing the storm protection service of estuarine and coastal ecosystems. *Ecosystem Services*, 11, 32–38. <https://doi.org/10.1016/j.ecoser.2014.06.010>
- Barbier, E. B. (2016). The protective service of mangrove ecosystems: A review of valuation methods. *Marine Pollution Bulletin*, 109(2), 676–681. <https://doi.org/10.1016/j.marpolbul.2016.01.033>
- 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. <https://doi.org/10.1890/10-1510.1>
- Barbier, E. B., Koch, E. W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J., Granek, E. F., Polasky, S., Aswani, S., Cramer, L. A., Stoms, D. M., Kennedy, C. J., Bael, D., Kappel, C. V., Perillo, G. M. E., & Reed, D. J. (2008). Coastal Ecosystem-Based Management with Nonlinear Ecological Functions and Values. *Science*, 319(5861), 321–323. <https://doi.org/10.1126/science.1150349>
- Barbosa Hurtado, J. P. (2018). *Estudio de los procesos de transporte (advección y dispersión) de los sólidos suspendidos totales en la bahía interior de Buenaventura, Colombia*. <https://bibliotecadigital.univalle.edu.co/entities/publication/69b550ef-ca62-4383-94d1-999526447f01/full>
- Bell, J., & Lovelock, C. E. (2013). Insuring Mangrove Forests for Their Role in Mitigating Coastal Erosion and Storm -Surge: An Australian Case Study. *Wetlands*, 33(2), 279–289. <https://doi.org/10.1007/s13157-013-0382-4>
- Belliard, J.-P., Dominguez-Granda, L. E., Ramos-Veliz, J. A., Rosado-Moncayo, A. M., Nath, J., Govers, G., Gourgue, O., & Temmerman, S. (2021). El Niño driven extreme sea levels in an Eastern Pacific tropical river delta: Landward amplification and shift from oceanic to fluvial forcing. *Global and Planetary Change*, 203, 103529. <https://doi.org/10.1016/j.gloplacha.2021.103529>
- Bimrah, K., Dasgupta, R., Hashimoto, S., Saizen, I., & Dhyani, S. (2022). Ecosystem Services of Mangroves: A Systematic Review and Synthesis of Contemporary Scientific Literature. *Sustainability*, 14(19), Article 19. <https://doi.org/10.3390/su141912051>

- Blanco, J. F., & Cantera, J. R. (1999). The Vertical Distribution of Mangrove Gastropods and Environmental Factors Relative to Tide Level at Buenaventura Bay, Pacific Coast of Colombia. *Bulletin of Marine Science*, 65(3), 617–630.
- Blankespoor, B., Dasgupta, S., & Lange, G.-M. (2017). Mangroves as a protection from storm surges in a changing climate. *Ambio*, 46(4), 478–491. <https://doi.org/10.1007/s13280-016-0838-x>
- Bongaarts, J. (2019). IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Population and Development Review*, 45(3), 680–681. <https://doi.org/10.1111/padr.12283>
- Boyer, T., & Polasky, S. (2004). Valuing urban wetlands: A review of non-market valuation studies. *Wetlands*, 24(4), 744–755. [https://doi.org/10.1672/0277-5212\(2004\)024\[0744:VUWARO\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2004)024[0744:VUWARO]2.0.CO;2)
- Bravo Pazmiño, H. E. (1998). *Diversidad Cultural y Manglares Del Pacífico Colombiano*. Ministerio del Medio Ambiente. <https://es.scribd.com/document/507999658/Diversidad-Cultural-y-Manglares-Del-Pacifico-Colombiano>
- Bryan-Brown, D. N., Connolly, R. M., Richards, D. R., Adame, F., Friess, D. A., & Brown, C. J. (2020). Global trends in mangrove forest fragmentation. *Scientific Reports*, 10(1), 7117. <https://doi.org/10.1038/s41598-020-63880-1>
- Bryant, M., Bryant, D., Provost, L., Hurst, N., McHugh, M., Wargula, A., & Tomiczek, T. (2022). *Wave attenuation of coastal mangroves at a near-prototype scale*. Engineer Research and Development Center (U.S.). <https://doi.org/10.21079/11681/45565>
- Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M., Murray, N. J., & Rebelo, L.-M. (2022). Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. *Remote Sensing*, 14(15), Article 15. <https://doi.org/10.3390/rs14153657>
- Caicedo, W. T. V. (2019). Caracterización de prácticas tradicionales de extracción de moluscos (Mollusca) y crustáceos (Crustacea) empleados para uso culinario en la comunidad de Quiroga, Consejo Comunitario Río Guajuí de la costa pacífica caucana colombiana. *Revista Bioetnia*, 16(1), Article 1. <https://doi.org/10.51641/bioetnia.v16i1.218>
- Cantera, J. R., & Blanco, J. F. (2001). The Estuary Ecosystem of Buenaventura Bay, Colombia. In U. Seeliger & B. Kjerfve (Eds.), *Coastal Marine Ecosystems of Latin America* (pp. 265–280). Springer. [https://doi.org/10.1007/978-3-662-04482-7\\_19](https://doi.org/10.1007/978-3-662-04482-7_19)
- Chen, X., Yin, Z., Li, Z., Wang, B., Tao, A., Guo, Z., Wang, F., An, Y., & O'Driscoll, K. (2024). Overview on Mangrove Forest Disaster Prevention and Mitigation Functions.

*Journal of Ocean University of China*, 23(1), 46–56. <https://doi.org/10.1007/s11802-024-5672-3>

Consejo Comunitario de la Comunidad Negra de Punta Soldado, Playa Viva, Puin Castaño, B., & Álvarez, A. M. (2023). *Punta Soldado: Historia y Decisiones*. Centro de Excelencia en Ciencias Marinas - CEMarin. [https://cemarin.org/wp-content/uploads/2023/11/e-book\\_Historia-y-Decisiones\\_PS.pdf](https://cemarin.org/wp-content/uploads/2023/11/e-book_Historia-y-Decisiones_PS.pdf)

Costanza, R. (2020). Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. *Ecosystem Services*, 43, 101096. <https://doi.org/10.1016/j.ecoser.2020.101096>

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253–260. <https://doi.org/10.1038/387253a0>

