Empirical Essays on the Economic Value of Mangrove Restoration in Colombia

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Abstract

This dissertation highlights the critical need for the conservation and restoration of mangrove ecosystems, particularly in Colombia, focusing on its contributions to local communities' subsistence and resilience. The study employs three distinct economic valuation methodologies to assess both historical and forthcoming mangrove restoration initiatives.

The first chapter addresses a notable gap in the literature regarding the economic valuation of mangroves in Latin America, with a specific focus on Colombia. By conducting a systematic review and meta-analysis, including studies from both published and unpublished sources across North, Central and South American countries. A meta-regression model is estimated using a multilevel approach, to identify key factors influencing mangrove value, including ecosystem services, study characteristics, socioeconomic variables, and site characteristics. Application of this model to the Cienaga Grande de Santa Marta (CGSM) in the Colombian Caribbean estimated a total value of US$91.7 million gained from mangrove restoration efforts between 2000 and 2020.

The second chapter assesses the economic value of mangrove nursery function as a contributing factor to local artisanal fisheries in CGSM. The results supported the positive correlation between mangrove cover and fisheries catches and revenues, demonstrating the positive marginal productivity of mangroves in this area and the contributions of restoration actions to local livelihoods. The third and final chapter investigates individual preferences for future mangrove restoration projects in CGSM, through a choice experiment survey, exploring the anticipated benefits of planned restoration actions. The choice experiment included attributes related to biodiversity, mangrove extension, fisheries, and contributions to restoration efforts (including monetary and time contributions). The analysis revealed a preference for volunteering in restoration activities over monetary contributions, and a willingness to make higher monthly payments and volunteer more hours for improvements in mangrove cover and fish catch, also conditioned to the distance to mangroves.

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In loving memory of Pilar Oñate, 1959-2018

Introduction

This dissertation is motivated by the global interest in mangrove ecosystem conservation and restoration efforts as a strategy to protect biodiversity, tackle climate change and promote social cohesion. This habitat is a crucial ecosystem for megadiverse developing countries like Colombia and the aim of this research is to support the evidence that investments in restoration activities, not only are crucial for its ecological value but also for the opportunity to target other Sustainable Development Goals like poverty alleviation and zero hunger, focusing on local communities' subsistence and resilience. This dissertation contributes to the economic valuation literature in developing countries, presenting estimates derived from three methodological approaches (benefit transfer, revealed preferences and stated preferences), to evaluate contributions from mangrove conservation, past restoration efforts, and preferences for future restoration initiatives in Colombia.

Ecosystem services help identify the various benefits that humans obtain from natural systems. Coined by a multidisciplinary team (Alcamo et al., 2003; MEA, 2005) and adopted by economists in the late 20th century, this framework has since evolved into a fundamental pillar of ecological research and resource management (Gómez-Baggethun et al., 2010). These services are typically categorized into four groups: provisioning (e.g., food, water), regulating (e.g., climate regulation, disease control), cultural (e.g., recreational and aesthetic value), and supporting (e.g., nutrient cycling, soil formation) services (de Groot et al., 2002; MEA, 2005). The valuation of ecosystem services is one of the topics of the environmental economics discipline, which applies economic principles to analyze environmental problems. Various methodologies can be used to assess the economic value of these services, providing insights that can inform policy decisions and resource allocation (Boyd & Banzhaf, 2007). This valuation is essential for understanding the trade-offs involved in natural resource management and for incorporating the value of ecosystems into economic decision-making processes.

The economic values associated with nature can be broadly classified into use values and non-use values. Use values are derived from the direct utilization of natural resources, including both consumptive (e.g., fishing, timber harvesting) and non-consumptive (e.g., recreation, tourism) activities. Non-use values, on the other hand, are not linked to consumption but represent the worth attributed to the mere existence or preservation of a particular ecosystem, including existence value and bequest value (de Groot et al., 2012; Kumar, 2010). To estimate these values a range of economic methods can be employed. Market-based approaches use observable prices to assess value, such as hedonic pricing, production function, and travel cost method. Non-market approaches include stated preferences, which rely on surveys and interviews to infer value (Kumar, 2010; Pearce et al., 2002). These methodologies are critical tools in understanding the economic importance of ecosystem services and play a crucial role in shaping conservation and restoration strategies.

Coastal ecosystems stand as vital bases of the global economy, offering a wide array of services. These ecosystems, including mangroves, salt marshes, and seagrass beds, play essential roles in supporting fisheries, providing shoreline protection, sequestering and storing carbon, and fostering tourism and recreation (Barbier et al., 2011). The economic value derived from coastal ecosystems can highlight the urgency of their conservation for policy decision-making. The loss of these ecosystems can have significant economic repercussions, affecting industries dependent on fisheries, increasing vulnerability to coastal hazards, and diminishing the appeal of coastal areas for tourism (Alcamo et al., 2005; zu Ermgassen, Mukherjee, et al., 2020). Thus, recognizing the economic significance of coastal ecosystems has become a driving force behind conservation efforts at a global scale (UNEP, 2022). Policymakers, recognizing the substantial economic benefits at stake, are increasingly implementing measures to protect these vital habitats, reflecting a growing understanding of the connection between healthy ecosystems and a sustainable economy. However, a general and comprehensive assessment of coastal ecosystems is missing and for mega biodiverse countries like Colombia a set of questions can emerge: are the coastal ecosystems' conservation efforts enough? what happens with the already lost and degraded areas? What are the consequences of mangrove loss for human wellbeing? Both, now and for future generations?

One can anticipate that eventually, these ecosystems will have a natural recovery. Nonetheless, will this happen in a human lifetime frame? or what can be done to stop and reverse ecosystem degradation? and What are the costs and benefits of these interventions? This crucial role of ecosystems and biodiversity has been a topic to reflect in the Convention of Biological Diversity CBD) COP15, where governments have agreed on supporting not only conservation but also restoration in “at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity” (UNEP, 2022). Moreover, the UN Decade for Restoration aims to prevent, end, and reverse ecosystem degradation to contribute to poverty alleviation climate change mitigation and prevent the global extinction of species (UNEP, 2023).

Among coastal ecosystems, mangroves are distinguished by their intertidal habitats and are essential to coastal areas around the globe. These ecosystems offer a variety of ecosystem services, such as safeguarding coastlines, storing carbon, and providing vital nursery grounds for various marine species, including endangered species (Barbier et al., 2011; Spalding & Leal, 2021). In addition to their ecological significance, mangroves are crucial to many coastal communities' socioeconomic well-being, especially in Latin America and the Caribbean, where rural communities are highly dependent on natural resource extraction (Carr et al., 2009). Mangroves play a vital role in the livelihoods of local communities by offering resources for subsistence and income generation (Carrasquilla-Henao & Juanes, 2017).

Despite its relevance, nearly one-third of global mangroves had disappeared by the early 2000s due to a variety of factors, including natural causes like sea level rise and erosion, as well as human activities such as deforestation, land use changes, fragmentation, and pollution (Friess et al., 2019). This loss has resulted in a decline in the ecosystem services provided by mangroves and has had a negative impact on a diverse array of species, impacting negatively local communities' livelihoods (Friess et al., 2019; zu Ermgassen, Mukherjee, et al., 2020).

To avoid the loss of mangrove areas and their ecosystem services, decision-makers must recognize the value of mangrove ecosystem services and take action to implement planning and management strategies, including restoration, to achieve important objectives including protecting biodiversity, mitigating climate change, and promoting sustainable development. Hence, restoration efforts helping to improve the functions of mangrove ecosystems (Barbier et al., 2011; Romañach et al., 2018; Su et al., 2021) deserve to be economically assessed and strategically planned.

Su et al. (2021) identified 26 studies evaluating mangrove restoration economic costs and benefits concluding that mangrove restoration exhibits a positive cost-benefit ratio, presenting this as a highly cost-effective management measure for coastal ecosystems (Sinclair et al., 2021). In the revision by Su et al. (2021), only two studies refer to mangroves in North and South America, one in Florida (Russell & Greening, 2013), and one in Brazil (de Rezende et al., 2015). These studies use methods like replacement costs and choice experiment methods to value benefits such as water quality improvement and biodiversity. However, none of the reviewed studies considers the direct contributions of mangrove restoration actions for the livelihoods of local communities in this region.

Most of the empirical literature generating evidence on mangroves concentrates on Asia, with a focus on the valuation of regulating and provisioning services from the conservation actions (Brander, Wagtendonk, et al., 2012). However, the evidence for Latin American and Caribbean countries is limited, even though they hold around 14% of the global mangrove cover (Brander, Wagtendonk, et al., 2012; Chaikumbung et al., 2016; Spalding & Leal, 2021), and therefore decision-makers struggle to incorporate the full extent of economic benefits in their policy choices. Moreover, Colombia, which holds 2% of the global mangrove cover and has two coasts (Pacific and Caribbean), usually relies on values transferred from other geographical zones when it comes to making decisions over land use and mangroves management strategies (i.e. conservation or restoration of mangroves versus grey infrastructure development) (Hamilton & Casey, 2016; Mads, 2018; Prato & Reyna, 2015).

This doctoral thesis aims to comprehensively evaluate the economic value of ecosystem services derived from mangroves in Latin America and the Caribbean, with a primary focus on a case study in Colombia, where specific attention is also dedicated to the values held by local communities. This will contribute to the existing knowledge of mangrove valuation studies and establish baseline values for sustainable development, conservation, and restoration initiatives in Colombia. The first chapter presents a systematic review of mangrove economic valuation studies that specifically focus on Latin American and Caribbean countries. With this, a meta-analysis of mangrove valuation studies is performed to assess mangrove values in a network of protected areas in Colombia through a benefit transfer valuation approach. Additionally, the meta-regression function is used to estimate the advantages of restoring one of the most critical coastal lagoons in the Colombian Caribbean, Cienaga Grande de Santa Marta (CGSM). Following this, the second chapter presents an assessment of how mangrove areas gained through the restoration process contribute to artisanal fisheries and revenues of local communities, using the production function method valuing the nursery function as an input factor in this economic activity.

Finally, the last chapter gains an understanding of factors influencing preference for mangrove restoration improvements when local beneficiaries with knowledge of precedent restoration activities are questioned. Hence, in chapter three a stated preference approach with a choice experiment survey is used to analyse the preferences of beneficiaries in CGSM, including local communities, on the improvement of the restoration programme in the future. Three main restoration outcomes are presented as attributes including mangrove cover, fisheries productivity, and biodiversity. The choice experiment includes two payment vehicles that allow capturing willingness to contribute from users with different socioeconomic backgrounds (i.e. rural communities versus urban populations). This approach aims to provide a perspective on the economic implications of mangrove restoration efforts, with specific attention to their impact on local communities. Given the socio-economic challenges faced by many Colombian coastal communities, where on average 35% (DANE, 2021) of the population has at least one unsatisfied basic need (i.e. housing, basic services, economic dependence), an evaluation of the economic benefits of mangrove restoration can offer valuable insights for policy-makers, resource managers, and restoration practitioners.

Chapter 1. The value of mangrove restoration in the Colombian Caribbean: A Meta-regression of Latin American and Caribbean mangrove valuation for benefit transfer

1.1 Introduction

Coastal areas sustain more than a third of the world's population (Carpenter et al., 2006), and most social and economic activities rely on goods and services provided by coastal ecosystems like mangroves. Mangroves are coastal wetlands that offer multiple ecosystem services, including, among others, raw materials for construction and fuel, food provision, coastal protection, carbon capture and storage, water quality regulation and habitat for multiple organisms (Brander, Wagtendonk, et al., 2012; Mitra, 2020; Rönnbäck, 1999). In the past two decades, the research on mangrove ecology has increased to reveal that mangroves provide the necessary habitat for several key organisms, including fish and birds (Carrasquilla-Henao & Juanes, 2017; Mitra, 2020; Nagelkerken et al., 2008). At the same time, researchers recognize mangroves' key role in climate change mitigation and adaptation strategies, as their rate of carbon capture and storage is significantly higher than in Amazon forests (Sasmito et al., 2019). Mangroves are also important to sustain the coastal line and protect it from hazards such as floods, coastal erosion, storms, and hurricanes, (Bao, 2011; Blanco-Libreros & Álvarez-León, 2019; Sasmito et al., 2016; Woodroffe et al., 2016). Friess et al. (2019) reported that by 2010, 35% of mangrove cover was lost, due to aquaculture, wood extraction, water diversion and tourism facilities. Hamilton and Casey (2016) claimed that despite the rates of mangrove loss having decreased in the new millennium, mangrove cover keeps being reduced at a rate of 0.2-0.6% per year.

To revert this trend is crucial that decision-makers understand the values of mangrove ecosystem services and implement planning and management strategies like restoration, that support social and economic development in coastal areas avoiding the loss of key mangrove areas (Barbier, 2012; Barbier et al., 2011). In the past decades., several studies valued mangrove ecosystem services, recognizing the importance of regulating and provisioning services with, specific attention to Asia (Himes-Cornell et al., 2018). Less evidence of mangroves' economic importance is available for decision-makers in Latin American and Caribbean countries although they concentrate approximately 14% of the global mangrove cover (Brander, Wagtendonk, et al., 2012; Chaikumbung et al., 2016; Spalding & Leal, 2021). Among Latin American and Caribbean countries, Colombia holds 2% of the global mangrove cover, being the fourth country with the most mangrove forest cover in Latin America, preceded by Brazil, Mexico and Venezuela (Hamilton & Casey, 2016; MADS, 2023c). Being a megadiverse country with two coasts (Pacific and Caribbean), Colombia concentrates a variety of mangrove species similar to South-East Asia hotspots, however, this geographical area has been less researched in terms of mangroves' ecology and economy (Castellanos-Galindo et al., 2020).

In this chapter, the goal is to contribute to the current literature on mangrove valuation studies and establish benchmark values for conservation and restoration efforts and sustainable development in Colombia. To achieve this, a systematic review of mangrove economic valuation studies that focus on South America is conducted. Next, the research develops a meta-analysis of mangrove valuation studies, obtaining a meta-regression function to apply a benefit transfer valuation in Colombia. Values for the network of marine protected areas, as well as the benefits of restoration in the most critical coastal lagoon in the Colombian Caribbean are estimated. The results of this study can aid in decision-making that supports the livelihoods of communities in Colombian mangrove areas.

The Colombian government has promoted the creation of 24 Marine Protected Areas (MPA) with mangroves in the Caribbean, Pacific and Islands of Colombia (Alonso et al., 2016); likewise, civil society reserves from private initiatives (i.e. private land with relevant natural attributes that are preserved by landowners usually receiving reductions in land taxes) have contributed to the MPAs network for mangrove conservation in the country. In general terms, pacific areas are less developed, and mangrove areas tend to be larger and less fragmented by grey infrastructure than on the Caribbean coast and Island sites. Other initiatives to promote mangrove sustainability have gained some ground, including blue carbon and nature-based solutions, increasing mangrove areas under protection and management (i.e. Payment for Ecosystem Services (PES) schemes based on carbon storage service). The conservation and sustainable use of mangroves can contribute to reducing greenhouse gas (GHG) emissions and reaching the Paris Agreement goals (20% reduction in GHG (IDEAM et al., 2016) as well as fulfilling the 30 by 30 restoration and conservation Convention of Biological Diversity targets (UNEP, 2022).

The lack of resources to undertake primary economic valuation studies on mangrove benefits promotes, among institutions, the diffused use of quick valuation approaches mainly based on market values or single values benefit transfer. Consequently, the lack of accurate and robust estimations of mangrove values is leading to less effective actions for mangrove management in favour of grey investments (Torres Guevara, 2015). For example, Sánchez-Núñez (2019) reported that the most important lagoon in the Colombian Caribbean, “Cienaga Grande de Santa Marta”, was altered to build the highways that interrupted the river and seawater flows. Likewise, Rojas et al. (2019) analysed the environmental costs of the potential construction of a deep-water port project on the Colombian Pacific coast. Both investments have led and can lead to the loss of vital ecosystem services for supporting local economic activities.

In this chapter, the valuation of Colombian mangroves is conducted through the benefit transfer meta-analysis method, which allows the identification and systematic test of mangroves' socio-economic and spatial attributes (i.e. population, income, and land cover around mangrove areas), and the estimation of a refined economic value informed by secondary data analysis. The results can help to identify key ecosystem services for restoration and conservation efforts and inform decision-makers on priority actions. Moreover, the benefit transfer meta-regression can expand the valuation tools available for government institutions and provide accessible estimates for mangrove ecosystems[1].

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[1]The Coastal and Marine Research Institute of Colombia (INVEMAR) developed the Information

1.2 Wetlands and mangrove meta-analysis

The purpose of meta-analysis for wetlands has evolved from synthesising and reviewing the literature from previous primary studies, to exploring the factors that influence wetlands values, and recently to producing and proposing a methodological improvement to benefit transfer meta-regression function application. Water regulation and supply, flood control, habitat and biodiversity, food provision, raw materials, and recreation are the most frequently studies ecosystem services in meta-analysis. At least 18 meta-analyses have been developed for wetland ecosystems including mangroves, but just two have been done specifically for mangroves ecosystems (Brander, Wagtendonk, et al., 2012; Salem & Mercer, 2012). Regarding the geographical distribution of the values reported, most of the primary studies are from Asia (~30%) and North America (~40%) (see Table 1-1).

Table 1-1. Meta-analysis for wetland economic valuation.