Dahdouh-Guebas, F., Hugé, J., Abuchahla, G. M. O., Cannicci, S., Jayatissa, L. P., Kairo, J. G., Kodikara Arachchilage, S., Koedam, N., Mafaziya Nijamdeen, T. W. G. F., Mukherjee, N., Poti, M., Prabakaran, N., Ratsimbazafy, H. A., Satyanarayana, B., Thavanayagam, M., Vande Velde, K., & Wodehouse, D. (2021). Reconciling nature, people and policy in the mangrove social-ecological system through the adaptive cycle heuristic. *Estuarine, Coastal and Shelf Science*. Scopus. <https://doi.org/10.1016/j.ecss.2020.106942>

Damastuti, E., & de Groot, R. (2019). Participatory ecosystem service mapping to enhance community-based mangrove rehabilitation and management in Demak, Indonesia. *Regional Environmental Change*, 19(1), 65–78. <https://doi.org/10.1007/s10113-018-1378-7>

Delgado, M. F., Gualteros, W., Espinosa, S., Lucero, C., Roldan, A. M., Zapata, L., & Cantera, J. R. (2010). *Pianguando—Estrategias para el manejo de la piangua (Cartilla)*. [https://wwflac.awsassets.panda.org/downloads/carrilla\\_pianguando\\_web\\_2.pdf](https://wwflac.awsassets.panda.org/downloads/carrilla_pianguando_web_2.pdf)

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J. R., Arico, S., Báldi, A., Bartuska, A., Baste, I. A., Bilgin, A., Brondizio, E., Chan, K. M., Figueroa, V. E., Duraiappah, A., Fischer, M., Hill, R., ... Zlatanova, D. (2015). The IPBES Conceptual Framework—Connecting nature and people. *Current Opinion in Environmental Sustainability*, 14, 1–16. <https://doi.org/10.1016/j.cosust.2014.11.002>

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., Van Oudenhoven, A. P. E., Van Der Plaats, F., Schröter,

- M., Lavorel, S., ... Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, 359(6373), 270–272. <https://doi.org/10.1126/science.aap8826>
- Elwell, T. L., Gelcich, S., Gaines, S. D., & López-Carr, D. (2018). Using people's perceptions of ecosystem services to guide modeling and management efforts. *Science of The Total Environment*, 637–638, 1014–1025. <https://doi.org/10.1016/j.scitotenv.2018.04.052>
- FAO. (2020). *Global Forest Resources Assessment 2020*. FAO ; <https://openknowledge.fao.org/handle/20.500.14283/ca9825en>
- Figueroa, L., Figueroa Del Castillo, L., & Álvarez-León, R. (2011). *Evaluation of mangrove soils in two localities of the Ensenada de Tumaco, Colombian Pacific*.
- Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., Lucas, R., Primavera, J., Rajkaran, A., & Shi, S. (2019). The State of the World's Mangrove Forests: Past, Present, and Future. *Annual Review of Environment and Resources*, 44(Volume 44, 2019), 89–115. <https://doi.org/10.1146/annurev-environ-101718-033302>
- Fuentes, J. E., Olaya, R. A., & Garcia, C. E. (2022). Evaluation of Coastal Erosion in the Watersheds of Municipality of Buenaventura, Colombia: Using Geospatial Techniques and the Composite Vulnerability Index. *ISPRS International Journal of Geo-Information*, 11(11), Article 11. <https://doi.org/10.3390/ijgi11110568>
- Gallego Perez, B. E., & Selvaraj, J. J. (2019). Evaluation of coastal vulnerability for the District of Buenaventura, Colombia: A geospatial approach. *Remote Sensing Applications: Society and Environment*, 16, 100263. <https://doi.org/10.1016/j.rsase.2019.100263>
- Gatt, Y. M., Andradi-Brown, D. A., Ahmadi, G. N., Martin, P. A., Sutherland, W. J., Spalding, M. D., Donnison, A., & Worthington, T. A. (2022). Quantifying the Reporting, Coverage and Consistency of Key Indicators in Mangrove Restoration Projects. *Frontiers in Forests and Global Change*, 5, 720394. <https://doi.org/10.3389/ffgc.2022.720394>
- Gedan, K. B., Kirwan, M. L., Wolanski, E., Barbier, E. B., & Silliman, B. R. (2011). The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. *Climatic Change*, 106(1), 7–29. <https://doi.org/10.1007/s10584-010-0003-7>
- Gijsman, R., Horstman, E. M., Van Der Wal, D., Friess, D. A., Swales, A., & Wijnberg, K. M. (2021). Nature-Based Engineering: A Review on Reducing Coastal Flood Risk With Mangroves. *Frontiers in Marine Science*, 8, 702412. <https://doi.org/10.3389/fmars.2021.702412>

Glaeser, B., Bruckmeier, K., Glaser, M., & Krause, G. (2009). Social-Ecological Systems Analysis in Coastal and Marine Areas: A Path toward Integration of Interdisciplinary Knowledge. In *Current Trends in Human Ecology* (1st ed., pp. 183–203). Cambridge Scholars Publishing. <https://doi.org/10.5848/CSP.0441.00008>

Glaser, M. (2003). Interrelations between mangrove ecosystem, local economy and social sustainability in Caeté Estuary, North Brazil. *Wetlands Ecology and Management*, *11*(4), 265–272. <https://doi.org/10.1023/A:1025015600125>

Gnansounou, S. C., Salako, K. V., Sagoe, A. A., Mattah, P. A. D., Aheto, D. W., & Glèlè Kakai, R. (2022). Mangrove Ecosystem Services, Associated Threats and Implications for Wellbeing in the Mono Transboundary Biosphere Reserve (Togo-Benin), West-Africa. *Sustainability (Switzerland)*, *14*(4). Scopus. <https://doi.org/10.3390/su14042438>

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, *26*(10), 5844–5855. <https://doi.org/10.1111/gcb.15275>

Golebie, E. J., Aczel, M., Bukoski, J. J., Chau, S., Ramirez-Bullon, N., Gong, M., & Teller, N. (2022). A qualitative systematic review of governance principles for mangrove conservation. *Conservation Biology*. Scopus. <https://doi.org/10.1111/cobi.13850>

Guannel, G., Ruggiero, P., Faries, J., Arkema, K., Pinsky, M., Gelfenbaum, G., Guerry, A., & Kim, C.-K. (2015). Integrated modeling framework to quantify the coastal protection services supplied by vegetation. *Journal of Geophysical Research: Oceans*, *120*(1), 324–345. <https://doi.org/10.1002/2014JC009821>

Herison, A., Bengen, D. G., Romdania, Y., Zakaria, A., Luthfiyani, H. N., Al Safar, M. R., & Arief, F. D. (2023). THE CONCEPT OF SUSTAINABLE DEVELOPMENT WITH THE MANGROVE AVICENNIA MARINA AS A REDUCTOR OF WAVE ENERGY. *ASEAN Engineering Journal*, *13*(2), 165–174. <https://doi.org/10.11113/aej.v13.19274>

Hernández-Blanco, M., Moritsch, M., Manrow, M., & Raes, L. (2022). Coastal Ecosystem Services Modeling in Latin America to Guide Conservation and Restoration Strategies: The Case of Mangroves in Guatemala and El Salvador. *Frontiers in Ecology and Evolution*, *10*. <https://www.frontiersin.org/articles/10.3389/fevo.2022.843145>

Hicks, C. C., & Cinner, J. E. (2014). Social, institutional, and knowledge mechanisms mediate diverse ecosystem service benefits from coral reefs. *Proceedings of the National Academy of Sciences*, *111*(50), 17791–17796. <https://doi.org/10.1073/pnas.1413473111>

Hill, R., Díaz, S., Pascual, U., Stenseke, M., Molnár, Z., & Van Velden, J. (2021). Nature's contributions to people: Weaving plural perspectives. *One Earth*, *4*(7), 910–915. <https://doi.org/10.1016/j.oneear.2021.06.009>

- Himes-Cornell, A., Grose, S. O., & Pendleton, L. (2018). Mangrove Ecosystem Service Values and Methodological Approaches to Valuation: Where Do We Stand? *Frontiers in Marine Science*, 5. <https://www.frontiersin.org/articles/10.3389/fmars.2018.00376>
- Hoffmann, O. (2007). *Comunidades negras en el Pacífico colombiano: Innovaciones y dinámicas étnicas* (Edición castellana). IFEA Instituto Francés de Estudios Andinos ; IRD Institut de recherche pour le développement : Ediciones Abya-Yala.
- Horstman, E., Dohmen-Janssen, M., Narra, P., Berg, N.-J. van den, Siemerink, M., Balke, T., Bouma, T., & Hulscher, S. (2012). WAVE ATTENUATION IN MANGROVE FORESTS; FIELD DATA OBTAINED IN TRANG, THAILAND. *Coastal Engineering Proceedings*, 33, Article 33. <https://doi.org/10.9753/icce.v33.waves.40>
- Horstman, E. M., Dohmen-Janssen, C. M., Narra, P. M. F., van den Berg, N. J. F., Siemerink, M., & Hulscher, S. J. M. H. (2014). Wave attenuation in mangroves: A quantitative approach to field observations. *Coastal Engineering*, 94, 47–62. <https://doi.org/10.1016/j.coastaleng.2014.08.005>
- Hu, Z., Suzuki, T., Zitman, T., Uittewaal, W., & Stive, M. (2014). Laboratory study on wave dissipation by vegetation in combined current–wave flow. *Coastal Engineering*, 88, 131–142. <https://doi.org/10.1016/j.coastaleng.2014.02.009>
- Hutchison, J., Manica, A., Swetnam, R., Balmford, A., & Spalding, M. (2014). Predicting Global Patterns in Mangrove Forest Biomass. *Conservation Letters*, 7(3), 233–240. <https://doi.org/10.1111/conl.12060>
- Hutchison, J., & Spalding, M. (2014). *The Role of Mangroves in Fisheries Enhancement*. The Nature Conservancy and Wetlands International. <https://www.wetlands.org/publication/the-role-of-mangroves-in-fisheries-enhancement/>
- Ilman, M., Dargusch, P., Dart, P., & Onrizal. (2016). A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. *Land Use Policy*, 54, 448–459. <https://doi.org/10.1016/j.landusepol.2016.03.010>
- INVEMAR. (2022). Mapa de manglares de Colombia. *Agenda del Mar Comunicaciones*. <https://agendadelmar.com/mapa-de-manglares-de-colombia/>
- Islam, M. M., Sunny, A. R., Hossain, M. M., & Friess, D. A. (2018). Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. *Singapore Journal of Tropical Geography*, 39(2), 244–265. Scopus. <https://doi.org/10.1111/sjtg.12241>
- K G, P., & Bhaskaran, P. K. (2017). Wave attenuation in presence of mangroves: A sensitivity study for varying bottom slopes. *The International Journal of Ocean and Climate Systems*, 8(3), 126–134. <https://doi.org/10.1177/1759313117702919>

- Kachler, J., Isaac, R., Martín-López, B., Bonn, A., & Felipe-Lucia, M. R. (2023). Co-production of nature's contributions to people: What evidence is out there? *People and Nature*, 5(4), 1119–1134. <https://doi.org/10.1002/pan3.10493>
- Kadykalo, A. N., López-Rodríguez, M. D., Ainscough, J., Droste, N., Ryu, H., Ávila-Flores, G., Le Clec'h, S., Muñoz, M. C., Nilsson, L., Rana, S., Sarkar, P., Sevecke, K. J., & Harmáčková, Z. V. (2019). Disentangling 'ecosystem services' and 'nature's contributions to people'. *Ecosystems and People*, 15(1), 269–287. <https://doi.org/10.1080/26395916.2019.1669713>
- Ke, G.-N., Utama, I. K. A. P., Wagner, T., Sweetman, A. K., Arshad, A., Nath, T. K., Neoh, J. Y., Muchamad, L. S., & Suroso, D. S. A. (2022). Influence of mangrove forests on subjective and psychological wellbeing of coastal communities: Case studies in Malaysia and Indonesia. *Frontiers in Public Health*, 10. Scopus. <https://doi.org/10.3389/fpubh.2022.898276>
- Kelly-Quinn, M., Christie, M., Bodoque, J. M., & Schoenrock, K. (2022). Ecosystem Services Approach and Natures Contributions to People (NCP) Help Achieve SDG6. In W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, & T. Wall (Eds.), *Clean Water and Sanitation* (pp. 144–156). Springer International Publishing. [https://doi.org/10.1007/978-3-319-95846-0\\_147](https://doi.org/10.1007/978-3-319-95846-0_147)
- Kelty, K., Tomiczek, T., Cox, D. T., Lomonaco, P., & Mitchell, W. (2022). Prototype-Scale Physical Model of Wave Attenuation Through a Mangrove Forest of Moderate Cross-Shore Thickness: LiDAR-Based Characterization and Reynolds Scaling for Engineering With Nature. *Frontiers in Marine Science*, 8, 780946. <https://doi.org/10.3389/fmars.2021.780946>
- Koch, E. W., Barbier, E. B., Silliman, B. R., Reed, D. J., Perillo, G. M., Hacker, S. D., Granek, E. F., Primavera, J. H., Muthiga, N., Polasky, S., Halpern, B. S., Kennedy, C. J., Kappel, C. V., & Wolanski, E. (2009). Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment*, 7(1), 29–37. <https://doi.org/10.1890/080126>
- Kochoni, B. I., Avakoudjo, H. G. G., Kamelan, T. M., Sinsin, C. B. L., & Kouamelan, E. P. (2023a). Contribution of mangroves ecosystems to coastal communities' resilience towards climate change: A case study in southern Cote d'Ivoire. *GeoJournal*, 88(4), 3935–3951. Scopus. <https://doi.org/10.1007/s10708-023-10845-2>
- Kochoni, B. I., Avakoudjo, H. G. G., Kamelan, T. M., Sinsin, C. B. L., & Kouamelan, E. P. (2023b). Contribution of mangroves ecosystems to coastal communities' resilience towards climate change: A case study in southern Cote d'Ivoire. *GeoJournal*, 88(4), 3935–3951. <https://doi.org/10.1007/s10708-023-10845-2>