Authors	**Ecosystem**	**Geographic area**	**Number of studies**	**Number of obs.**
(Brouwer et al., 1997)	Wetlands	North America Europe (Developed countries)	30	103
(Woodward & Wui, 2001)	Wetlands	Not specified	39	65
(Brander et al., 2006)	Wetlands	Australia (7), Africa (16), Asia (46), Europe (23), South America (12), North America (111)	80	215
(Borisova-Kidder, 2006)	Wetlands	North America	30	--
(Liu et al., 2008)	Coastal ecosystem services	North America, Asia, Oceania, South America, Europe	39	120

System for the Management of Mangroves in Colombia. (SIGMA for its acronym in Spanish), which collects information from the national monitoring of mangroves condition, undertaken by local environmental authorities. The goods and services module of the platform expect to incorporate information about mangroves ecosystem services values and its contribution to economic activities, which will be available to policymakers to be incorporated in planning and management instruments.

Authors	Ecosystem	Geographic area	Number of studies	Number of obs.
(Ghermandi et al., 2009)	Natural and man-made wetlands	North America (129), Asia (89), Europe (80), Africa (53), South America (18), and Australasia (16)	167	385
(Moeltner & Woodward, 2009)	Wetlands	North America	9	12
(Brouwer, 2009)	Wetlands and rivers	Australia	--	--
(Chen, 2010)	Natural and man-made wetlands	North America	30	--
(Enjolras & Boisson, 2010)	Coastal lagoons	North America (54), Europe (12), Australia (1)	32	67
(Ghermandi et al., 2011)	Natural and man-made wetlands	North America (132), Asia (106), Europe (93), Africa (53), South America (22), Australia (16)	170	422
(Salem & Mercer, 2012)	Mangrove	Thailand, Asia (Excl Thailand), Middle East and Africa, America, Other (Fiji/Micronesia)	44	145
(Brander, Wagtendonk, et al., 2012)	Mangrove	Oceania (5), Africa (11), Southeast Asia (61), South Asia (21), South America (18), North America (14)	41	130
(Brander, Bräuer, et al., 2012)	Wetlands in the temperate climate zone	Template climate zone	120	222
(Camacho-Valdez et al., 2013)	Natural and Constructed Wetlands	North America (132), Asia (106), Europe (93), Africa (53), South America (22), Australia (16)	170	418
(Sen et al., 2014)	Habitats for recreation including wetlands	Not specified	98	297
(Bu et al., 2014)	Wetlands	North America	67	163
(Chaikumbung et al., 2016)	Wetlands in developing countries	Southeast Asia (174), Africa (81), South Asia (68), Latin America (33), Middle East (22), North Africa (1)	379	1432

Results across wetland meta-analysis tend to be consistent: decreasing returns to scale, with a negative and inelastic relationship between wetlands values and its total area, substitute relationship with other wetlands areas in the vicinity, and positive and significant role of population and income in the estimated values. For studies that do not differentiate mangrove ecosystems but include them in a wider category of wetlands, such as estuarine, seawater or marine wetlands, some of them report a positive influence of this category (mangrove) in the estimated value (Chaikumbung et al., 2016; Ghermandi et al., 2009), while others report non-significant results of this type of wetlands in the meta-regression (Brander et al., 2006).

Regarding mangrove meta-analysis, Salem and Mercer (2012) focused on the examination of factors that determine mangrove economic valuation, mainly from methodological characteristics, using 145 observations from 44 primary studies. On the other Brander, Wagtendonk, et al. (2012) stand out as the first study to estimate a value for the change in ecosystem services provision due to the loss of mangrove areas in Southeast Asia, using a benefit transfer meta-regression function. In this paper, they reported 130 observations from 41 studies. Both meta-analyses pooled primary studies mainly from Asia, and present similar analyses and methods, including variables that describe the ecosystem (mangrove size and ecosystem services), study (type of value and valuation method), and socioeconomic (income as GDP per capita) characteristics. However, just in Salem and Mercer (2012) variables denoting the country (Asia excluding Thailand) and protection status resulted significant for the value estimation (negative and positive respectively) as well as the interaction between income (GDP per capita) and ecosystem services (forestry, coastal protection and non-use). In Brander et al., (2012) the implementation of GIS tools improved the analysis and supported the inclusion of context and socio-economic variables (mangrove abundance, roads, and population density) that were significant in the model estimation and relevant for benefit transfer application

1.3 Methods

1.3.1 Benefit transfer meta-analysis method

The benefit transfer method is defined as the use of pre-existing primary data results to estimate economic values for new sites or policy contexts. Benefit transfer can be done by transferring singular values or more complex functions (derived from a single or a set of primary studies). The researcher can use a benefit transfer function to estimate a welfare measure adjusted to the selected characteristics of the new site or policy site (Rolfe, Brouwer, et al., 2015). Meta-regression is the statistical technique used to build the meta-analysis function, where the dependent variable is usually a welfare measure that is commensurable across the primary studies (Nelson, 2015), in this study the welfare measure is the estimated annual mangrove value per hectare from primary studies (similarly to Brander, Wagtendonk, et al. (2012)). The explanatory variables in the model represent the site, population, natural resources, and study characteristics from the primary studies.

One of the advantages of this method is the capacity to summarize information from multiple studies and, at the same time, to control for observable heterogeneity and specific features of primary studies increasing the accuracy of benefit transfer results (Rolfe, Johnston, et al., 2015). The method has to fulfil some requirements to satisfy the accuracy of values: i) similarities between primary studies characteristics and policy sites, these include biophysical conditions, population characteristics, and the scale of the environmental change valued and ii) validity of primary data results, related with the adequate application of valuation methods (Rolfe, Johnston, et al., 2015). In this research, primary studies from a socio-economic, geographic, and cultural area (Latin America) similar to the policy area (Colombia) are used, just considering primary studies with complete information that have been generated by recognised institutions (i.e. Universities and research centers).

1.3.2 Systematic review process

The first step for the meta-analysis was a systematic literature review of empirical economic valuation studies, reporting information about the values of mangroves. Once the studies were collected, the method required carefully identifying the appropriate information to be extracted, and how this information should be standardized to create comparable measures across studies (Nelson, 2015; Nelson & Kennedy, 2009). The selection of primary studies for this paper was framed following Moher et al. (2010) guidelines, previous systematic reviews for mangrove ecosystem services (Himes-Cornell et al., 2018) as well as meta-regression guidelines for economic analysis proposed by Stanley et al. (2013). According to Nelson and Kennedy (2009), the diversification of sources of primary studies, including grey literature such as institutional reports and thesis, can help to increase the sample size and handle publication bias in meta-analysis, which is related to the fact that publication and non-publication of empirical studies are frequently limited by the statistical significance of the estimation reported. A digital search was therefore made in common databases (Scopus, ScienceDirect, and Google Scholar), in Colombian and Latin American journals databases, such as Latintex, Scielo, Dialnet, and CLASE, and in university repositories. Finally, a list of environmental economists in Latin America was contacted directly to gain access to their published and unpublished studies (see Figure 1-1).

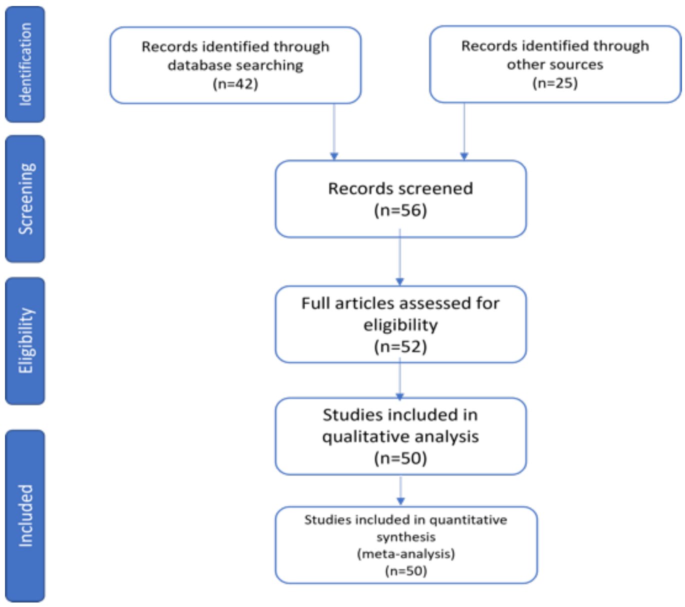

Figure 1-1. Systematic review process.

Initial criteria for study selection were: i) to be a primary economic valuation study; ii) be published in a specific year (between 1990 and 2020); iii) to be in a specific and identifiable geographical location (giving priority to Colombian and Latin American and the Caribbean studies); and iv) reporting at least one value estimation for mangroves ecosystem services in a monetary unit. The studies identified at an initial stage that did not comply with these criteria and did not report enough information to standardise the values were discarded during the screening and eligibility stages. The compiled dataset included the year of publication, type of publication (i.e. paper, report, thesis or other), values reported per each ecosystem service, using the TEEB classification (de Groot et al., 2010), the valuation method(s) used, the mangrove area, and beneficiaries (number and type, when reported). Most of these variables could be extracted directly from primary studies and/or obtained from external sources, such as public records or other publications. Spatial information was also collected for each mangrove site, including significant variables in previous studies such as the abundance of other mangrove areas, and road density around the main mangrove, this data was obtained from public records (Bunting et al., 2018; INVEMAR, 2014). Finally, socioeconomic variables like population density and GDP per capita were included relying on official data services (CIESIN, 2018; World Bank, 2021). Spatial variables were linked to each site and study year and processed with QGIS software. The estimated value reported by the primary studies was then standardised to annual value per hectare per total of beneficiaries in 2019 international dollars using World Bank information and the standardization process used in the Ecosystem Services Valuation Database (ESVD) (de Groot et al., 2020).

1.3.3 Meta-regression model specification

The meta-regression function allows controlling for factual or observable heterogeneity, methodological diversity, and possible biases in primary studies. There is a trade-off between the inclusion of more studies and the homogeneity of the sample in a meta-regression. Heterogeneity can be managed depending on the source of those differences, this is, when the sources of differences are observable, these can be included in the meta-regression as control variables (Borenstein et al., 2010; Chaikumbung et al., 2016; Nelson, 2015; Nelson & Kennedy, 2009). This research procures enough studies from similar geographical locations in Latin America and the Caribbean countries while controlling for other observable sources of heterogeneity like the ecosystem services value, the type of study or more specific site-related characteristics.

As described previously, the dependent variable is the standardized value per hectare per year in 2019 international dollars. Four groups of independent variables were tested: i) Ecosystem services, ii) study characteristics, iii) socioeconomic variables and iv) site characteristics. Each value is linked to an ecosystem service and is included in a primary study, which is also included in a region[2]. Therefore the data is configured in a hierarchical format and alternative stratification options were possible (Rolfe, Brouwer, et al., 2015). Among the explanatory variables, there are individual observation level variables X_{ij} (Ecosystem services) and grouping level or study level variables Z_j (i.e. study characteristics, site characteristics, and socioeconomic variables).

The meta-regression model for mangroves' economic valuation in Latin America is as follows:

$$y_{ij} = \alpha + \beta_x X_{ij} + \beta_{z_1} Z_{1j} + \beta_{z_2} Z_{2j} + \beta_{z_3} Z_{3j} + \beta_{z_3 x_{ij}} Z_{3j} X_{ij} + \mu_{xj} X_{ij} + \mu_j + c_{ij} \quad (1)$$

Where:

y_{ij} represents the $i = 1 \ldots . n$ individual estimated value from primary studies and standardized accordingly with the meta-regression protocols, in the $j = 1 \ldots . J$ primary study which constitutes the second level in our multilevel model. α is a constant term.

X_{ij} represents the individual level variables specified as dummies for each ecosystem service.

Z_{1j} represents the study characteristics (i.e. publication year and type of publication).

[2] Region variable indicates in which region is the primary study taking place, North America, Central America, South America, or Colombia. Colombia is included as a category given that the systematic search focused on this country, and it is the policy site for benefit transfer application.

Z_{2j} represents the socioeconomic characteristics (i.e. population density and GDP per capita).

Z_{3j} refers to the site characteristics (i.e. Mangrove size (area), other mangroves' size (area) and road length).

μ_j is a random residual error at the study level and it is assumed to be independent of the residual error at the value level c_{ij} (Bergstrom & Taylor, 2006; Brander, Bräuer, et al., 2012; Brander, Wagtendonk, et al., 2012; Hox et al., 2017; Nelson, 2015; Rolfe, Brouwer, et al., 2015).

Moreover, following the modelling specification by Hox et al. (2017) interactions between levels were included, as the study level variables act as moderator variables between level 1 variables and the outcome (values). Hence, $Z_{3j}X_{ij}$ represents the interaction between ecosystem services and site characteristics. Likewise, a random slope for ecosystem service was included, allowing variability in the relationship between this variable and the values, this is, adding the term $\mu_{xj}X_{ij}$ where μ_{xj} is different for every group. Coefficient estimation was done using a linear mixed effects model in the statistic software R using the lmer and lmerTest packages (Bates et al., 2015; Kuznetsova et al., 2017).

Finally, to test the validity of the benefit transfer function it was necessary to account for internal and external validity or the transfer error. The internal validity was measured through the Mean Absolute Percentage Error (MAPE), defined as the mean of $[y_{ij} - \hat{y}_{ij}]/y_{ij}$. The external validity for benefit transfer was tested through convergent validity, this is, comparing the estimates from meta-regression with primary valuation results; one way to undertake this was using a data-splitting technique that estimates n-1 functions to predict the values excluded from the sample and measuring the MAPE for this estimations (Chaikumbung et al., 2016; Salem & Mercer, 2012).

1.4 Results

1.4.1 Systematic review of mangrove economic valuation in Latin America

As a result of the systematic review, 67 mangrove valuation studies were identified, from which 56 were screened, and finally, 50 were selected and included in the meta-analysis database. On average each study reported 3 value estimates for the same or different ecosystem services (primarily valued with market-based methods), which leads to a total of 153 observations (see A.1), excluding outliers. The geographical distribution of the studies is presented in Figure 1-2 with Colombia being the country with the most studies in the database (≈ 50%).

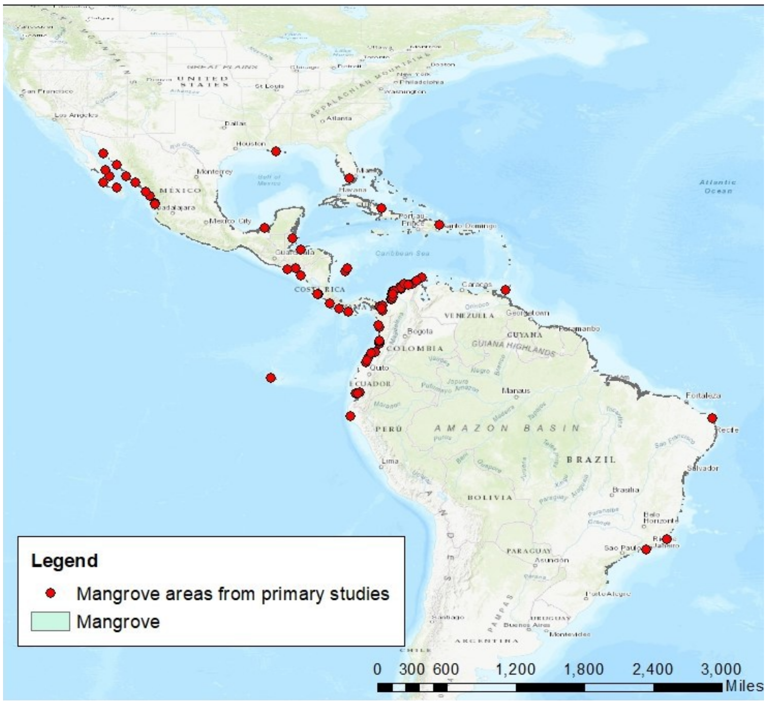

Figure 1-2. Geographical distribution of primary studies.

The ecosystem services most frequently assessed in Latin America and the Caribbean are food provision through fisheries and recreation; while the economic valuation methodologies most frequently used are those using market values (i.e. market prices and Net Factor Income), followed by stated preferences techniques like contingent valuation and choice experiments (see Figure 1-3).

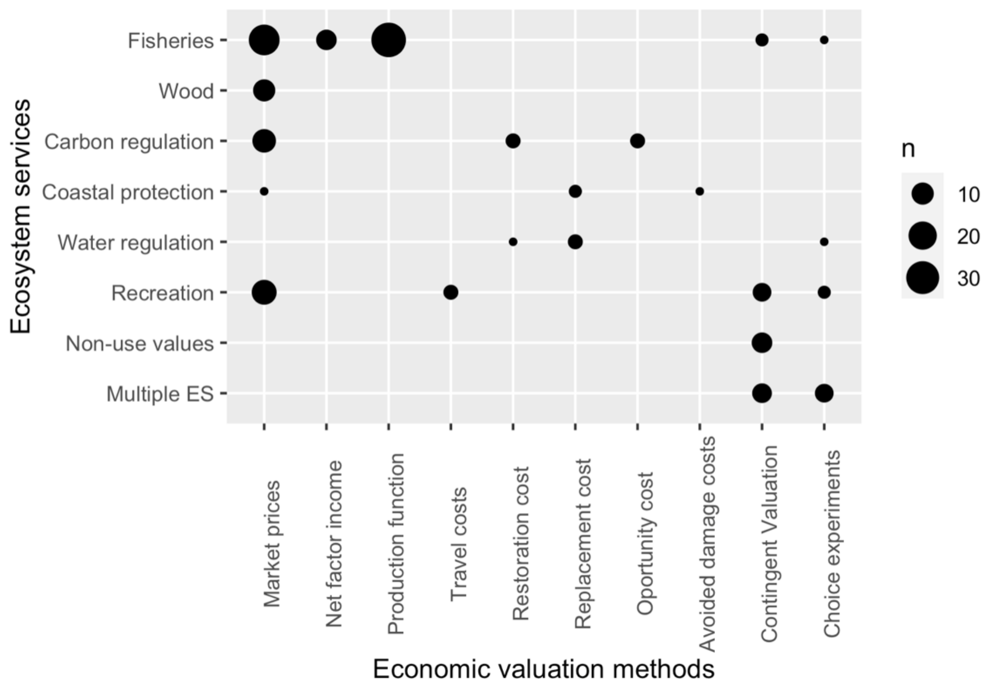

Figure 1-3. Distribution of ecosystem services and valuation methods.