- Kuckartz, U. (2014). *Qualitative Text Analysis: A Guide to Methods, Practice & Using Software*. SAGE Publications Ltd. <https://doi.org/10.4135/9781446288719>
- Lamnek, S. (1993). *Qualitative Sozialforschung: Methoden und Techniken*. Beltz, Psychologie Verlags Union.
- Leal, M., & Spalding, M. (2022). *The State of the World's Mangroves 2022*. Global Mangrove Alliance. [https://www.mangrovealliance.org/wp-content/uploads/2022/09/The-State-of-the-Worlds-Mangroves-Report\\_2022.pdf](https://www.mangrovealliance.org/wp-content/uploads/2022/09/The-State-of-the-Worlds-Mangroves-Report_2022.pdf)
- Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., McKee, K., Bosire, J. O., Cannicci, S., Diele, K., Fromard, F., Koedam, N., Marchand, C., Mendelssohn, I., Mukherjee, N., & Record, S. (2014). Ecological role and services of tropical mangrove ecosystems: A reassessment. *Global Ecology and Biogeography*, *23*(7), 726–743. <https://doi.org/10.1111/geb.12155>
- Liquete, C., Zulian, G., Delgado, I., Stips, A., & Maes, J. (2013). Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators*, *30*, 205–217. <https://doi.org/10.1016/j.ecolind.2013.02.013>
- López-Portillo, J., Lewis, R. R., Saenger, P., Rovai, A., Koedam, N., Dahdouh-Guebas, F., Agraz-Hernández, C., & Rivera-Monroy, V. H. (2017). Mangrove Forest Restoration and Rehabilitation. In V. H. Rivera-Monroy, S. Y. Lee, E. Kristensen, & R. R. Twilley (Eds.), *Mangrove Ecosystems: A Global Biogeographic Perspective* (pp. 301–345). Springer International Publishing. [https://doi.org/10.1007/978-3-319-62206-4\\_10](https://doi.org/10.1007/978-3-319-62206-4_10)
- Lovelock, C. E., Barbier, E., & Duarte, C. M. (2022a). Tackling the mangrove restoration challenge. *PLoS Biology*, *20*(10), e3001836. <https://doi.org/10.1371/journal.pbio.3001836>
- Lovelock, C. E., Barbier, E., & Duarte, C. M. (2022b). Tackling the mangrove restoration challenge. *PLoS Biology*, *20*(10), e3001836. <https://doi.org/10.1371/journal.pbio.3001836>
- Lozano Montoya, J. S., & Restrepo Cárdenas, S. F. (2019). *Cambios socio-ambientales del poblado de punta soldado, Buenaventura, entre 1970 y 2018, debido a la erosión costera*. <https://bibliotecadigital.univalle.edu.co/entities/publication/c4937299-189c-4f0d-9a8a-3cc1e8ecba23>
- Mallick, B., Priodarshini, R., Kimengsi, J. N., Biswas, B., Hausmann, A. E., Islam, S., Huq, S., & Vogt, J. (2021). Livelihoods dependence on mangrove ecosystems: Empirical evidence from the Sundarbans. *Current Research in Environmental Sustainability*, *3*, 100077. <https://doi.org/10.1016/j.crsust.2021.100077>
- Marois, D. E., & Mitsch, W. J. (2015). Coastal protection from tsunamis and cyclones provided by mangrove wetlands – a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *11*(1), 71–83. <https://doi.org/10.1080/21513732.2014.997292>

- Martín-López, B., Iniesta-Arandia, I., García-Llorente, M., Palomo, I., Casado-Arzuaga, I., Amo, D. G. D., Gómez-Baggethun, E., Oteros-Rozas, E., Palacios-Agundez, I., Willaarts, B., González, J. A., Santos-Martín, F., Onaindia, M., López-Santiago, C., & Montes, C. (2012). Uncovering Ecosystem Service Bundles through Social Preferences. *PLOS ONE*, 7(6), e38970. <https://doi.org/10.1371/journal.pone.0038970>
- Maza, M., Lara, J. L., & Losada, I. J. (2019). Experimental analysis of wave attenuation and drag forces in a realistic fringe *Rhizophora* mangrove forest. *Advances in Water Resources*, 131, 103376. <https://doi.org/10.1016/j.advwatres.2019.07.006>
- Mazda, Y., Magi, M., Ikeda, Y., Kurokawa, T., & Asano, T. (2006). Wave reduction in a mangrove forest dominated by *Sonneratia* sp. *Wetlands Ecology and Management*, 14(4), 365–378. <https://doi.org/10.1007/s11273-005-5388-0>
- Mazda, Y., Magi, M., Kogo, M., & Hong, P. N. (1997). Mangroves as a coastal protection from waves in the Tong King delta, Vietnam. *Mangroves and Salt Marshes*, 1(2), 127–135. <https://doi.org/10.1023/A:1009928003700>
- McIvor, A. L., Möller, I., Spencer, T., & Spalding, M. (2012). Reduction of Wind and Swell Waves by Mangroves. *Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40. ISSN 2050-7941*. <https://repository.tudelft.nl/islandora/object/uuid%3Ac77ceec8-8db6-4080-b5bb-f414dca9d39d>
- Menéndez, P., Losada, I. J., Beck, M. W., Torres-Ortega, S., Espejo, A., Narayan, S., Díaz-Simal, P., & Lange, G.-M. (2018). Valuing the protection services of mangroves at national scale: The Philippines. *Ecosystem Services*, 34, 24–36. <https://doi.org/10.1016/j.ecoser.2018.09.005>
- Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The Global Flood Protection Benefits of Mangroves. *Scientific Reports*, 10(1), 4404. <https://doi.org/10.1038/s41598-020-61136-6>
- Millennium Ecosystem Assessment (Program) (Ed.). (2005). *Ecosystems and human well-being: Wetlands and water synthesis: a report of the Millennium Ecosystem Assessment*. World Resources Institute.
- Mitra, A. (2020). Mangroves: A Natural Ecosystem of Cultural and Religious Convergence. In A. Mitra, *Mangrove Forests in India* (pp. 337–352). Springer International Publishing. [https://doi.org/10.1007/978-3-030-20595-9\\_10](https://doi.org/10.1007/978-3-030-20595-9_10)
- Mohamed, M. K., Adam, E., & Jackson, C. M. (2024). Assessing the Perception and Contribution of Mangrove Ecosystem Services to the Well-Being of Coastal Communities

- of Chwaka and Menai Bays, Zanzibar. *Resources*, 13(1). Scopus. <https://doi.org/10.3390/resources13010007>
- Morris, R. L., Boxshall, A., & Swearer, S. E. (2020). Climate-resilient coasts require diverse defence solutions. *Nature Climate Change*, 10(6), 485–487. <https://doi.org/10.1038/s41558-020-0798-9>
- Mosquera Torres, G., & Aprile Gniset, J. (2018). *Aldeas de la costa de Buenaventura (v3)*. <https://bibliotecadigital.univalle.edu.co/entities/publication/09484b76-c593-439b-b45d-420189e38cf1>
- Mshale, B., Senga, M., & Mwangi, E. (2017). *Governing mangroves: Unique challenges for managing Tanzania's coastal forests*. Center for International Forestry Research (CIFOR). <https://doi.org/10.17528/cifor/006596>
- Muis, S., Haigh, I. D., Guimarães Nobre, G., Aerts, J. C. J. H., & Ward, P. J. (2018). Influence of El Niño-Southern Oscillation on Global Coastal Flooding. *Earth's Future*, 6(9), 1311–1322. <https://doi.org/10.1029/2018EF000909>
- Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and Ecosystem-based Adaptation: A new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, 5(1), 67–71. <https://doi.org/10.1016/j.cosust.2012.12.001>
- Mwansasu, S. (2016). *Causes and Perceptions of Environmental Change in the Mangroves of Rufiji Delta, Tanzania: Implications for Sustainable Livelihood and Conservation*. <https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-128074>
- Narayanan, D., N, Karthi., S, Balamurugan., & Ramesh, D. A. (2023). Integrated ecosystem-based risk reduction into environmental-economic accounting in Gujarat coastal zones. In *Climate Change, Community Response and Resilience* (pp. 451–465). Elsevier. <https://doi.org/10.1016/B978-0-443-18707-0.00024-2>
- Nyangoko, B. P., Berg, H., Mangora, M. M., Gullström, M., & Shalli, M. S. (2021). Community perceptions of mangrove ecosystem services and their determinants in the Rufiji Delta, Tanzania. *Sustainability (Switzerland)*, 13(1), 1–23. Scopus. <https://doi.org/10.3390/su13010063>
- Nyangoko, B. P., Berg, H., Mangora, M. M., Shalli, M. S., & Gullström, M. (2022a). Community perceptions of climate change and ecosystem-based adaptation in the mangrove ecosystem of the Rufiji Delta, Tanzania. *Climate and Development*, 14(10), 896–908. Scopus. <https://doi.org/10.1080/17565529.2021.2022449>
- Nyangoko, B. P., Berg, H., Mangora, M. M., Shalli, M. S., & Gullström, M. (2022b). Local perceptions of changes in mangrove ecosystem services and their implications for

livelihoods and management in the Rufiji Delta, Tanzania. *Ocean & Coastal Management*, 219, 106065. <https://doi.org/10.1016/j.ocecoaman.2022.106065>

Odériz, I., Silva, R., Mortlock, T. R., & Mori, N. (2020). El Niño-Southern Oscillation Impacts on Global Wave Climate and Potential Coastal Hazards. *Journal of Geophysical Research: Oceans*, 125(12), e2020JC016464. <https://doi.org/10.1029/2020JC016464>

Ohira, W., Honda, K., Nagai, M., & Ratanasuwan, A. (2013). Mangrove stilt root morphology modeling for estimating hydraulic drag in tsunami inundation simulation. *Trees*, 27(1), 141–148. <https://doi.org/10.1007/s00468-012-0782-8>

Olaya Requene, A. Y. (2022). El pacífico colombiano y las comunidades negras en el contexto de la firma del acuerdo de paz: Aportes al campo de los estudios afrocolombianos. *Tabula Rasa*, 41, 11–19. <https://doi.org/10.25058/20112742.n41.01>

Osorio-Cano, J. D., Osorio, A. F., & Peláez-Zapata, D. S. (2019). Ecosystem management tools to study natural habitats as wave damping structures and coastal protection mechanisms. *Ecological Engineering*, 130, 282–295. <https://doi.org/10.1016/j.ecoleng.2017.07.015>

Owuor, M. A., Mulwa, R., Otieno, P., Icely, J., & Newton, A. (2019). Valuing mangrove biodiversity and ecosystem services: A deliberative choice experiment in Mida Creek, Kenya. *Ecosystem Services*, 40, 101040. <https://doi.org/10.1016/j.ecoser.2019.101040>