Values reported in primary studies have a mean of US$10,018 per hectare per year, and a median of US$182, hence this is a right-skewed distribution. The distribution of values by method and ecosystem services showed that on average cost methods exhibit higher values than the rest, however, stated preference methods and market price methods reported higher variability (i.e. a range of US$34,900/ha/year). Regarding the valued services, 82% of the studies reported individual values for ecosystem services, and among these, regulating services reported the highest values on average, however, it is important to acknowledge that the proportion of the sample for this type of ecosystem services was small. Provisioning services reported the lowest values per hectare, although a higher variability in this sub-sample was also observed (see Figure 1-4 and Figure 1-5).

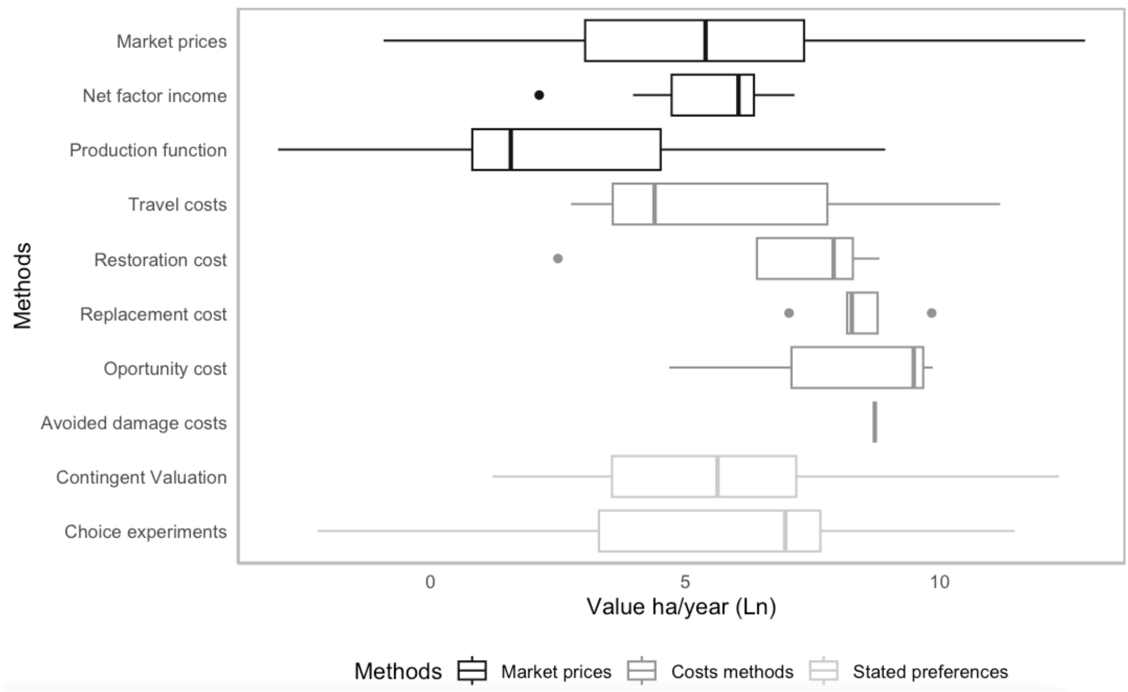

Figure 1-4. Mean value per valuation method.

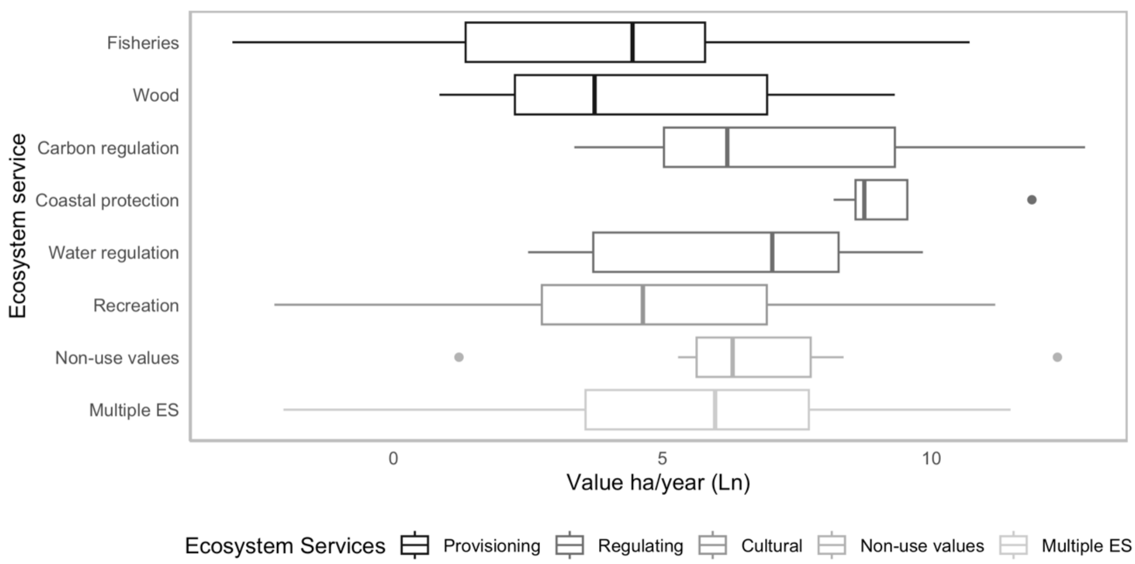

Figure 1-5. Mean value per ecosystem service.

1.4.2 Meta-regression model

Ecosystem services were included as dummies, and recreation was the omitted category. Valuation methods were not significant and were correlated with the ecosystem services valued, hence were not included in the reduced form of the meta-regression. This model also controlled for the type of publication, including dummies for papers and reports, leaving another type of publication (i.e. thesis and conference proceedings) as the omitted category. Additionally, a control for the publication year using dummies was included. Other independent variables were mangrove area, other mangrove patches in a radius of 50km from the centroid of the study site, roads within a 50 km radius from the study site, GDP per capita and population within a 50 km radius from the study site, all these expressed in logarithm values, following previous meta-regressions for mangroves economic valuation. Table 1-2 depicts the number of observations, the mean and standard deviation for the dependent and explanatory variables used in the meta-regression model.

Table 1-2. Descriptive statistics for economic valuation studies variables.

Variable	Description	n	Mean	St. Dev.
Annual value per hectare (ln)	Annual value per hectare (ln) & Monetary measure reported by primary valuation studies, standardized to value per hectare per year in 2019 international dollars in logarithmic form	153	5.01	3.53
Publication year	Year of publication of the primary studies from 1994 to 2019	153	--	--
Paper	Dummy for valuation studies published in academic journals	50	0.33	0.47
Report	Dummy for valuation studies presented as report	34	0.22	0.42
Other	Dummy for valuation studies presented as other type of publication like thesis, conference proceedings and working papers	69	0.45	0.43
Market prices	Dummy for values estimated with market prices valuation method	62	0.41	0.49
Net Factor Income	Dummy for values estimated with net factor income valuation method	8	0.05	0.22
Production function	Dummy for values estimated with production function valuation method	34	0.22	0.42
Opportunity cost	Dummy for values estimated with opportunity costs method	3	0.02	0.14
Replacement cost	Dummy for values estimated with replacement cost valuation method	5	0.03	0.18
Restoration cost	Dummy for values estimated with restoration cost valuation method	4	0.03	0.16
Avoided damage cost	Dummy for values estimated with avoided damage valuation method	1	0.01	0.08
Travel cost	Dummy for values estimated with travel cost valuation method	3	0.02	0.14
Contingent valuation	Dummy for values estimated with contingent valuation method	23	0.15	0.36
Choice experiment	Dummy for values estimated with choice experiment valuation method	10	0.07	0.25
Fisheries	Provision of food from fish	70	0.46	0.5
Timber	Provision of wood as firewood or timber for construction	10	0.07	0.25
Carbon regulation	Dummy for values of carbon stock and carbon sequestration in mangroves biomass and soil	18	0.12	0.32

Variable	Description	n	Mean	St. Dev.
Coastal protection	Dummy for values of protection of the coastline against extreme events	4	0.03	0.16
Water quality	Dummy for values of regulation of water quality	5	0.03	0.18
Recreation	Dummy for values of opportunities for recreation and tourism	25	0.16	0.37
Non-use values	Dummy for values that do not represent use of ecosystem services	8	0.05	0.22
Multiple ecosystem services	Dummy for values reported for more than one ecosystem service	13	0.08	0.28
Mangrove Area (ha/Ln)	Natural logarithm of mangrove area in hectare. This information was obtained from the Global Mangrove Watch indicator on mangrove cover reported for the most proximate year to the publication year of the study.	153	8.51	1.94
Mangrove abundance (ha/Ln)	Natural logarithm of the area in hectares of other mangroves patch in a radius of 50 km from the main mangrove area centroid. This information was obtained from the Global Mangrove Watch indicator on mangrove cover reported for the most proximate year to the publication year of the study.	153	8.2	4.63
Road's length (km/Ln)	Natural logarithm of Km of roads in a radius of 50 km from the main mangrove area centroid	153	6.33	1.41
GDP per capita (US$/Ln)	Natural logarithm of the GDP per capita in 2019 international dollars per each country or region, for the publication or study year.	153	9.37	0.58
Population density (Ln)	Natural logarithm of the average of population density within a 50km radius from the main mangrove area centroid, for the publication or study year.	153	5.87	1.86

Table 1-3 presents the best-fitted meta-regression function for the economic valuation of mangroves in Latin America. Only fisheries, carbon regulation and coastal protection ecosystem services coefficients resulted in statistical significance when the omitted category is recreation. Estimations for non-use values and regulation services (carbon regulation, coastal protection, and water regulation) are positively correlated with the value per hectare of mangrove; on the other hand, provision ecosystem services (Fish and wood) are negatively correlated with the value per hectare of mangroves. The coefficients

(β) can be interpreted as the percentage of change in the value per hectare when valuing each ecosystem service (for example when valuing coastal protection, we would expect the value per hectare to increase by 2.89%). Likewise, when valuing fishing support, we would expect the average value per hectare across all groups to be reduced by 11%, however, we might find groups where the value per hectare could be reduced by a lower or larger percentage when valuing this ecosystem service, as we introduced a random slope for fisheries ecosystem service to capture this variability. The random slope for fisheries ecosystem service (μ_{xj}) is significant, meaning that the effect of this ecosystem service over the value estimated in primary studies is not constant across different studies. Instead, it varies in a way that is captured by the random effect. The covariance between the random effects, this is, the covariance between intercepts and slopes for the studies shows that the studies that have a large random slope (μ_x) are expected to have a smaller random intercept (μ_j), this means that when valuing fisheries, the study random intercept is lower.

On the other hand, the effect of the mangrove size is conditioned by the type of ecosystem services being valued (e.g. provisioning ecosystem services), so introducing interactions between ecosystem services and the mangrove size, resulted in only the interaction with fisheries being significant for the model, (0.02 p-value), hence, when valuing fish provision the average total effects of a change in 1% of mangrove area across studies, is 0.96%, this means that bigger areas of mangrove can be directly related with more carrying capacity per hectare for fish production. Regarding other ecosystem services, the interaction with mangrove size was not significant. On the other hand, the average effect of a 1% change in the mangrove area over value when valuing ecosystem services different than provisioning ones is negative and inelastic ($-0.44*$).

As for the socioeconomic variables, the population density presented a positive but inelastic effect on mangrove value, while GDP per capita was positive and elastic, this can be interpreted as mangrove ecosystem value increasing in line with an increment in the number of beneficiaries and their income, in a lower and larger proportion respectively. In relation to the spatial explanatory variables introduced in the model, the sign in the mangrove abundance variable (other patches of mangrove around the area being valued) shows that a 1% more mangrove area around the study site can decrease the value estimated by 0.18% which implies a substitution relationship between neighbouring mangroves areas. There is a negative relationship between the roads and values indicating that fragmented mangroves could have less value per hectare Hence, a 1% increase in road density leads to a 0.78% decrease in mangrove value per hectare.

Table 1-3. Linear mixed model results.

Linear Mixed Model: Value US$ /ha/year (2019)		
Variables	Coefficient	Standard Error
Ecosystem services		
Fisheries	-11.4***	(2.91)
Wood extraction	-10.22	(6.51)
Carbon Regulation	3.53***	(1.02)
Coastal protection	2.89**	(1.45)
Water quality	2.13	(1.34)
Multiple ES	0.06	(1.25)
non-use values	2.37	(1.49)
Socioeconomic variables		
Population Density (Ln)	0.54*	(0.30)
GDP per capita (ln)	1.77*	(0.98)
Spatial variables		
Mangrove Area (ln)	-0.44*	(0.23)
Other mangroves areas (ln)	-0.18	(0.12)
Roads (ln)	-0.78*	(0.44)
Interactions		
Total Mangrove Area: Fisheries	1.4***	(0.32)
Total Mangrove Area: wood	1.23	(0.77)
Study Features		
Paper	0.63	(1.17)
Report	2.3	(1.49)
Year: 1998	−6.93*	(4.16)
Year: 2005	−7.17*	(4.08)
Year: 2018	−11.76**	(5.31)
Intercept	-3.21	(8.14)
Var: Study (Intercept)	4.12	
Var: Study Fisheries	7.52	
Cov: Study (Intercept) Fisheries	-2.53	
Var: Residual	4.35	
Rm	0.44	
Rc	0.75	
Num. obs.	153	
Num. groups: Study	50	

***p < 0.01; **p < 0.05; *p < 0.1

Regarding the study characteristics, the model included years as dummies to capture the effect of specific years over the estimated values. The complete model with years coefficients can be found in A.3. Just 1998, 2005 and 2018 were significant and negatively related to the value per hectare (having 1996 as a reference category). Also, considering the magnitude of coefficients for these years (increasing with the years), recent studies produce lower values per hectare. This can be explained by the priority given to more important sites in the early stages of mangrove's economic valuation, where policymakers were more interested in particular relevant areas to be valued. In relation to the publication type, these variables were not significant. Finally, with a marginal $R^2_{(m)} = 0.44$, fixed effects explained in an acceptable proportion the variability in the values for mangroves, and when accounting for fixed and random effects, the model explained 75% of the variability in values ($R^2_{(c)} = 0.75$).

1.4.3 Benefit transfer for Colombian mangroves

1.4.3.1 System of Marine Protected Areas

To apply the meta-analysis function for benefit transfer in Colombia, this research uses the System of Marine Protected Areas of Colombia as a management unit to provide information on protected areas values to local beneficiaries (i.e. population in a radius of 50km), and better understand the economic contribution of conservation and potential restoration in contrast with other land uses like ports and major infrastructure development. This included those areas managed by Environmental Regional Authorities, the National Natural Parks Administrative Unit, and the Civil Society (RUNAP, 2020). The areas of mangroves for each site were estimated from the Information System for the Management of Mangroves in Colombia. (SIGMA for its acronym in Spanish), as well as the spatial information reported in the National Protected Areas Registry (RUNAP for its acronym in Spanish) (INVEMAR, 2014; RUNAP, 2020). The sites corresponded to protected areas in the Colombian Caribbean and Pacific coasts, as well as the San Andres and Providencia archipelago. Using the new database with the relevant variables from Table 1-3, (ecosystem services, socioeconomic and spatial variables) for each protected area, the corresponding values for mangroves were estimated.

The values estimated for provision, regulation and cultural ecosystem services are illustrated in Figure 1-6 (a list of estimated values can be found in A.5). In general, most areas were valued between US$1/ha/yr and US$370,000/ha/yr, depending on the type of ecosystem service considered. Values larger than US$500.000/ha/yr were mainly for the Islands which have a higher than average (in this sample) population density and GDP per capita. Regulation services are the ones with higher values per hectare, especially carbon regulation (sequestration and stock) and coastal protection, followed by non-use values. Overall, the lowest values estimated were for provision ecosystem services, however, for some large areas (i.e. Sanquianga, VIPIS, SFF CGSM), the value per hectare per year for fish provision is larger than values estimated for recreation ecosystem service; and the opposite happens in smaller areas (i.e. Musichi, Tayrona, SNSM, Old Point and Old Providence). This is a good reflection of the current uses for these mangrove areas, for example, Natural National Park Tayrona is one of the national protected areas that generate more income from ecotourism, while in the sanctuary for flora and fauna Cienaga Grande de Santa Marta, the use is mainly for fisheries support rather than recreative activities (Gómez Cardona et al., 2023; Romero & Cardenas, 2017). Mangroves in the Marine Protected Areas Network in Colombia exhibit mean values between US$138,000/ha/yr and US$324,000/ha/yr per hectare per year depending on the ecosystem service being valued and in which coast (i.e. Pacific, Caribbean or Islands). Estimations report more areas with higher values per hectare per year for carbon sequestration and coastal protection than for recreation and fisheries support services (see Figure 1-6).