P, S., J. M, K., & S, K. (2024). A REVIEW ON ECOLOGICAL IMPORTANCE OF MANGROVES. In Dr. Anil Kumar, Dr. J. M. Koli, Dr. Ayushi Varshney, R. Kumar, Dr. Ashish Kumar, Dr. Kartikey Chaturvedi, Dr. Nitish Sharma, K. S. Balasaheb, Dr. Awanish Kumar Singh, Dr. Pramod Katti, Dr. Lakhesing Anandsing Girase, N. Faheem, Er. Mukul Sain, Dr. Manoj Kumar Sarma, Dr. Bipasha Mridha Ghosh, Dr. Pawan Kumar, Dr. Taale, Dr. Subbalakshmi, Dr. Himangshu Barman, ... B. Rajasekaran (Eds.), *Futuristic Trends in Agriculture Engineering & Food Sciences Volume 3 Book 15* (First, pp. 1–17). Iterative International Publisher, Selfypage Developers Pvt Ltd. <https://doi.org/10.58532/V3BCAG15P1CH1>

Palacios, M. L., & Cantera, J. R. (2017). Mangrove timber use as an ecosystem service in the Colombian Pacific. *Hydrobiologia*, 803(1), 345–358. <https://doi.org/10.1007/s10750-017-3309-x>

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., ... Yagi, N. (2017). Valuing nature's contributions to people: The IPBES approach. *Current Opinion in Environmental Sustainability*, 26–27, 7–16. <https://doi.org/10.1016/j.cosust.2016.12.006>

- Peterson, G. D., Harmáčková, Z. V., Meacham, M., Queiroz, C., Jiménez-Aceituno, A., Kuiper, J. J., Malmborg, K., Sitas, N., & Bennett, E. M. (2018). Welcoming different perspectives in IPBES: Nature's contributions to people; and Ecosystem services; *Ecology and Society*, 23(1), art39. <https://doi.org/10.5751/ES-10134-230139>
- Prahl, H. von, Cantera, J. R., & R, C. R. C. (1990). *Manglares y hombres del Pacífico colombiano*. COLCIENCIAS.
- Qualitative and Quantitative Research Techniques for Humanitarian Needs Assessment*. (2012, May 18). ACAPS. <https://reliefweb.int/report/world/qualitative-and-quantitative-research-techniques-humanitarian-needs-assessment>
- Quang Bao, T. (2011). Effect of mangrove forest structures on wave attenuation in coastal Vietnam. *Oceanologia*, 53(3), 807–818. <https://doi.org/10.5697/oc.53-3.807>
- Queiroz, L. D. S., Rossi, S., Calvet-Mir, L., Ruiz-Mallén, I., García-Betorz, S., Salvà-Prat, J., & Meireles, A. J. D. A. (2017). Neglected ecosystem services: Highlighting the socio-cultural perception of mangroves in decision-making processes. *Ecosystem Services*, 26, 137–145. Scopus. <https://doi.org/10.1016/j.ecoser.2017.06.013>
- Quevedo, J. M. D., & Kohsaka, R. (2024). A systematic review of cultural ecosystem services of blue carbon ecosystems: Trends, gaps, and challenges in Asia and beyond. *Marine Policy*, 159, 105898. <https://doi.org/10.1016/j.marpol.2023.105898>
- Quevedo, J. M. D., Uchiyama, Y., & Kohsaka, R. (2020). Perceptions of the seagrass ecosystems for the local communities of Eastern Samar, Philippines: Preliminary results and prospects of blue carbon services. *Ocean and Coastal Management*, 191. Scopus. <https://doi.org/10.1016/j.ocecoaman.2020.105181>
- Rao, N. S., Ghermandi, A., Portela, R., & Wang, X. (2015). Global values of coastal ecosystem services: A spatial economic analysis of shoreline protection values. *Ecosystem Services*, 11, 95–105. <https://doi.org/10.1016/j.ecoser.2014.11.011>
- Refulio-Coronado, S., Lacasse, K., Dalton, T., Humphries, A., Basu, S., Uchida, H., & Uchida, E. (2021). Coastal and Marine Socio-Ecological Systems: A Systematic Review of the Literature. *Frontiers in Marine Science*, 8, 648006. <https://doi.org/10.3389/fmars.2021.648006>
- Restrepo, E. (2016). Espacialidades afrodescendientes en el Pacífico Colombiano. In *Territorios de gente Negra: Procesos, transformaciones y adaptaciones: Ensayos sobre Colombia y Brasil*.
- Reyes-Arroyo, N., Camacho-Valdez, V., Saenz-Arroyo, A., & Infante-Mata, D. (2021). Socio-cultural analysis of ecosystem services provided by mangroves in La Encrucijada

- Biosphere Reserve, southeastern Mexico. *Local Environment*, 26(1), 86–109.  
<https://doi.org/10.1080/13549839.2020.1867836>
- 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*, 113(2), 344–349. <https://doi.org/10.1073/pnas.1510272113>
- Richardson, L., Loomis, J., Kroeger, T., & Casey, F. (2015). The role of benefit transfer in ecosystem service valuation. *Ecological Economics*, 115, 51–58.  
<https://doi.org/10.1016/j.ecolecon.2014.02.018>
- Rodríguez-Rodríguez, J. A., Gonzalez-Polo, D., Manuel, J., & Otero, R. R. (n.d.). *MEMORIAS DE LOS TALLERES DE CAPACITACIÓN EN EL MANEJO DEL SISTEMA DE INFORMACIÓN PARA LA GESTIÓN DE LOS MANGLARES DE COLOMBIA-SIGMA*.
- Rossi, S., & Soares, M. D. O. (2017). EFFECTS OF EL NIÑO ON THE COASTAL ECOSYSTEMS AND THEIR RELATED SERVICES. *Mercator*, 16(12), 1–16.  
<https://doi.org/10.4215/rm2017.e16030>
- Roy, S., Zafarullah, H., & Das, A. K. (2020). Unwrapping the memory box: Gendered livelihoods in a forest community in the Sundarbans, Bangladesh. *Asian Journal of Social Science*, 48(3–4), 375–394. Scopus. <https://doi.org/10.1163/15685314-04803010>
- Sánchez-Núñez, D. A., Bernal, G., & Mancera Pineda, J. E. (2019). The Relative Role of Mangroves on Wave Erosion Mitigation and Sediment Properties. *Estuaries and Coasts*, 42(8), 2124–2138. <https://doi.org/10.1007/s12237-019-00628-9>
- Sánchez-Páez, H., Álvarez-León, R., Pinto-Nolla, F., Sanchez-Alfarez, A., Pinto-Renjifo, J., Acosta-Peñaloza, M., & García-Hansen Honkala, I. (1997). *Diagnóstico y zonificación preliminar de los manglares del Pacífico de Colombia*.
- Sathirathai, S., & Barbier, E. (2001). VALUING MANGROVE CONSERVATION IN SOUTHERN THAILAND. *Contemporary Economic Policy*, 19(2), 109–122.  
<https://doi.org/10.1111/j.1465-7287.2001.tb00054.x>
- Scemama, P., Regnier, E., Blanchard, F., & Thébaud, O. (2022). Ecosystem Services Assessment for the Conservation of Mangroves in French Guiana Using Fuzzy Cognitive Mapping. *Frontiers in Forests and Global Change*, 4. Scopus.  
<https://doi.org/10.3389/ffgc.2021.769182>
- Schlüter, A., Van Assche, K., Hornidge, A.-K., & Văidianu, N. (2020). Land-sea interactions and coastal development: An evolutionary governance perspective. *Marine Policy*, 112, 103801. <https://doi.org/10.1016/j.marpol.2019.103801>

Selvaraj, J. J., & Gallego Pérez, B. E. (2023). Estimating mangrove aboveground biomass in the Colombian Pacific coast: A multisensor and machine learning approach. *Heliyon*, 9(11), e20745. <https://doi.org/10.1016/j.heliyon.2023.e20745>

Sievers, M., Brown, C. J., McGowan, J., Turschwell, M. P., Buelow, C. A., Holgate, B., Pearson, R. M., Adame, M. F., Andradi-Brown, D. A., Arnell, A., Mackey, B. G., Ermgassen, P. S. E. zu, Gosling, J., McOwen, C. J., Worthington, T. A., & Connolly, R. M. (2023). Co-occurrence of biodiversity, carbon storage, coastal protection, and fish and invertebrate production to inform global mangrove conservation planning. *Science of The Total Environment*, 904, 166357. <https://doi.org/10.1016/j.scitotenv.2023.166357>

Silver, J. M., Arkema, K. K., Griffin, R. M., Lashley, B., Lemay, M., Maldonado, S., Moultrie, S. H., Ruckelshaus, M., Schill, S., Thomas, A., Wyatt, K., & Verutes, G. (2019). Advancing Coastal Risk Reduction Science and Implementation by Accounting for Climate, Ecosystems, and People. *Frontiers in Marine Science*, 6. <https://www.frontiersin.org/articles/10.3389/fmars.2019.00556>

Slovic, P. (1987). Perception of Risk. *Science*, 236(4799), 280–285. <https://doi.org/10.1126/science.3563507>

Slovic, P., & Peters, E. (2006). Risk Perception and Affect. *Current Directions in Psychological Science*, 15(6), 322–325. <https://doi.org/10.1111/j.1467-8721.2006.00461.x>

Spalding, M. D., Mclvor, A. L., Beck, M. W., Koch, E. W., Möller, I., Reed, D. J., Rubinoff, P., Spencer, T., Tolhurst, T. J., Wamsley, T. V., van Wesenbeeck, B. K., Wolanski, E., & Woodroffe, C. D. (2014). Coastal Ecosystems: A Critical Element of Risk Reduction. *Conservation Letters*, 7(3), 293–301. <https://doi.org/10.1111/conl.12074>

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., & Beck, M. W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management*, 90, 50–57. <https://doi.org/10.1016/j.ocecoaman.2013.09.007>

Spalding, M., Mclvor, A. L., Tonneijck, F. H., & Van Eijk, P. (2014). *Mangroves for coastal defence. Guidelines for coastal managers and policy makers*. Wetlands International and The Natura Conservancy. <https://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf>

Staplin, N., Herrington, W. G., Judge, P. K., Reith, C. A., Haynes, R., Landray, M. J., Baigent, C., & Emberson, J. (2017). Use of Causal Diagrams to Inform the Design and Interpretation of Observational Studies: An Example from the Study of Heart and Renal Protection (SHARP). *Clinical Journal of the American Society of Nephrology*, 12(3), 546–552. <https://doi.org/10.2215/CJN.02430316>

Strain, E. M. A., Kompas, T., Boxshall, A., Kelvin, J., Swearer, S., & Morris, R. L. (2022). Assessing the coastal protection services of natural mangrove forests and artificial rock

revetments. *Ecosystem Services*, 55, 101429.  
<https://doi.org/10.1016/j.ecoser.2022.101429>

Su, J., & Gasparatos, A. (2023). Perceptions about mangrove restoration and ecosystem services to inform ecosystem-based restoration in Large Xiamen Bay, China. *Landscape and Urban Planning*, 235. Scopus. <https://doi.org/10.1016/j.landurbplan.2023.104763>

Suarez, A., Ruiz-Agudelo, C. A., Arias-Arévalo, P., Flórez-Yepes, G. Y., Arciniegas, N., Vargas-Marín, L. A., Marulanda, A., Ramirez, J., Castro-Escobar, E., Bastidas, J. C., & Blanco, D. (2022). Recognizing, normalizing and articulating: An approach to highlight plural values of water ecosystem services in Colombia. *Heliyon*, 8(9), e10622.  
<https://doi.org/10.1016/j.heliyon.2022.e10622>

Thelen, E., & Smith, L. B. (2007). Dynamic Systems Theories. In W. Damon & R. M. Lerner (Eds.), *Handbook of Child Psychology* (1st ed.). Wiley.  
<https://doi.org/10.1002/9780470147658.chpsy0106>

Triyanti, A., Walz, Y., Marfai, M. A., Renaud, F., & Djalante, R. (2017). Ecosystem-Based Disaster Risk Reduction in Indonesia: Unfolding Challenges and Opportunities. In R. Djalante, M. Garschagen, F. Thomalla, & R. Shaw (Eds.), *Disaster Risk Reduction in Indonesia* (pp. 445–467). Springer International Publishing. [https://doi.org/10.1007/978-3-319-54466-3\\_18](https://doi.org/10.1007/978-3-319-54466-3_18)

Uribe-Castañeda, N., Satizabal, C. A., Herrera-Orozco, L., & Kintz, J. R. C. (2020). Ecosystems services vulnerability of Uramba Marine Protected Area. *Boletín de Investigaciones Marinas y Costeras*, 49(SuplEsp), Article SuplEsp.  
<https://doi.org/10.25268/bimc.invemar.2020.49.SuplEsp.1055>