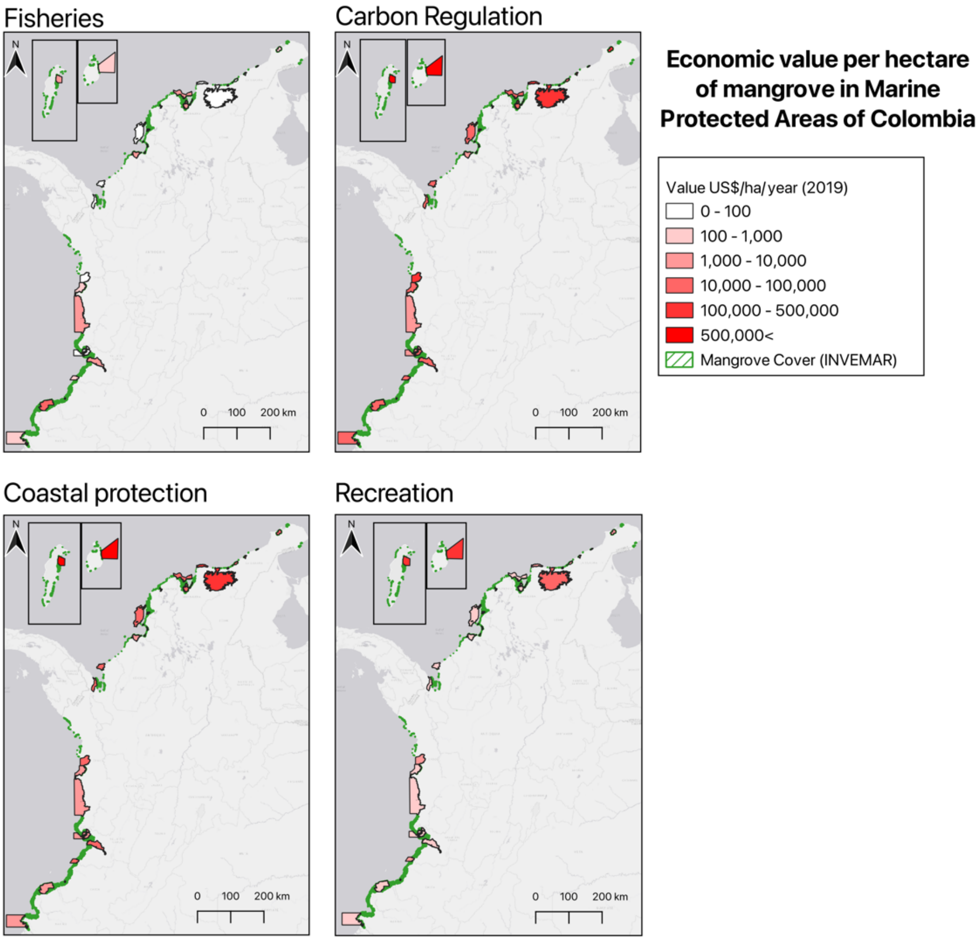

Figure 1-6. Mangrove values for MPAs in Colombia.

1.4.3.2 Restoration in Cienaga Grande de Santa Marta

To apply the values for management evaluation and to analyse possible future management scenarios, this research focuses on the RAMSAR site Cienaga Grande de Santa Marta (RAMSAR, 1998) which is the larger mangrove area in the Colombian Caribbean (see Figure 1-7), with approximately 37,500 hectares of mangrove by 2020 and benefiting at least 3 millions of inhabitants in nearest cities and villages (DANE, 2018; INVEMAR, 2021; Rodríguez-Rodríguez et al., 2016). This site suffered a major degradation process during the second half of the XX century, losing 50% of its cover, and has been the focus of several restoration activities to recover the mangrove ecosystem. To estimate the value of the changes in mangroves the period between 2000 to 2020 is used, as most of the restoration activities took place at the beginning and near to end of this period (Rodríguez-Rodríguez et al., 2021). Using the context variables values for both years (i.e. population density, GDP per capita, mangrove area, mangrove area in the surroundings and road length) and the meta-regression function, estimates for value per hectare per ecosystem service and total value per hectare for each period or scenario were obtained. Following (Brander, Bräuer, et al., 2012) the average value for both years analysed is used (i.e. the average between the values per hectare for 2000 and 2020) and multiplied for the change in the mangrove area (see Table 1-4) to obtain the total value of mangrove change.

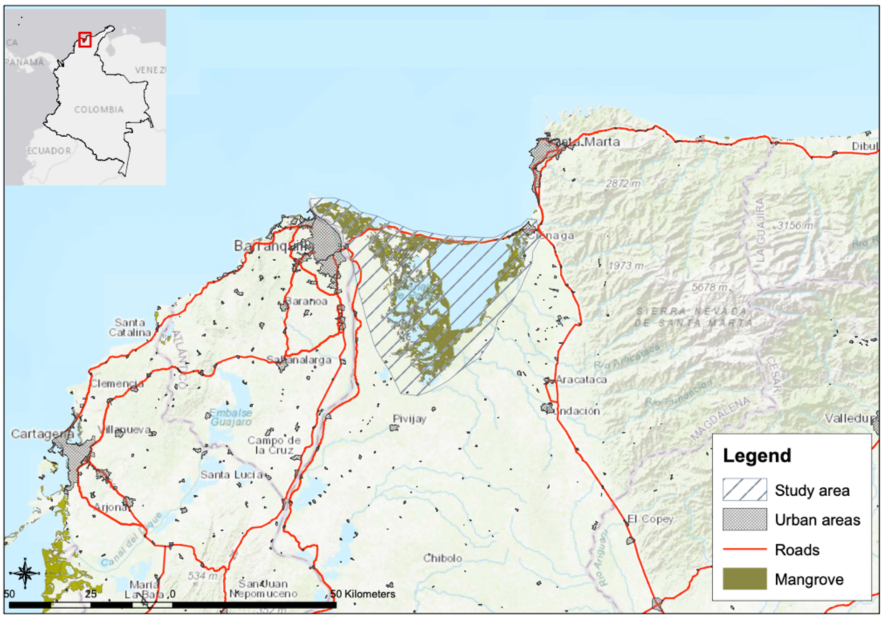

Figure 1-7. Cienaga Grande de Santa Marta.

Additionally, two possible future scenarios for 2030, based on historical changes are presented:

i) An improved restoration scenario, where a Community-Based Ecological Mangrove Restoration (CBEMR) is implemented, considering the higher success rate for this type of program (Rodríguez-Rodríguez et al., 2021); and,

ii) A pessimistic scenario with no restoration activities being developed from 2020.

For the first scenario, there is an improvement in the average change per year of mangrove cover reported in the last 20 years, (up to 800ha/year, equivalent to 8,000 hectares in a 10-year period). In addition, the analysis considers a minimum mangrove annual loss rate of 0.05% which is less than what has been reported in recent years (Hamilton & Casey, 2016); while for the second scenario, it is assumed that without restoration activities the area can face mangrove annual loss rates similar to before restoration in the mid-90s (≈ 2% (Friess et al., 2019)) plus no active recovery of mangrove area is developed. Projections for socioeconomic values (DANE, 2018; OECD, 2021) and spatial variables (i.e. an increase of 10% in road length) are used. Results can be seen in Table 1-4.

Table 1-4. Scenarios assessment for Cienaga Grande de Santa Marta.

Scenario	**Change in mangrove area (ha;000's)**	**Average value/ha (2019; US$000's/year)**	**Value of change (2019; US$ Million)**
Restoration activities 2000-2020	12.0	14.2	91.7
2020 - 2030 Restoration activities as usual	4.0	8.0	31.9
2020 to Improved ecosystem restoration (2030)	7.0	11.1	77.7
2020 to No ecosystem restoration (2030)	-7.9	12.1	-95.7

For the 2000 – 2020 period, the estimated total benefit attributed to mangrove restoration is US$91.7 million. This is the aggregated value from ecosystem services including food provision (fisheries), wood extraction, carbon regulation, coastal protection, water quality regulation, recreation, and non-use values. These benefits represent an increase of 25% in the mangrove total value at the beginning of the period. Moreover, Rodríguez-Rodríguez et al. (2021), reported costs of restoration activities in this period of around US$49 million, which are lower than the benefits here estimated, justifying, and reinforcing the importance of mangrove areas.

Looking forward, if restoration activities are carried on as usual, by 2030 the additional benefits for mangrove cover gains and its ecosystem services can equal US$31.9 million if the recovery trends does not change. Moreover, if an improved restoration program is implemented (i.e. including CBEMR), increasing the area recovered by 7,000 hectares, the equivalent increase in the benefit is US$77.7 million. On the other hand, when assessing a scenario with no restoration activities for the 2020-2030 period, a loss of 7,900 hectares is estimated (considering an annual loss rate of 2%) which represents a loss of US$95.7 million in terms of the value of ecosystem services for the direct beneficiaries, which is equivalent to losing 16% of its current total value.

1.5 Discussion and Conclusions

This chapter provides a comprehensive review of the economic valuation of mangroves in Latin America. This review has focused on Latin American countries' mangroves which account for ~14% of the world's mangrove cover but have not been adequately represented in previous meta-analyses (Brander et al., 2006; Brander, Wagtendonk, et al., 2012; Ghermandi et al., 2009, 2011; Salem & Mercer, 2012). The review revealed that food provision (Fisheries) is the most frequently valued ecosystem service, followed by recreation and carbon regulation, similar to global trends. However, other regularly valued ecosystem services at a global scale, like coastal protection and support of life cycles and biodiversity, do not have a proportional number of case studies for this region. Climate regulation was found to have the highest values per hectare of mangroves; while values for provision-type ecosystem services show a high variability both globally and regionally (Salem & Mercer, 2012).

Regarding the valuation methods, as in previous meta-analysis, in this study market prices has been the most used method, however, in this review, there is a higher proportion of studies using stated preference methods (contingent valuation and choice experiments) than in global meta-analysis (Brander et al., 2006; Brander, Wagtendonk, et al., 2012; Salem & Mercer, 2012). This can be related to the improvement in the stated preferences methodology and the increase in native researchers applying these methods in the last decades. Likewise, this analysis reports that the contingent valuation method yielded a higher mean value than the market prices method, whereas Salem and Mercer (2012) reported a mean value for the market price method three times higher than the contingent valuation method value (US$31 and US$10 thousand per hectare per year respectively), although values elicited with market prices (usually for provision ecosystem services) had a high dispersion in Salem and Mercer (2012) revision.

In terms of the meta-regression results, this chapter presented results consistent with previous mangrove valuation meta-analyses (Brander, Wagtendonk, et al., 2012; Salem & Mercer, 2012) which reported that regulation services (e.g. coastal protection, carbon sequestration, water quality), increase the estimated value compared with other types of ecosystem services (e.g. provisioning). In this study, when comparing with recreation ecosystem service, regulating ecosystem services and non-use values increase the economic value per mangrove hectare, while provisioning ecosystem services (fisheries and wood) reduce the estimated value. On the other hand, Salem and Mercer (2012) concluded that the contingent valuation method estimates the highest values for mangroves compared with other methods, which is consistent with our descriptive analysis. Similarly, here estimated values are sensitive to income effects (i.e. GDP per capita as a proxy of income), and mangrove value increases with the population living in the surroundings, which are considered direct beneficiaries of mangrove ecosystem services.

Results for spatial variables were consistent with those from previous wetland meta-analyses. The coefficient for area presents diminishing returns to scale (Chaikumbung et al., 2016), this is, the value of adding one additional hectare in a small mangrove is higher than the value of adding one hectare in a large mangrove patch (Brander, Bräuer, et al., 2012). However, in this research, the effect of total mangrove area is conditioned by the type of ecosystem service being valued, in fact when fisheries or wood are considered and interacted with mangrove extent, the value per hectare will increase if the total mangrove area increases (see A.2). Finally, more roads or larger roads will have a negative impact on mangrove value. These can also be interpreted as an approximation of the condition for mangrove areas, as water flows are essential for mangroves' health, and more roads in the surroundings interrupt sea and river water flows for mangrove areas (Sánchez-Núñez, 2019).

To validate meta-regression results an in-sample and out-of-sample MAPE was estimated (Brander et al., 2006; Salem & Mercer, 2012). The meta-regression model presents an in-sample MAPE of 40%, which is close to the values reported by Salem and Mercer (2012) (35% to 40%) and Brander et al. (2006) (58%). Likewise, the out-of-sample MAPE of 71.5% is close to the estimates from Brander et al. (2006) and like them, here the average MAPE tends to be higher for larger observed values, and around 14% of the sample got errors lower than 10%, while 18% of the sample got an error larger than 100%. Moreover, for lower values, the meta-regression function tends to over-predict mangrove values, while it tends to under-predict higher mangrove values Brander et al. (2006) (see A.4).

On the other hand, Brander, Wagtendonk, et al. (2012) validate their meta-regression results by applying the benefit transfer function to estimate mangrove change value for the period 2000–2050 in Southeast Asia per country, using information about mangrove size, mangrove abundance, road density, GDP per capita and population for each mangrove sites identified in these countries (Brander, Wagtendonk, et al., 2012). This procedure is emulated here by estimating values for the Colombian Marine Protected Areas System mangroves that also contribute to decision-making for conservation and restoration processes. Results showed that the Pacific Coast mangrove in protected areas exhibit higher values than the Caribbean Coast protected mangroves in term of conservation and in particular for regulating ecosystem services, considering as well that the Pacific Coast has less infrastructure development and population density, hence mangroves are in better conditions. Additionally, the value of the mangrove gained through the restoration has generated an estimated of US$91.7 million in benefits for regulating, provisioning, and cultural ecosystem services, as well as non-use values, estimated through this study's meta-regression function.

Chapter 2. The economic value of mangrove contributions to artisanal fisheries in Cienaga Grande de Santa Marta, Colombia.

2.1 Introduction

Many small-scale fishers in mangrove countries depend on this ecosystem, with over 80% of fishers depending on mangroves in Central and West Africa (zu Ermgassen, Mukherjee, et al., 2020). To investigate the contributions of mangrove restoration efforts to artisanal fisheries this chapter focuses on valuing the capacity of coastal and estuarine wetlands to provide nursery and breeding habitat for commercial species. This ecosystem function acts as an input for harvested fish production, enhancing the productivity of inshore fisheries, which can be valued for their commercial catch (Barbier, 2007; Barbier et al., 2023). The majority of studies applying ecosystem services valuation methods have reported monetary values from benefits derived from this ecosystem service in North, Central and South America (Brander, Wagtendonk, et al., 2012; Himes-Cornell et al., 2018). The value estimation of mangrove contribution to fisheries is highly context-dependent, as the value is directly linked to the commercial species analysed and these can vary from site to site according to the local market preferences, especially for small-scale fisheries. In consequence, this is one of the ecosystem services with the highest variability in values reported, especially when using market-based methods (see Chapter 1: Systematic review). It is then relevant to use methods that estimate the contribution of mangroves to local livelihoods considering the specific setting of fisheries and the scope of the market in the particular site of analysis, like the production function approach (Barbier, 2007).

In Colombia among other South American countries, the mangrove's nursery function that contributes to the fisheries production (Barbier, 2000, 2007; Carrasquilla-Henao & Juanes, 2017) is relevant, not only for the national economy (Cuervo-Sánchez et al., 2014;

Cuervo-Sánchez et al., 2018), but especially for local artisanal fisheries, which are highly dependent on fisheries productivity. Local communities relying on artisanal fisheries are especially vulnerable to shifts in environmental conditions as their livelihoods depend on fish harvest (Matera, 2016). Moreover, most of these communities present a limited income diversification and they struggle to successfully adapt to ecosystem degradation (Béné et al., 2009). Furthermore, artisanal fishery tends to be practiced in rural areas where living conditions are precarious with limited State presence and high deprivation (DANE, 2021).

The aim of this paper is to estimate the contributions of mangrove cover gained through restoration efforts to artisanal fisheries in Cienaga Grande de Santa Marta (CGSM), measuring the economic value of mangrove nursery function as an input factor in this economic activity. The research hypothesis is that the mangroves' cover is positively correlated with fisheries catch and revenues, this is, the marginal productivity of mangroves is positive. It is then possible to use this to assess the benefits of restoration efforts. The results of this analysis provide evidence of the effects of the mangrove restoration (INVEMAR, 2022; Rodriguez-Rodriguez, 2022) on providing ecosystem services to support local communities' livelihoods and inform decision-makers on the importance of continuing and improving the restoration programs in mangrove areas.

The next sections of this chapter describe the empirical literature on mangroves and fisheries in Latin America, following a description of the study area and the production function approach used to analyse the data. Finally results for mangrove marginal productivity for artisanal fishery and contributions from mangrove restoration to fishermen revenues are presented.

2.2 Economic valuation of mangroves and fisheries linkages and mangrove restoration

Most of the applications of production function method to estimate the value of fisheries and mangrove relationship have been done in Southeast Asia (Indonesia, Vietnam and the Philippines) with only some cases in America (Aburto-Oropeza et al., 2008), and one publication in Colombia (Cuervo-Sánchez et al., 2018). Cuervo-Sánchez et al. (2018) estimated the value of the provision of fishing resources from an increase in the system of marine protected areas in Colombia, including those areas with mangrove cover. Using a dynamic approach of the production function method and focusing on the Pacific Coast industrial and artisanal shrimp fisheries, they analysed the fish mobility among a protected and unprotected area, evaluating different scenarios for the reduction of fishing area and increasing of the protected area, as well as changes in catch, effort, biomass, and economic benefits. Finally, they concluded that although there is a reduction in the fishing area, the spillovers from an expansion of the marine protected area increase the available fish biomass and economic benefits associated with the fishing activity in the following 20 years.

Barbier (2007) used a static approach to estimate the values of changes in mangrove areas across five coastal zones in Thailand. He estimated parameters for a log-linear version of a Cobb-Douglas production function and used information on harvest and effort of demersal fisheries and shellfish and mangrove area data from the five sites over a 14-year period. The study compared different regression methods, including ordinary least squares (OLS), panel analysis of fixed and random effects, and maximum likelihood estimation by generalized least squares (GLS). GLS was the preferred method, allowing for corrections of group heteroskedasticity and within and between groups correlation. The paper also reports a welfare loss of approximately US$99,000 for annual loss (~18km2) of mangrove area (FAO, 2003).