Valderrama, E. (2023). *Análisis del cambio morfológico en la línea de costa de la bahía de Buenaventura (Pacífico Colombiano) a través de sensores remotos de 2016 a 2021*. [Universidad de Antioquia].  
[https://bibliotecadigital.udea.edu.co/bitstream/10495/37118/2/EisinguerKevin\\_2023\\_An%C3%A1lisisMorfol%C3%B3gicoBuenaventura.pdf](https://bibliotecadigital.udea.edu.co/bitstream/10495/37118/2/EisinguerKevin_2023_An%C3%A1lisisMorfol%C3%B3gicoBuenaventura.pdf)

van Bijsterveldt, C. E. J., van Wesenbeeck, B. K., van der Wal, D., Afiati, N., Pribadi, R., Brown, B., & Bouma, T. J. (2020). How to restore mangroves for greenbelt creation along eroding coasts with abandoned aquaculture ponds. *Estuarine, Coastal and Shelf Science*, 235, 106576. <https://doi.org/10.1016/j.ecss.2019.106576>

van der Westhuysen, A. J., Zijlema, M., & Battjes, J. A. (2007). Nonlinear saturation-based whitecapping dissipation in SWAN for deep and shallow water. *Coastal Engineering*, 54(2), 151–170. <https://doi.org/10.1016/j.coastaleng.2006.08.006>

- van Hespen, R., Hu, Z., Borsje, B., De Dominicis, M., Friess, D. A., Jevrejeva, S., Kleinhans, M. G., Maza, M., van Bijsterveldt, C. E. J., Van der Stocken, T., van Wesenbeeck, B., Xie, D., & Bouma, T. J. (2023). Mangrove forests as a nature-based solution for coastal flood protection: Biophysical and ecological considerations. *Water Science and Engineering*, 16(1), 1–13. <https://doi.org/10.1016/j.wse.2022.10.004>
- Vanegas G, C. A., Osorio, A. F., & Urrego, L. E. (2019). Wave dissipation across a *Rhizophora* mangrove patch on a Colombian Caribbean Island: An experimental approach. *Ecological Engineering*, 130, 271–281. <https://doi.org/10.1016/j.ecoleng.2017.07.014>
- Vardi Venkateswarlu, Chenji Venkatrayulu, Adelina Jaya Harsha M, & Govardhan Reddy G. (2023). Review on mangrove restoration: Re-greening the sea coast. *GSC Biological and Pharmaceutical Sciences*, 22(3), 130–143. <https://doi.org/10.30574/gscbps.2023.22.3.0112>
- Vignola, R., Locatelli, B., Martinez, C., & Imbach, P. (2009). Ecosystem-based adaptation to climate change: What role for policy-makers, society and scientists? *Mitigation and Adaptation Strategies for Global Change*, 14(8), 691–696. <https://doi.org/10.1007/s11027-009-9193-6>
- Villanueva, A. J., Vernaza-Quiñónez, L., & Granado-Díaz, R. (2023). Disentangling the heterogeneity of mangrove managers' perception of ecosystem services. *Ecological Economics*, 213. Scopus. <https://doi.org/10.1016/j.ecolecon.2023.107969>
- Viveros Duiza, J. L. (2021). *Evaluación de técnica de restauración de Manglares en Punta Soldado basado en la implementación de la Resolución 1263 del 2018 de Colombia*. Pontificia Universidad Javeriana de Cali.
- Vo, Q. T., Kuenzer, C., Vo, Q. M., Moder, F., & Oppelt, N. (2012). Review of valuation methods for mangrove ecosystem services. *Ecological Indicators*, 23, 431–446. <https://doi.org/10.1016/j.ecolind.2012.04.022>
- Vos, K., Harley, M. D., Turner, I. L., & Splinter, K. D. (2023). Pacific shoreline erosion and accretion patterns controlled by El Niño/Southern Oscillation. *Nature Geoscience*, 16(2), 140–146. <https://doi.org/10.1038/s41561-022-01117-8>
- Wang, Y., Yin, Z., & Liu, Y. (2022). Laboratory study on the drag coefficient for mangrove forests in regular waves. *Ocean Engineering*, 255, 111522. <https://doi.org/10.1016/j.oceaneng.2022.111522>
- Ward, R. D., Friess, D. A., Day, R. H., & Mackenzie, R. A. (2016). Impacts of climate change on mangrove ecosystems: A region by region overview. *Ecosystem Health and Sustainability*, 2(4), e01211. <https://doi.org/10.1002/ehs2.1211>

- Waryszak, P., Gavaille, A., Whitt, A. A., Kelvin, J., & Macreadie, P. I. (2021). Combining gray and green infrastructure to improve coastal resilience: Lessons learnt from hybrid flood defenses. *Coastal Engineering Journal*, 63(3), 335–350. <https://doi.org/10.1080/21664250.2021.1920278>
- Winterwerp, J. C., Albers, T., Anthony, E. J., Friess, D. A., Mancheño, A. G., Moseley, K., Muhari, A., Naipal, S., Noordermeer, J., Oost, A., Saengsupavanich, C., Tas, S. A. J., Tonneijck, F. H., Wilms, T., Van Bijsterveldt, C., Van Eijk, P., Van Lavieren, E., & Van Wesenbeeck, B. K. (2020). Managing erosion of mangrove-mud coasts with permeable dams – lessons learned. *Ecological Engineering*, 158, 106078. <https://doi.org/10.1016/j.ecoleng.2020.106078>
- World Bank Group. (2016). *Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs*. World Bank, Washington, DC. <https://doi.org/10.1596/23775>
- Yanagisawa, H., Koshimura, S., Miyagi, T., & Imamura, F. (2010). Tsunami damage reduction performance of a mangrove forest in Banda Aceh, Indonesia inferred from field data and a numerical model. *Journal of Geophysical Research: Oceans*, 115(C6), 2009JC005587. <https://doi.org/10.1029/2009JC005587>
- Zamboni, N. S., Prudêncio, M. da C., Amaro, V. E., Matos, M. de F. A. de, Verutes, G. M., & Carvalho, A. R. (2022). The protective role of mangroves in safeguarding coastal populations through hazard risk reduction: A case study in northeast Brazil. *Ocean & Coastal Management*, 229, 106353. <https://doi.org/10.1016/j.ocecoaman.2022.106353>