Aburto-Oropeza et al. (2008), evaluated the contribution of mangroves to commercial fisheries in the Gulf of California, Mexico. Applying a static approach of the production function method, they estimated the annual value of the mangrove nursery function, using the mangrove fringe area, as well as fisheries data for the main commercial species (blue crabs, grunts, snappers, mullets, among others) in 25 landing points with mangroves in the surroundings (50km radius). They focus on the effects of mangrove changes on fisheries revenues, estimating a median value of US$ 80,614/ha/yr.

In Campeche, Mexico, Barbier and Strand (1998), analysed the connection between mangroves and fisheries in Terminos Lagoon. They used a bioeconomic model for shrimp fisheries to estimate the impact of changes in mangrove cover on carrying capacity and harvest from 1980 to 1990. Their findings showed that the loss of mangroves led to a reduction in harvest and revenue for fishermen. The estimated elasticity for mangroves (2.8) evidenced a high marginal productivity of mangrove habitat in this study case, making that any decline in this ecosystem has a more significant effect on fish catch. Furthermore, they studied the marginal effects of effort, such as the number of vessels, and found that under open-access conditions, the effort has a negative marginal effect (-0.7) over fish harvest. This is evidence of over-exploitation in the region, where the number of vessels nearly doubled in a decade. Their results also showed the need for mangrove protection and proper management of effort intensity to prevent negative effects on harvest and revenue, as they estimated a loss of US$5,330 in annual revenue for each mangrove hectare lost.

Most of these studies evaluated the effects of conservation or loss of the mangrove ecosystem on fisheries, while there are fewer studies evaluating the contributions of mangrove restoration (i.e. recovery of mangrove areas), especially in South America. Su et al. (2021) identified 26 studies evaluating mangroves restoration economic costs and benefits, of which two correspond to study sites in the Americas, in mangroves of Florida (Russell & Greening, 2013), and Brazil (de Rezende et al., 2015) (de Rezende et al., 2015). These studies use methods like replacement costs and choice experiments to value benefits such as denitrification, carbon sequestration and biodiversity. However, there is no published economic valuation using the production function method to estimate the mangrove restoration contribution to artisanal fisheries in Latin America. The majority of the peer-reviewed studies reported by Su et al. (2021) are in South Asia, including those using the production function method to estimate the value of restored mangrove functions. In Western India for example, Das (2017) estimated the contribution of reforested mangroves at a value of US$7002/ha/yr for 817 km^2.

2.3 Methods

To estimate the marginal productivity of mangroves as an input in the artisanal fishery of CGSM, and evaluate the contributions of restored mangroves to fisherman revenues, this research uses the production function method (Barbier, 2007). Considering that there is available data from the monitoring of this area on catch, prices, costs and mangrove cover (INVEMAR, 2022) it is possible to study the relationship between mangrove and fish catch and its value over time, controlling for the characteristics of the fishing activity like effort and fishing technology.

2.3.1 Study site

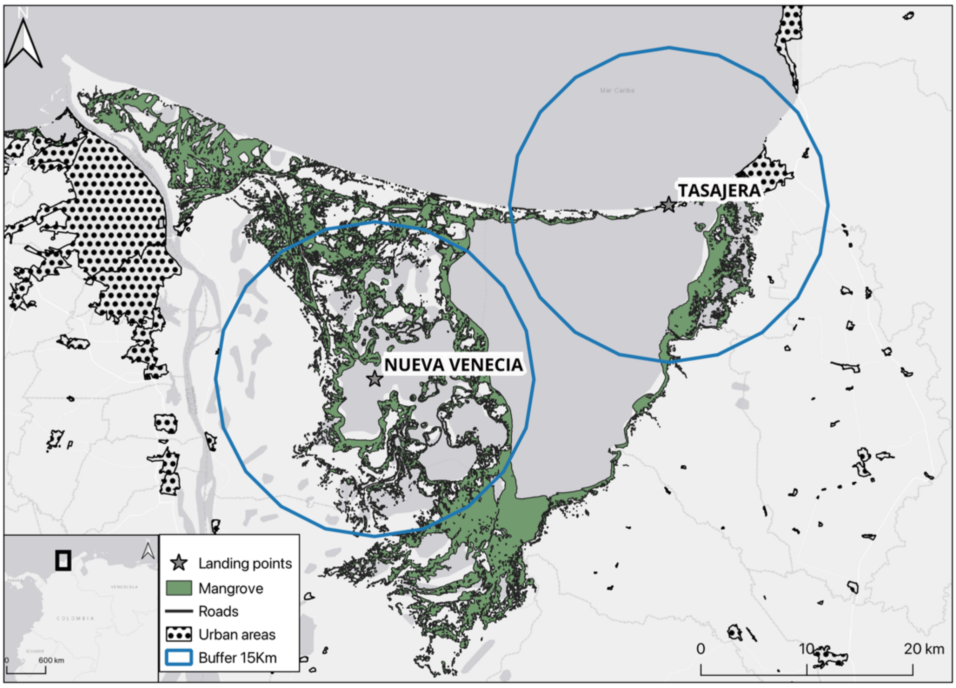

Figure 2-1. Cienaga Grande de Santa Marta main fishing landing points.

Cienaga Grande de Santa Marta (CGSM) is the largest mangrove area in the Colombian Caribbean, currently with nearly 38,000 hectares by 2021 (see Figure 2-1). This area has local and regional importance for its role in sustaining local communities' livelihoods and regional ecosystem connectivity, linking the Sierra Nevada de Santa Marta mountain system, the Magdalena River and the Caribbean Sea (Rodríguez-Rodríguez et al., 2018). Despite its ecological importance, CGSM suffered a major mangrove loss between the 50s and the late 90s, caused by multiple drivers including road construction, that closed several interconnection points between the Magdalena River, the sea, and the lagoon (1956-1960), and increase in wood extraction. All these impacts, added to the decrease in the Sierra Nevada de Santa Marta's rivers flow (mainly for agricultural use), resulted in an increase in soil and water salinity, the death of 55.8% of mangrove forests, the disappearance of oysters and other mollusks, and periodic fish mortality affecting artisanal fisheries, that as in other developing countries, are the main livelihood activity for the local communities (INVEMAR, 2022).

To recover and prevent continuous deterioration, different management and conservation strategies have been implemented, including two mangrove-focused protected areas (Via Parque Isla de Salamanca National Natural Park – VIPIS, declared in 1964, and The Sanctuary of Wildlife and Flora of the Cienaga Grande de Santa Marta - SFF CGSM, declared in 1977), as well as the declaration as RAMSAR wetland (1998), an Area of International Importance for Bids conservation (IBA), and a Biosphere Reserve (2000). Additionally, restoration activities started to be implemented in 1994, trying to regain hydrological connectivity with the Magdalena River and the Sea (Rodríguez-Rodríguez et al., 2021). The main restoration activities in this area included reforestation and hydrological restoration; this last one had a direct impact on the salinity and abundance of freshwater fish species in the system. Main restoration activities took place from 1999 to 2004, including reforestation, hydrological restoration, community-based restoration, and topographic modifications, this allowed the recuperation of ~13.500 hectares until 2015, when the cover started to fell until ~7.400 hectares were lost by 2017, mainly due to failure in the hydrologic restoration that led to obstruction of some mangrove areas, increasing salinity levels and causing mangrove mortality. After this, manual works were done to restore the areas in need and the overall cover started to increase, gaining ~5.800 hectares by 2021 and reaching 37,700 hectares in total. In the period between 1999 and 2021, approximately 12,000 hectares were recovered (INVEMAR, 2022; Rodríguez-Rodríguez et al., 2021).

As part of the management program and considering the environmental importance of this ecosystem, there has been monitoring for fishing activities and mangrove extension for the past decades. This monitoring goes from 1994 until the present, and reports monthly catch for at least three landing points in the coastal lagoon, taking records of catch, gear, duration of fishing activity, costs, prices and number of fishermen from 30% of the fishing economic units (boats) in the respective landing point (INVEMAR, 2022).

Artisanal fishing is the main activity supporting livelihoods in this area and previous studies have identified the main fish species related to mangroves in Colombian and specifically in CGSM mangroves (Carrasquilla-Henao et al., 2022; Londoño et al., 2020; Nagelkerken & Velde, 2004; Sandoval et al., 2020; Sandoval-Londoño, 2015; zu Ermgassen, Grove, et al., 2020; Zugelter, 2019). The identification of species in CGSM is based on ecological indicators of fish caught at different distances from mangroves, as well as informal interviews with fishermen in the main landing points in this area reported by Carrasquilla-Henao et al. (2019) and Carrasquilla-Henao et al. (2022). The species are mainly estuarine, with a few marine and freshwater (see B.1), which are also important for commercial fisheries. The fish is usually first sold by fishermen or a family member (usually his partner) at the landing points and then commercialized in the nearby cities (Cienaga, Santa Marta, Barranquilla, and Cartagena). Similarly, fishermen in this area identified the main fishing gear used. The main gears are castnets, encircling gillnets, set gillnets and seine nets. Seine nets are mostly used within mangrove areas proximate to the Nueva Venecia landing point and the Magdalena River while encircling nets are mostly used in the main lagoon near the Tasajera landing point and fringe mangrove (Carrasquilla-Henao et al., 2019; INVEMAR, 2022). According to local ecological knowledge, most fisherman fish in areas closer to their homes and the landing points, so each landing point receives the catch from the most proximate areas in the lagoon system. Additionally, fishermen self-reported that their catch is done in mangrove proximity, usually within 20 meters (Carrasquilla-Henao et al., 2019; INVEMAR, 2022), thus, landing points are indicative of the areas where fishing takes place.

2.3.2 The production function approach

The production function approach suggests that certain ecosystem services contribute to economic activity as inputs to produce private goods and services. However, these services do not have an explicit market value. With this method, it is possible to estimate the effects of changes in the natural asset or ecosystem service flow in production outputs and its value, when there is available information on market prices for the final good or service. First, it is necessary to determine the physical effects of changes in the ecosystem service over the economic activity, and then the impact of the environmental changes can be valued in terms of the change in the marketed outputs. This is the case for mangroves acting as breeding grounds and nursery habitats for inshore and offshore fisheries (Barbier, 2000, 2007; Freeman, 1991).

In the case of fisheries, the harvested fish is a function of private goods like vessels and gears, human capital, as well as environmental inputs like the mangrove nursery function (1). Under the static approach, the common assumption is that the production function takes a Cobb-Douglas form (Ellis & Fisher, 1987; Freeman, 1991) (2), where the objective is to maximize the harvested quantities h, as a function of the effort and other fishing-related inputs E, and the mangrove area M, which can be used as a proxy of the habitat input to fisheries (Barbier, 2007, 2019; Barbier et al., 2023).

$$h = f(E, M) \tag{1}$$

$$h = AE^{\alpha}M^{\beta} \tag{2}$$

In equation (2), A is a constant that reflects the level of technology and other factors affecting production; α is the elasticity that indicates how the output (h) would change given a change in the vector of inputs E in the production function; and β, represents the elasticity of M indicating the marginal productivity of mangroves in terms of $\beta = 1 - \alpha$.

To estimate the unknown parameters α and β the log-linear version of the Cobb- Douglas production function is used (3),

$$\ln h_{ist} = \beta_0 + \beta_1 \ln E_{1ist} + \beta_2 \ln E_{2ist} + \beta_3 \ln M_{st} + \beta_4 O_t + \beta_5 G_{st} + \beta_6 S_t + \beta_7 T_t + \mu_{ist} \tag{3}$$

Where h_{ist} corresponds to the landed catch for the $i - est$ gear in the s site in year t. Here $\beta_0 = \ln A$, $\alpha = \beta_1 + \beta_2$, and $\beta = \beta_3 = 1 - \beta_1 + \beta_2$ is equivalent to the marginal productivity of mangroves which is the focus of this chapter. The data is organized as a panel data set where the catch is reported by gear for each site and year in the period analysed.

E_1 is the total effort intensity as hours*man and E_2 is total fishery expenditure (not including labour costs), M is mangrove cover (ha) in year t, O is the mean Oceanic Nino Index for year t, and G, S and T are dummies for gear landing point and year respectively. fixed effects for year allow to capture non-linear trends and changes over discrete time periods.

2.3.3 Fisheries and mangrove data

The data for this analysis comes from the monitoring of the two main artisanal fisheries landing points in the Cienaga Grande de Santa Marta coastal lagoon (Tasajera and Nueva Venecia); Tasajera is a community living nearby the main road and hence to the main markets in the region (i.e. urban areas like Cienaga, Santa Marta and Barranquilla). While Nueva Venecia is a community inside the mangrove area and where access is mainly by boat (see Figure 2-1).

The data delimitation includes the most common gear (B.2) used by fishermen in both landing points, consisting of castnets, gillnets and encircling gillnets (Carrasquilla-Henao et al., 2019; INVEMAR, 2022), as well as the main estuarine and freshwater species associated whit mangroves in the literature and that corresponds to a significant proportion of the total catch in this area (~55%). As the monitoring has been taking place since the late 90s in this research the sample is limited to those years with the most complete information, this is with more than 8 months of sampling per year, being this the 2000 to 2021 period. Hence, the data is organized in a hierarchical form, where each data point corresponds to the catch (kg), revenue (using first sale prices), effort in terms of hours/man, and costs (excluding labour costs), for each gear or fishing method, in each landing point for the each year from 2000 to 2021 period, for the main commercial species

(B.1). All values are reported in 2021-US$.

Regarding environmental variables, the annual mangrove cover (ha) information reported by INVEMAR (2022) is used to estimate the mangrove area within 5, 10, 15 and 20 kilometers radius from the landing point. Measures for each year in the period are estimated using the same annual change rate from the total area in CGSM. Additionally, The Oceanic Niño Index (ONI), which is a measure of the Nino climatologic phenomenon (NOAA, 2022), is tested as a factor associated with precipitation levels and salinity in this ecosystem, hence with the abundance of marine, estuarine or freshwater species (INVEMAR, 2022).

2.4 Results

2.4.1 Descriptive analysis

The sample consisted of 132 observations (3 types of gear x 2 landing points x 22 years), reporting total catch, revenues, effort, and costs. Nueva Venecia concentrated a major proportion of the catch for the gears analysed at the beginning of the period (with an average proportion of ~70%) but after a decline in harvest in 2005 and for the rest of the period, Tasajera increased the catch landings (with an average proportion of ~64%), especially for the surge in the use of encircling gillnets that started to represent a bigger proportion of the total catch among the gears evaluated (see Figure 2-2). As for the prices, these are almost three times higher in Tasajera (see Figure 2-3), as this landing point is closer to the main markets in the region, and hence benefits from higher demand (see Figure 2-4). Regarding the revenues from the group of species and gears analysed, Tasajera concentrates a major proportion of the total catch value, mainly for its higher prices.

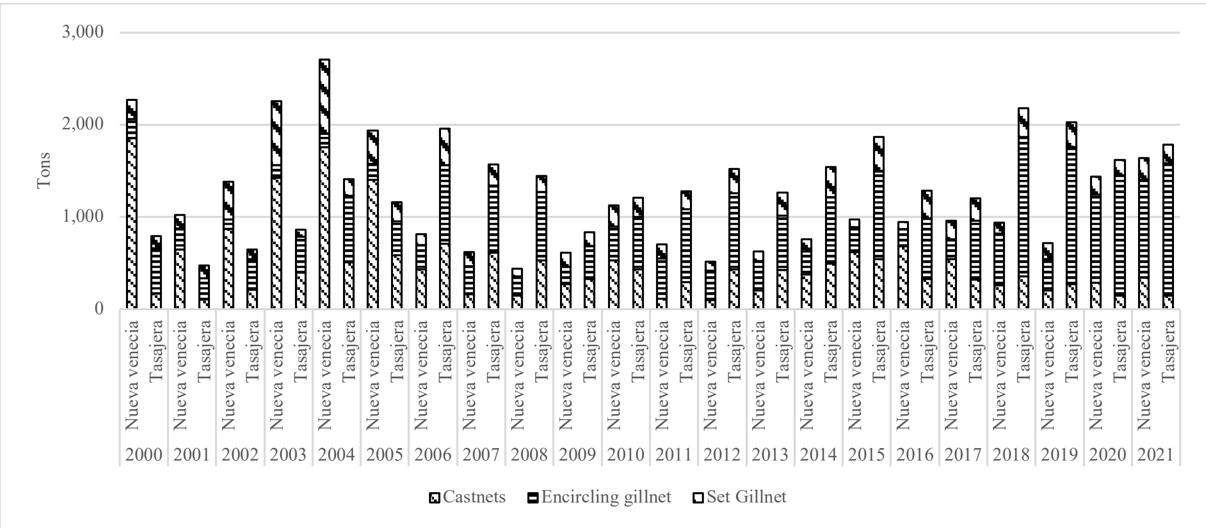

Figure 2-2. Total catch by gear and landing point

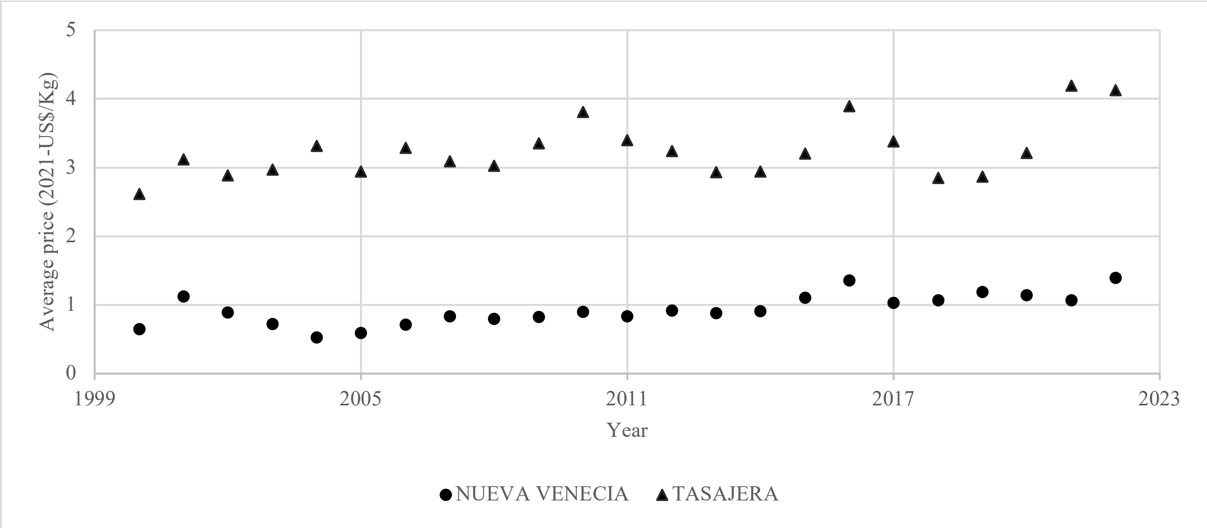

Figure 2-3. Average prices by landing point (2021 US$).

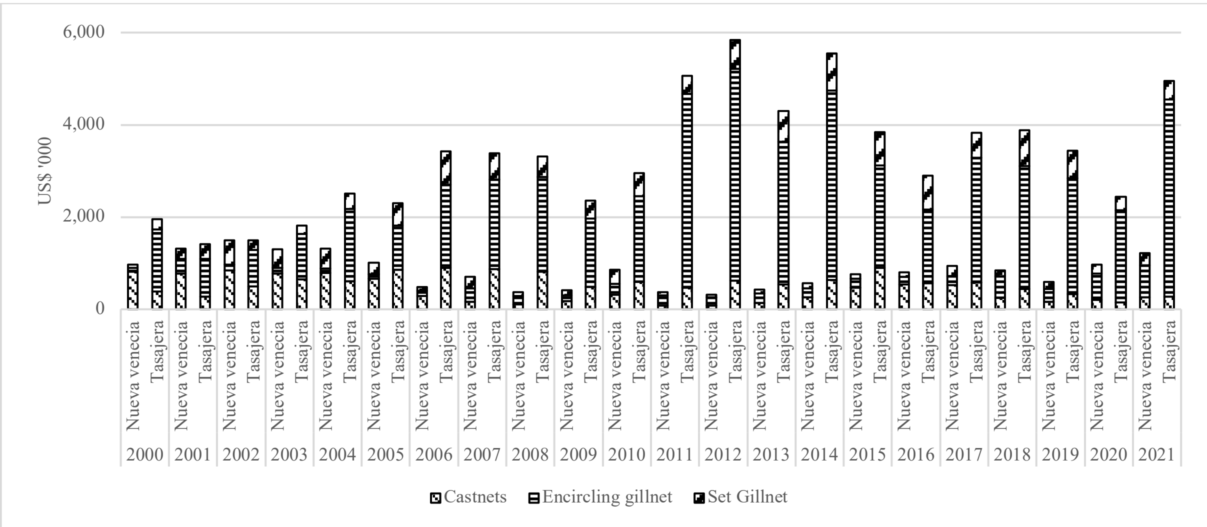

Figure 2-4. Total revenue by gear and landing point (2021 US$).

During the period evaluated the landing points exhibit differences in catch and revenues, with Nueva Venecia reporting 385 tons and US$273,697 on average annually, while Tasajera has on average an annual catch of 454 tons and an average annual revenue of US1.1 million. Although there is no statistical difference between the average catch in both points for the gears evaluated ($95\%CI_{NV\text{-}TA}$: -192.843 kg, 54.056 kg; p-value = 0.26), the mean prices per kilogram, and in consequence the revenue, are statistically different

(95%CI_{NV-TA}: -US$2.4, -2.2; p-value=0.000. 95%CI_{NV-TA}: -US$1'099.230, -US$566.255; p-value = 0.000, for differences in mean prices and revenues respectively). Similarly, the effort in terms of total annual hours spent fishing, and annual costs are higher in Tasajera landing point with an average of 452,482 hours invested in fishing annually (95%CI_{NV-TA}: -79,506 hrs, -22,400 hrs, p-value=0.000. 95%CI_{NV-TA}: US$-212.782, -US$-117.660 p-value=0.000, for differences in mean annual effort and costs respectively). There is also a difference in the total annual effort and costs of gears within the landing point, as in Nueva Venecia there is a higher annual effort and expenses put into castnets, while this is the case for encircling gillnets in Tasajera (see Table 2-1).

Table 2-1 Mean and standard deviation of main variables reported by CGSM fishing monitoring during the period 2000-2021.

LANDING POINT	**NUEVA VENECIA**			**TASAJERA**		
Gear	**Castnets**	**Encircling gillnets**	**Set gillnets**	**Castnets**	**Encircling gillnets**	**Set gillnets**
Catch (ton)	602 (534)	329.5 (243.6)	223.6 (189)	379.9 (165)	759 (376)	224 (83.9)
Revenue (us$ - 2021)	394,021 (269,912)	236,131 (157,615)	190,940 (130,332)	563,995 (211,862)	2'256,042 (1'160,430)	499,283 (195,959)
Effort intensity (total hrs)	171,653 (129,818)	51,865 (26,060)	76,102 (70,229)	113,050 (40,743)	193,274 (51,789)	146,158 (61.399)
Costs (us$ - 2021)	58,812 (71,818)	18,477 (12,901)	18,103 (22,145)	65,529 (33,375)	433,603 (138,676)	91,924 (26,897)
Catch by fishing trip (kg)	2.40 (1.80)	12.01 (9.87)	3.80 (4.90)	2.97 (0.91)	6.45 (2.05)	1.65 (0.60)
Revenue by fishing trip (us$ - 2021)	1.69 (1.10)	8.23 (5.53)	2.85 (1.70)	4.41 (1.12)	20.76 (12.54)	3.61 (0.94)
Effort by fishing trip (total hrs*man)	11.33 (2.18)	14.34 (1.70)	15.80 (4.81)	10.21 (0.63)	21.19 (0.62)	12.23 (3.61)
Costs by fishing trip (us$ - 2021)	2.51 (1.47)	5.42 (2.42)	3.09 (1.59)	2.56 (0.51)	11.42 (1.86)	3.04 (1.91)

On the other hand, analysing the average catch of particular species by fishing trips, this is, every time the fisherman goes out in their boat with an assumed specific gear, the quantity of fish harvested by this effort unit gives hints of the abundance of the resource in the ecosystem. In general, more kilograms of fish are captured with the encircling gillnet gear in both sites. Furthermore, more weight of a particular species is caught by fishing trip in Nueva Venecia compared to Tasajera (95%CI_{NV-TA}: 0.36kg, 4.3kg; p-value = 0.020). However, as prices are significantly higher in the Tasajera landing point, the average value of catch per trip for a particular species in this landing point again exceeds that of Nueva Venecia (CI_{NV-TA}: -US$8.17, -US$2.50; p-value = 0.000). As for the time spent on each fishing trip, there is no significant difference between sites but there is between gears (F-value= 48.51; Pr(>F) = <2e-16 ***).

2.4.2 The production function for fisheries in CGSM

Ordinary least squares (OLS) and Panel regression methods were used to estimate the fishing and environmental factors parameters. OLS regression with fixed effects for gear, site and year is the preferred method as it exhibits a better fit to the data analysed (see B.4). The model described in the methods section was estimated using R software. Table 2 shows the main results for the OLS regressions with fixed effects. The dependent variables are total annual catch and average catch per fishing trip for two of the most representative species linked with mangroves (i.e. *Ariopsis canteri* and *Mugil incilis*). Variable O_t, indicating the Index for the Niño Phenomenon intensity, and the dummy for the landing point were not significant for any of the models.

Considering that fishing activities usually take place near landing points and mangrove areas (Carrasquilla-Henao et al., 2019), the best results for mangrove cover are those when using a 15km buffer from the landing point. The marginal contribution of mangroves is equivalent to the regression coefficients for mangroves, and hence, a 1% increase in mangrove cover in a buffer of 15km from the landing point, will improve the annual catch by 0.44% for the analysed species, keeping all other factors constant. Regarding the fisheries inputs, in the case of total annual catch, the total cost (not including labour costs) and effort intensity are significant, showing a positive but inelastic relationship with catch. This indicates that a rise of 1% in the total annual costs will improve the total annual catch by 0.4%. While an increase of 1% in the total time spent fishing, will enhance the total annual catch by 0.36%. Finally, from the gears included in the analysis, encircling gillnets (the base category) contribute positively to the harvest for the species analysed when compared with the other two gears.

Table 2-2. Main multinomial logit regression results.

	OLS Total catch (ln- Kg)	**OLS Ariopsis canteri catch by fishing trip (ln- Kg)**	**OLS Mugil incilis catch by fishing trip (ln-Kg)**
Mangrove 15km (ln - ha)	0.44 (0.06)***	0.25 (0.13)**	0.58 (0.14)***
Effort intensity (ln-Hrs)	0.36 (0.09)***	-0.65 (0.17)***	-0.68 (0.20)***
Effort/trip (ln-Hrs)		0.88 (0.55)	1.15 (0.62)*
Costs (ln-US$)	0.40 (0.07)***		
Costs/trip (ln-US$)		1.33 (0.31)***	0.54 (0.35)
Gear castnets	0.04 (0.09)	1.94 (0.43)***	0.88 (0.48)*
Gear set gillnets	-0.42 (0.09)***	0.48 (0.35)	-1.29 (0.39)***
Intercept	0.48 (0.85)	-0.41 (2.21)	1.65 (2.48)
R^2	0.85	0.51	0.65
Adj. R^2	0.82	0.38	0.56
Num. obs.	132	132	132

In the case of catch per fishing trip, two of the most popular commercial species linked to mangroves are analysed: *Ariopsis canteri* and *Mugil incilis*. The latter is one of the most abundant species in the study site. For both species, mangroves in the proximity of fishing sites are significant and positively related to catch per fishing trip, as for a 1% increase in mangrove area, within a radius of 15km from the landing point, the catch per trip will increase in 0.25% for *Ariopsis canteri* and 0.58% for *Mugil incilis*. As for the effort factor a 1% increment in costs per trip increases the *Ariopsis canteri* catch by 1.33% but seems to have no significant effect over *Mugil incilis* catch; while an increase of 1% in the time spent fishing does not have a significant effect over *Ariopsis canteri* catch but increase *Mugil incilis* catch in 1.15%. On the other hand, the effort intensity, which indicates the total fishing intensity, has a significant and negative relationship with both species' catch per trip, this is, an increment of 1% in the total time spent fishing by all the fishermen in all the vessels, is related to a decrease of 0.65% and 0.68% for *Ariopsis canteri* and *Mugil incilis* catch per trip respectively.

For average values (see Table 2-1) one additional hectare of mangrove in the proximity of landing points can contribute between 22kg/yr and 149kg/yr to the artisanal fisheries for the delimited species and gears in Nueva Venecia and Tasajera respectively. In terms of revenue, using the average prices of the pooled species for 2021, one additional hectare of mangrove can increase the fishermen's revenue between US$24/yr and US$628/yr in Nueva Venecia and Tasajera landing points respectively. In consequence, the mangrove restoration actions that led to the increase of 38% in the mangrove cover between 2000 and 2021, have then contributed US$938,759 in total for both landing points. Finally, considering that the active intervention to restore mangroves led to increases in cover for the total area with an average rate of ~2% in the studied period, projecting the same recovery for the near future if restoration and conservation actions continue, mangrove gains could contribute with ~US$432,732 by 2030 and ~US$1.72 million by 2050 with a 5% discount rate, for both sites respectively, considering the species and gears delimited, and that other production factors like effort remain fairly constant.

2.5 Discussion and Conclusions

Previous studies in Latin America including published and not published, have estimated mangrove nursery ecosystem service through fisherman revenues, reporting mostly values below US$1,000/ha/yr, with a few values over US$20,000/ha/yr (see Chapter 1). Less published studies have used the production function method to estimate the value of mangrove support to local artisanal fisheries in Latin America. Barbier and Strand (1998) estimate annual mangrove loss in terms of impacts over shrimp harvested at approximately US$ 5,330/ha/yr (2021 values). Aburto-Oropeza et al. (2008), estimated a mean value of mangrove fringe contribution to artisanal and industrial fisheries in the Gulf of California at US$80,614/ha/yr (2021 values). The present research estimations fall in the lower end of the range of values estimated for the nursery and habitat for commercial fish ecosystem service, with values of US$24/ha/yr and US$628/ha/yr. These estimations represent a lower bound of mangrove economic contribution to local livelihoods in this site, as only a delimited group of species and gears is used in the analysis. These results are coherent with other estimations for this mangrove area using market prices, for example, Contreras (2016) approximates mangrove values in CGSM through market prices of species caught proximate to mangroves at US$303/ha/yr and US$374/ha/yr for the total mangrove cover in this area, although these estimations do not consider the effects of effort over the fish harvested as the present research does, attributing the total catch value to mangroves.

Restoration activities in this site have recovered 38% of the mangrove cover reported at the beginning of the period with a mean recovery rate of ~2% (INVEMAR, 2022). Assuming that the mangroves around both landing points present similar increasing rates, the restoration efforts during the period studied have contributed to fisherman revenues an average of US$48,600/yr for both landing points.

Mangrove value estimation is related to other fishing factors like the effort, the technology used, the commercial species available in the ecological system and the market prices considered. In this study, besides the extension of mangroves available for fish habitat, other fishing factors, such as the type of gear used, the intensity of the effort in terms of hours spent fishing and the costs of materials used, and the proximity to the market significantly determine the fish harvest and the fishermen's revenue. Hence, the values here estimated are conditioned to the species delimited, the gears used to catch them and where in the CGSM the fishermen fish and sell their catch.

The time put into fishing is a good indicator of harvested quantity for a fishing unit (fishermen, boat and gear used), but the aggregation of the fishing effort can contribute to the decline in catch per effort unit, and hence in any benefit related to mangrove providing habitat for fish. This conclusion is similar to that expressed in Barbier and Strand (1998), where surges in effort intensity also affect the harvest levels with an elasticity of -0.74 in Terminos Lagoon. This means that even with restoration efforts and mangrove cover gains in time, the catch and revenue of fishermen, and in consequence the value related to mangrove marginal productivity, will be negatively affected by the rise in the total fishing effort (i.e. the total time of all fishermen spent fishing). It is then relevant to involve the local communities in the planning and management of restoration efforts that also tackle overfishing, among other pressures over the mangrove ecosystem in CGSM (Vilardy, 2009).

Chapter 3. Preferences for mangrove restoration in the Colombian Caribbean

3.1 Introduction

The United Nations (UN) Decade on Ecosystem Restoration is directed towards the prevention, ending, and reversal of ecosystem degradation. Its primary objective is to address multidimensional challenges including poverty alleviation, climate change mitigation, and preventing mass extinction (UNEP, 2020). Ecosystem restoration constitutes the deliberate process of reversing the decline of ecosystems, with the aim of recovering their ecological functionality and capacity to provide essential ecosystem services aligned with social needs (CBD Secretariat & SER, 2019). Furthermore, there exists a global aim to promote restoration endeavours, intended to fight the trajectory of biodiversity loss, while enhancing community resilience through the adoption of nature-based solutions (UNEP, 2022).

Among coastal ecosystems, mangroves hold an important role in supporting biodiversity, as they are home to approximately 341 internationally endangered species. Additionally, this ecosystem is highly relevant for local communities as a nature-based solution for climate change effects like coastal erosion, sea level increase and extreme weather (Spalding & Leal, 2021; Spalding et al., 2014) increasing the community's resilience. Moreover, the population living in mangrove proximities usually rely on artisanal fisheries and other mangrove-supported activities like wood extraction for their subsistence (Béné et al., 2001; Béné et al., 2009). However, around one-third of mangroves have been lost until early 2000, with an average annual loss rate of 2%, due to multiple stressors including natural drivers, like sea level rise and erosion, and anthropogenic hazards, such as land use changes, deforestation, fragmentation, and pollution. This has propitiated the loss of ecosystem services and affected the biodiversity hosted by mangroves (Friess et al., 2019). Hence, restoring mangroves can help achieve several important goals such as safeguarding biodiversity, reducing the impacts of climate change, and promoting sustainable development (Su et al., 2021).

Rodríguez-Rodríguez et al. (2021) reported that Restoration efforts benefit from the integration of scientific with traditional knowledge systems and community involvement. Moreover, since local communities are highly dependent on the ecosystem, as over one-third of fishermen in mangrove countries rely on this ecosystem (zu Ermgassen, Mukherjee, et al., 2020), their knowledge of the ecosystem functioning is valuable and their approach to conservation is driven by a safeguarding approach.

Considering the important role that mangrove ecosystems play in the achievement of different SGD goals, including poverty reduction and food security, especially for coastal vulnerable communities, and the fact that Colombia's government is currently promoting restoration initiatives in different ecosystems (UNEP, 2023), this research aims to analyse preferences for mangrove restoration in the Colombian Caribbean, using stated preference methods.

The study case site is the Cienaga Grande de Santa Marta (CGSM) coastal lagoon, which is a Ramsar site, where restoration actions have been implemented since the late 90s, with a total net gain of approximately 12,000 hectares until 2021 but with negative results for some years (see Figure 3-1). The aim of the study is to analyse preferences for improving the current restoration program. Specifically, this research aims to answer: i) What environmental outcome from mangrove restoration has the highest marginal willingness to pay? ii) what is the willingness to pay for an additional hectare of mangrove restored? iii) Do people's preferences for improvements in restoration differ according to different payment vehicles? And vi) How beneficiaries' spatial distribution and heterogeneity influence preferences over restoration outcomes and ecosystem services from mangroves.

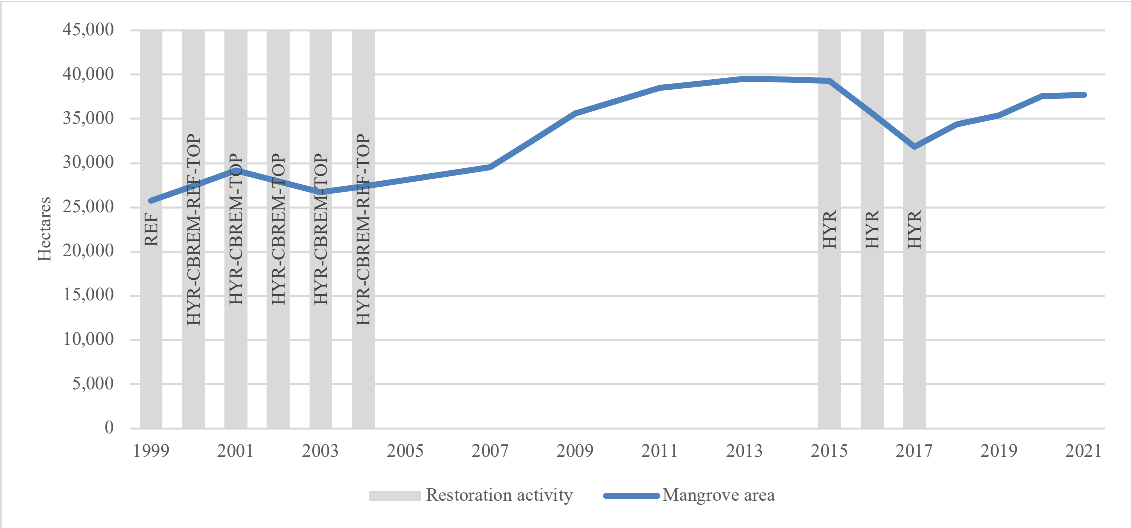

Figure 3-1. Mangrove cover and restoration activities over time in Cienaga Grande de Santa Marta (CGSM). Source:(INVEMAR, 2022; Rodríguez-Rodríguez et al., 2021). Where REF: reforestation, HYR: hydrological restoration, CBREM: community-based ecological mangrove restoration, and TOP: topography modification.

Previous studies in Colombia have implemented stated preferences methods to estimate local communities' willingness to pay using voluntary work as a payment vehicle and sample sizes from 261 to 280 respondents, for coastal protection, water quality regulation, fisheries support and cultural services (Oliva Posada & Londoño Diaz, 2011; Vargas-Morales et al., 2013). These studies focused mainly on fishermen, who represent a specific segment of the potential beneficiaries of mangrove ecosystem services. Just one study reported willingness to pay from different types of stakeholders, interviewing 592 respondents in Barranquilla and Santa Marta, which are the nearest cities to CGSM. However, the objective of this study was environmental quality and not mangrove restoration or conservation schemes (Herrera & Vargas-Morales, 2014).

This research will therefore complement the previous empirical evidence from Colombia providing valuation estimates for mangrove restoration options. Even more, this study will add to the scarce literature on mangroves' economic valuation in South America, supporting policy initiatives for mangroves restoration and conservation in the continent.

3.1.1 Preferences for mangrove restoration

Since local communities benefit and rely on mangroves, it is relevant to identify the community's motivation to support restoration efforts at a local scale. Previous studies have identified factors that influence the preferences for restoration initiatives in mangrove ecosystems around the globe. For example, using a contingent valuation method Stone et al. (2008) assessed factors influencing the willingness to contribute to mangrove restoration actions for three social groups: farmers, fishermen, and fisherwomen. They concluded that fishermen are motivated by the nursery capacity of mangroves and their contribution to livelihoods, while fisherwomen are driven by mangroves' wider contribution to the entire community. On the other hand, farmers give higher importance to the role of mangroves in soil erosion and pest control when choosing restoration alternatives. Moreover, using the same method in Thi Nai Lagoon, Vietnam, Tuan et al. (2014), concluded that local awareness of the mangroves' importance in facing climate change effects is explained by a permanent residency in the area and high dependence on mangroves. These results are similar to those reported by Pham et al. (2018), where gender, education level, occupation, the participation of respondents in mangrove restoration activities, and their attitudes toward the impact of climate change were significant factors in respondents' willingness to pay for mangrove restoration.

Other studies have investigated mangrove restoration preferences using choice experiments, which are a convoluted alternative to contingent valuation. Milon and Scrogin (2006) used a latent class choice experiment to evaluate preferences for the restoration of the Greater Everglades ecosystem in Florida, using mangrove attributes and respondents' characteristics to explain preferences and values for restoration. They presented two sets of mangrove restoration information as treatments. One set with structural characteristics of mangroves as attributes (i.e. description of reforestation based on changes in population levels of native fauna), and another set defining functional characteristics of mangroves (focusing on spatial and temporal variations of water levels). The group presented with structural characteristics showed a higher portion of individuals supporting the restoration, indicating strong preferences towards the enhancement of endemic species, over water regulation services. Tan et al. (2018) considered a protected area in China and used choice experiments to present future scenarios of restoration including among the attributes mangrove cover, water quality and biodiversity, resulting in the mangrove cover as the most valued. These results match those of Sinclair et al. (2021) where local stakeholders assign the greatest value to mangrove conservation, followed by water quality and sustainably managed fisheries. As an alternative approach, de Rezende et al. (2015) set restoration program characteristics as the attributes of mangrove restoration scenarios, this is, the level of restoration, the estimated time of restoration, and two possible contributions as weekly hours of volunteering and monthly payment to an NGO. In this study, people showed a strong preference for moderate restoration in 10 years and complete restoration in up to 20 years. Finally, Su et al. (2021) concluded that mangrove restoration provides higher ecosystem functions than unvegetated coast, although lower than natural mangroves; additionally, economic results from mangrove restoration exhibit positive cost-benefit rations, presenting this as a highly cost-effective management measure for coastal ecosystems (Sinclair et al., 2021; Su et al., 2021).

3.2 Methods

3.2.1 Study Area

Cienaga Grande de Santa Marta (CGSM), on the Colombian Caribbean Coast, is considered the largest coastal lagoon in Colombia and one of the most productive coastal ecosystems in the neo-tropics. It is connected to the Magdalena River, the largest river in Colombia, to the Sierra Nevada de Santa Marta, which gives an important hydrological resource to the lagoon and to the Caribbean Sea, creating an ideal environment for mangroves development (Rodríguez-Rodríguez et al., 2021). This area has 5 conservation figures including Ramsar site, UNESCO Biosphere Reserve, Important Bird and Biodiversity Area (IBA), and two National Natural Parks (National Natural Park Isla Salamanca and Sanctuary for Plants and Animals CGSM) (Birdlife International, 2008; MADS, 2023a, 2023b; RAMSAR, 1998; UNESCO, 2019). Populations living in the mangrove proximities are mostly rural, however, two cities could also be considered as direct beneficiaries of mangrove ecosystem services as these are within a 50 km radius from the mangrove area centroid (Brander, Wagtendonk, et al., 2012). In total, more than 3 million inhabitants live within 50 km of this mangrove area centroid (DANE, 2018).

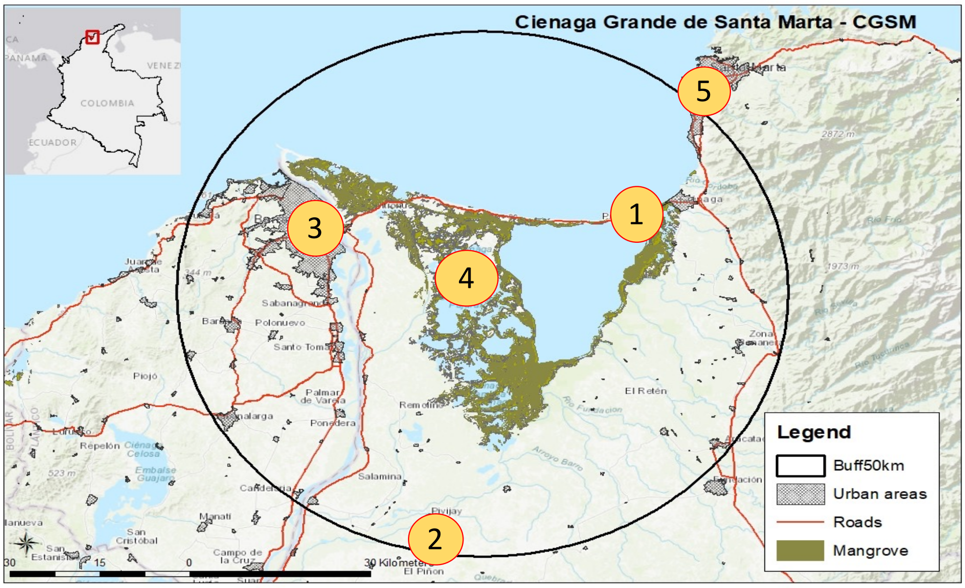

Figure 3-2. Study area and populations prioritized.

Economic activities in this area are focused on the agricultural sector, including artisanal fisheries, (considering this site aggregates the biggest artisanal fisheries activity in Colombia with an estimate of 1200 fishermen), oil palm and bananas crops, and buffalo livestock, which is negatively impacting mangrove areas (Contreras, 2016; Vargas-Morales et al., 2013). An important road infrastructure has been developed in this area, interrupting hydrological connectivity and generating considerable impact on the mangrove ecosystem (Jaramillo et al., 2018; Sánchez-Núñez, 2019). Rural areas and communities living closer to mangrove areas are still highly dependent on extractive activities (fisheries and wood extraction), while communities more connected to urban areas (e.g. site 1 in Figure 3-2) have a higher diversity in economic activities, including commerce and tourism. Rural areas present high socioeconomic vulnerability, with more than 50% of the population living in poverty and basic needs still not covered (e.g. water for human consumption and sewage system) (DANE, 2021). On the other hand, in urban areas, the main economic activities include industrial and manufacturing sectors, commerce supported by port activity and tourism.

Despite its ecological importance, this area has suffered a major degradation process mainly driven by the loss of hydrological connectivity with key water sources (i.e. Magdalena River and the rivers from the Sierra Nevada de Santa Marta). This disruption has caused an ecological unbalance, especially with the increase in salinity levels that affect the growth of mangrove trees, resulting in a reduction of mangrove cover from approximately 51,150 hectares in 1956 to 22,580 hectares in 1995 (or more than 50% of mangrove cover). This deterioration was mainly associated with human intervention, like road infrastructure development, agricultural expansion, the reduction in the water input (used in agriculture and other economic activities), and recently the increase in logging. Additionally, global climate change has intensified the shocks from hydrological imbalance with extremely dry seasons (Rodríguez-Rodríguez et al., 2021; Sánchez-Núñez, 2019).

To contribute to the restoration of mangroves cover and functionality, since 1996, different actions have been implemented, including reconnection with Magdalena River (mainly through the dredging of water channels), reforestation, and recently (2017) manual opening of water channels that complemented the machinery work. However, most of these actions were implemented separately, at different moments during the past decades, and without the active participation of stakeholders, leading to medium to low success in most of zones. Hence, mangroves' benefits have fluctuated during this period, and although since 1996 there has been a net recovery of mangrove cover in the proximate areas of restoration actions, other areas have presented ecological deterioration and cover loss. For example, in 2017 was registered a loss of 8.703 hectares which led to the implementation of additional dredging and the subsequent recovery of mangrove cover between 2018 and 2019 (Gómez Cardona et al., 2023; INVEMAR, 2021; Rodríguez-Rodríguez et al., 2021; Sánchez-Núñez, 2019).

Currently, new restoration actions have been planned for those areas in need, in specific points inside the CGSM with Community based Ecological Mangrove Restoration approximation, including topographic assessment, dredging, community-based work, reforestation, and monitoring among other site-specific activities with stakeholders' involvement, to reduce impacts, recover ecosystem and its functionality and improve management to meet society needs. This will complement the previous and current actions leading to a sustainable improvement in the conditions of mangrove ecosystem services in CGSM (Rodríguez-Rodríguez et al., 2021).

3.2.2 Method and empirical approach

The methodology used in this research is based on Random Utility Models, which assumes the individuals exhibit a maximization of the utility behaviour, this is, the individual is motivated by the maximization of the utility that different alternatives can provide to her. This model also assumes that individuals are rational, they have perfect information, and alternatives presented to them are mutually exclusive (Cascetta, 2009; Grilli et al., 2021; Walker & Ben-Akiva, 2002).

The utilities (U) are considered latent variables, while the researcher observes preference indicators (y) as a manifestation of the underlying utilities. The utility that the individual derives from the alternatives is assumed to be a function of explanatory variables X that describe the i individual and the j alternative. Hence, U_{ji} will represent the utility of the alternative j for the individual i. For the researcher, this utility is composed of an observable part or systematic utility $V(X_{ji};\beta)$, which includes the observable characteristics of the individual and alternatives, and an error term ε_{ji} picking up all unobservable factors that also influence the individuals' choices (Walker & Ben-Akiva, 2002).

$$U_{ji} = V(X_{ji}; \beta) + \varepsilon_{ji}$$

where j=1, 2, 3….J represents the alternatives presented to the *i-est* individual. And i=1, 2, 3….N represent an individual within a population. β represents the parameters, and ε_{ji} the random disturbance.

Hence, it is assumed that individual *i* chooses alternative j if and only if the utility gained from j is higher than the utility from all other alternatives k, from a set of alternatives faced by i.

This is, U_{ij} >U_{ik} $\forall k \epsilon t_i$, where t_i is the set of alternatives faced by individual *i*.

The researcher cannot observe individuals' utilities but can observe attributes of the choices and the chosen option, and according to the error term can predict the probability of individual *n* choosing alternative *j* over *k*.

$$P(j|X_i; \beta, \theta_\varepsilon) = P[U_{ji} > U_{ki} \forall k \epsilon i]$$

This is, the probability of choosing *j*, given the individual's characteristics X_i, the parameters β, and the parameters that determine the distribution of the error term θ_ε, is equal to the probability that the utility that the individual *i* obtains from the alternative *j* is higher than the utility she obtains from alterative *k*, For all *k* alternatives in t_i.

The specific econometric model used to analyse the preferences will be conditioned to the assumptions of the distribution of the error term, including most used choice models like probit or generalized extreme value (GEV) (Cascetta, 2009).

3.2.3 Survey and experiment design

Choice experiments are used in environmental economics as a stated preference method to estimate ecosystem service values and model public preferences over environmental attributes (Johnston et al., 2017). The process of designing the final survey was carried into three main stages. First, interviews and focus groups with experts from the Marine and Coastal Research Institute of Colombia (INVEMAR) (n=8) were conducted to discuss the restoration process, mangrove ecology, and social and economic dynamics in the study area, and to evaluate the adequacy of the attributes to be presented. Following this, a pilot survey was applied selecting different socio-economic groups around the mangrove area including an urban area and villages (n=49), with the support of one enumerator from INVEMAR. Preliminary information was used to revise the questionnaire and choice cards, as well as define the logistics of the face-to-face survey considering the limitations during the COVID-19 pandemic. INVEMAR provided a group of three enumerators who were trained to apply the main survey.

As a presentation of the research and introduction to the survey, informed consent was presented to all participants before the survey was applied, following the UEA School of Economics Ethics Committee guidelines. This also allowed us to inform the participants about COVID-19 risks. The survey was conducted between October and November 2021 in five different locations around the mangrove area, two cities (Barranquilla -site 3 and Santa Marta – site 5 in Figure 3-2), with a population between 500 and 1000 thousand inhabitants, and three rural areas (Pueblo Viejo – site 1, Pivijay – site 2 and Palafitos – site 4 in Figure 3-2) with populations between 3 and 30 thousand of inhabitants (DANE, 2018). The survey collected information from individuals living within a 50 km ratio from the geographical centre of the mangrove area, which has been proven to be a significant spatial threshold to determine potential beneficiaries of mangroves and wetlands ecosystems services (Brander, Bräuer, et al., 2012; Brander, Wagtendonk, et al., 2012; Ghermandi et al., 2009)

The questionnaire was organized into three main sections i) individual's knowledge, attitudes, and experience with mangroves in this area and the restoration process, ii) the choice task, where individuals were presented with the current situation and the change proposed in terms of different alternatives, that simulate possible scenarios for improvements in restoration, and iii) a series of socio-economical questions to characterize the respondent (see C.1).

3.2.3.1 Attributes and levels

To describe the current situation and the changes in the potential restoration programs, and how these changes might impact the environmental quality of mangrove areas, three ecological attributes were selected: biodiversity, represented by the richness of bird species in this area, mangroves extension in hectares to be restored, and fisheries represented by the annual catch (Ton) in this area. Finally, a fourth attribute was a contribution to support the improvement of the restoration program. This contribution was presented as i) a monthly monetary contribution and ii) a weekly time contribution for voluntary work in the restoration program, considering the inclusion of urban and rural areas and the hypothesised constrictions of cash use in rural versus urban areas. Contributions were not presented at the same time, but they were presented sequentially to the complete sample.

A. Biodiversity

The bird-watching potential in the CGSM is supported by its capacity to provide habitat to more than 270 species of birds, including endemic and vulnerable species of national and international interest. Moreover, CGSM was declared an Important Bird Area (IBA) in 2001 (Birdlife International, 2008; INVEMAR, 2019). The diversity in the landscape composition which includes, among others, mudflats and mangrove forests, allows for the presence of diverse birds that can be of general interest to residents and more specialized users like bird watchers. The diversity and abundance of birds in this region also represent an alternative livelihood for fishermen and their families. Creating good conditions for small species that find refuge in mangrove cover can also improve the trophic chain and benefit bigger species living in open areas. The enhancement can be achieved by improving the monitoring and control of deforestation and freshwater diversion as part of the restoration programs. Upgrades in biodiversity can be an indirect indicator of the ecological quality of the mangrove areas. For this study, this attribute was represented as the qualitative change in birds' biodiversity and abundance in the study area, based on information collected by the monitoring in specific years, and academic studies (Gómez Cardona & Ospina López, 2019; INVEMAR, 2019). Hence the improvement in biodiversity conditions was presented as a small, medium, or large change from the current situation that might not be directly visible to individuals.

B. Mangrove extension

Historically, the restoration and recovery of mangrove areas have been mostly associated with direct reforestation interventions, although by itself this technique does not guarantee a successful mangrove cover increment. The mangrove growth is highly dependent on good water conditions, as well as the intensity of human and natural stressors (Su et al., 2021). One of the main factors affecting the increase in mangrove cover includes the adequate balance of water salinity, conditioned by the hydrological balance between marine and freshwater contributions to the lagoon (Sánchez-Núñez, 2019). This balance can be addressed by the restoration program habilitating water channel connectivity within mangrove areas, jointly with reforestation activities in appropriate spots (Rodríguez-Rodríguez et al., 2021). In this choice experiment, this attribute represents the extension in hectares of mangroves that could be gained with the improvement in the restoration program. This is an important attribute to be included as it represents the main goal of the current restoration program, and it is one of the ecological indicators of restoration success. This attribute was presented to the public as small, medium, and large changes in mangrove hectares based on historical data from the monitoring carried out in this area for 20 years (2000 – 2019).

C. Fisheries

Food provision, through fisheries' productive cycle support, is a well-known and widely assessed ecosystem service from the mangroves (Barbier, 2007; Carrasquilla-Henao et al., 2022; Das, 2017). The monitoring program in CGSM has collected data on fisheries since 1994, identifying at least 113 different commercial species. Contreras (2016) estimated mean values for the mangrove role in fisheries support at around US$374/ha/yr per hectare per year for 9 of the most commercial species related to the mangrove (also see Chapter 2). Thus, this is considered a relevant attribute as it is related to the water quality improvements (INVEMAR, 2021), and constitutes the basis of local communities' livelihoods (see Chapter 2); additionally, there is historical information on fish catch to design possible scenarios. The levels for this attribute will consider the average annual catch for the most common fishing gear in this area (castnets) and the main commercial species related to mangrove ecosystems during 20 years (2000-2019) (Carrasquilla-Henao & Juanes, 2017; Contreras, 2016).

D. Contribution and Payment vehicle

Considering the diverse types of beneficiaries in the population (i.e. rural and urban areas), two options were hypothesised. Individuals in urban areas will be keener to contribute with a monetary payment, while individuals in rural areas would prefer contributing with their time doing restoration activities. Hence these contribution options were included in the choice tasks (Hassan et al., 2018). The proposed payment vehicles were a monthly payment through a household bill for the next five years, and a contribution in hours per week to do restoration activities, including mangrove reforestation, monitoring, control, and educational activities with the public, for up to six months per year for 5 years. The levels for this attribute were tested during the pilot survey and based on previous economic valuation reports in this area (Herrera & Vargas-Morales, 2014; Vargas-Morales et al., 2013).

Table 3-1. Attributes and levels (source: historical data and pilot survey).

Attribute		**Levels**				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Biodiversity of birds	Changes in the biodiversity of birds represented by the number of different species that could be found in this area	Small change	Medium change	Large change		
Mangrove cover change	Change in mangrove cover regarding the current situation	Small change Up to 3000 ha can be gained	Medium change Up to 8000 ha can be gained	Large change Up to 14000 ha can be gained		
Fisheries	The annual catch of most commercial fish in this	Small decrease	Small increase	Medium increase	Large increase	

Attribute		Levels				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
	area	-10% 450 ton.	20% 600 ton.	60% 800 ton.	120% 1.100 ton.	
Contribution	Contribution as a monthly payment per person for the next 5 years to support restoration activities. (US$)	$ 1.25	$2.5	$5	$7.5	$12.5
	Contribution as hours of voluntary work per week for up to 6 months to do restoration activities.	2	4	8	10	16

The Ngene© software was used to get an efficient design of the cards that would be presented to individuals in the sample. In total 24 combinations or sets of two alternatives representing possible future conditions were produced and grouped in three blocks of eight sets each. The first four sets of choice tasks were assigned with monetary contribution and the following four were assigned with time for volunteering contribution. To randomize the order of the type of contribution presented first to the individuals, the blocks were expanded changing the order of the type of contribution presented in the first four sets. As a result, six blocks of eight sets, with two alternatives, were established. Blocks 1 to 3 presented monetary contributions first and blocks 4 to 6 presented time for voluntary work first. To complete the choice set, a third alternative of no contribution or op-out was added. Each individual was randomly assigned one of the six blocks, facing eight choice tasks with a set of three alternatives including two possible new restoration scenarios plus the no contribution/opt-out alternative. Each person was asked to contribute with a monthly payment on four of the cards and with time for voluntary work for mangrove restoration on the following four cards (see Figure 3-3 and C.2).

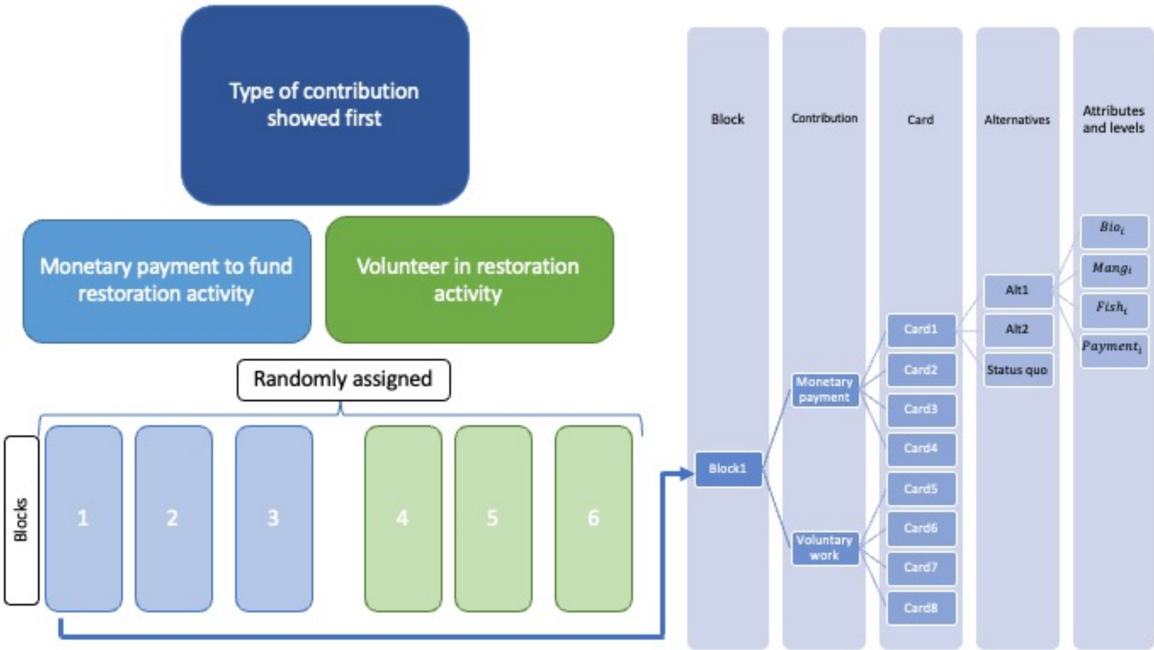

Figure 3-3. Representation of experiment design.

3.3 Results

3.3.1 Perception of mangrove restoration

In total 430 surveys were applied in 5 sites prioritized within a 50km radius of the mangrove area centroid (see Figure 3-2) from October to December of 2021, with a convenience sampling approach (Galloway, 2004). Enumerators approached people in locations known to be frequented by a diversity of socioeconomic strata (i.e. low, medium, and high income) in urban areas such as parks and malls, while in rural areas additional door-to-door visits were implemented, always considering public health measures in place. The number of valid responses was 371, considering enumerators' mistakes, incomplete surveys, and protest answers. The distribution of surveys per site is presented in Figure 3-4.i. During the application, surveyors assigned randomly the block of choice cards that were presented to each person using a dice (Figure 3-4.ii) so there could be a fair distribution of cards in the sample.

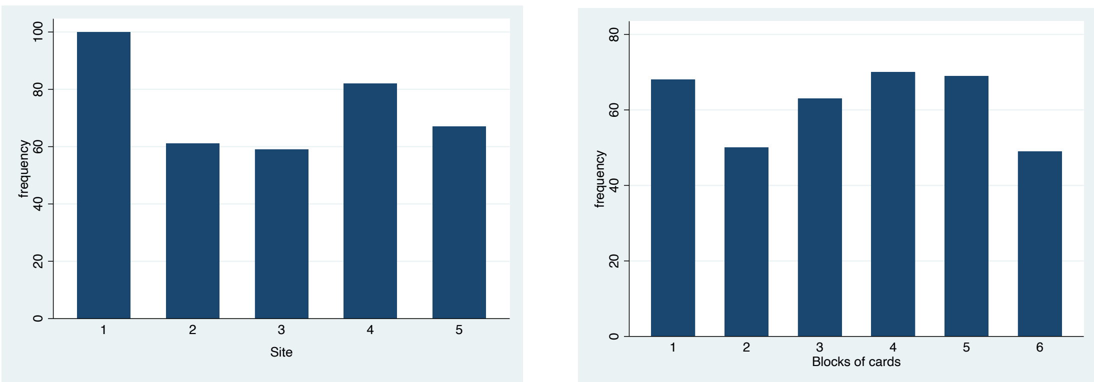

Figure 3-4. i) Distribution of surveys per site and ii) distribution of blocks of cards.

70% of the respondents are men, 68% have a partner, 52% self-reported being in the lowest category of individual income (less than a minimum national wage rate), and only 7% reported they completed studies beyond high school. 26% of the sample reported fishing as the main activity in which they interact with the mangrove. Finally, 34% of the sample corresponds to individuals living in urban areas, while 17% are considered to live in the furthest site from mangroves which is also considered a rural site, this is site 2 in Figure 3-2 (see Figure 3-5).

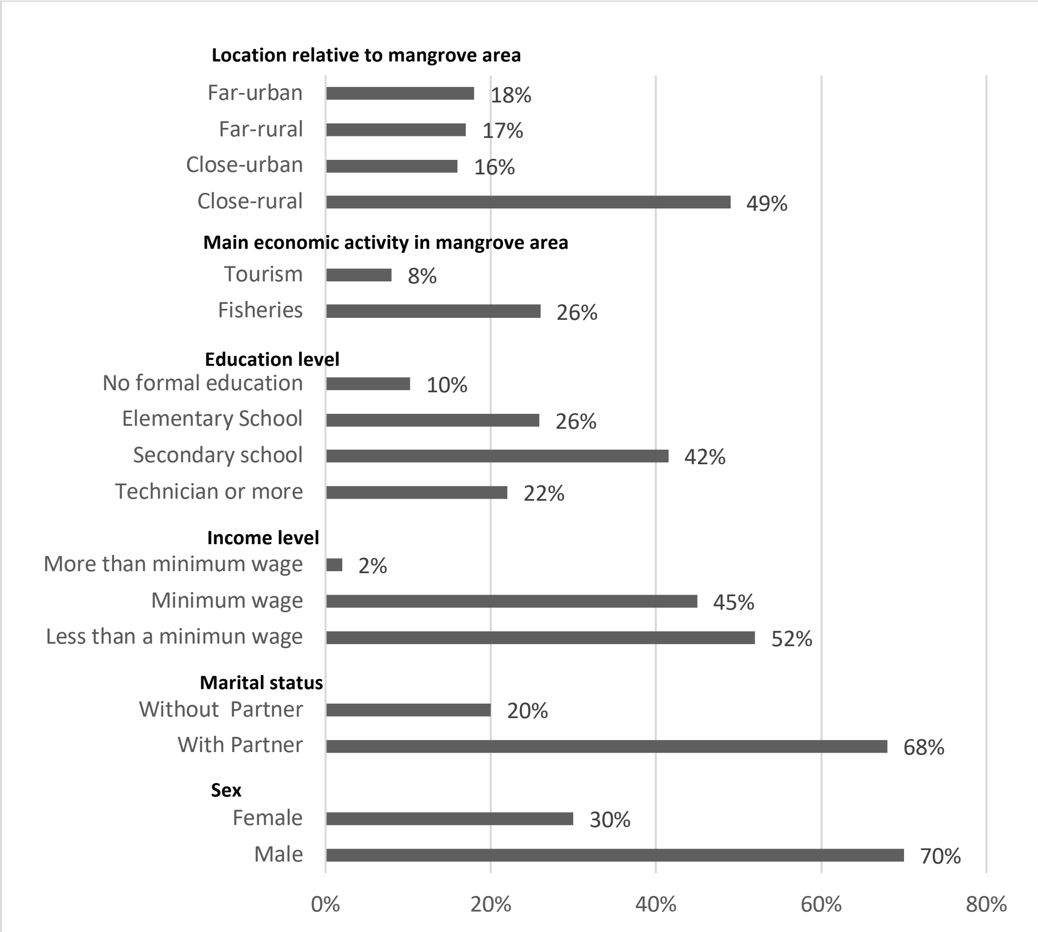

Figure 3-5. Main characteristics of the sample.

Regarding the perception of the mangrove area, 86% of the respondents reported knowing the site. 64% of respondents reported having direct interaction with mangroves, including fishing, tourism and living surrounded by mangrove areas. People stated what zone they interact with the most, within the mangrove area in Cienaga Grande de Santa Marta, including the Marine Protected Areas Salamanca Island (VIPIS) and Sanctuary for Flora and Fauna (SFF), the Road zone, the Agricultural zone and the mangrove surrounding the communities living over the estuary waters (Palafitos) (see C.2). For those zones, people reported their perception of changes in mangroves in the last 20 years, or from when they started the interaction. In general, 33% of the sample perceived a negative change in the mangrove area they interacted with the most. On the other hand, 36% of the sample perceived a positive change, and 17% did not perceive any changes in mangroves in this period. 12% of the sample considered they did not have enough knowledge or interaction with this area to perceive any changes. In terms of specific zones, a majority of people perceive a positive change in the Palafitos' mangrove (the zone with mangroves surrounding communities living over the estuary), while in the other zones, the proportion of people perceiving positive changes was at most six percentage points higher than the proportion of people perceiving negative changes (see Figure 3-6). Finally, 41% of respondents stated they knew about the restoration process before this survey.

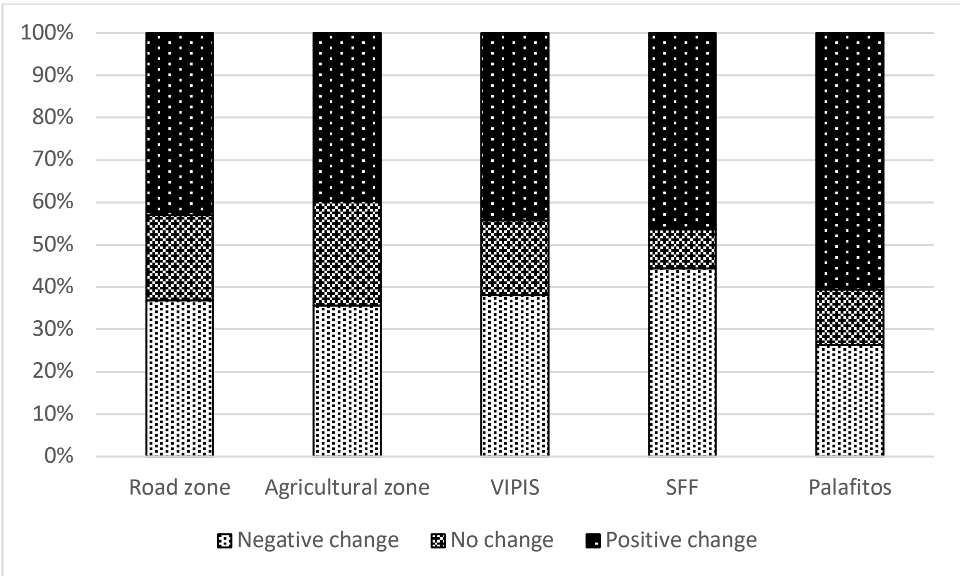

Figure 3-6. Perception of mangrove change by zones in CGSM.

Regarding the institutions related to the management, research, and environmental regulation in this area, and the public perception of them to potentially manage the restoration program, in general terms, there is a better perception of institutions in urban areas. INVEMAR (the institution applying the survey) and the National Natural Park Administration - PNN (with local presence in two protected areas in CGSM), are the institutions with the higher favourability regarding their potential role as restoration program managers in this site. In contrast, CORPAMAG which is the environmental authority in charge of the restoration program and administration of the economic resources invested in environmental programs in this area (the area that is not under National Natural Parks coverage), has a less favourable perception on its role in restoration management, together with the private sector. Finally, there is a statistically significant difference between the perception of people living in mangrove areas, urban areas, and the furthest surveyed site, about the role of CORPAMAG, NGOs, PNN, and the private sector in managing the restoration program (see Figure 3-7).

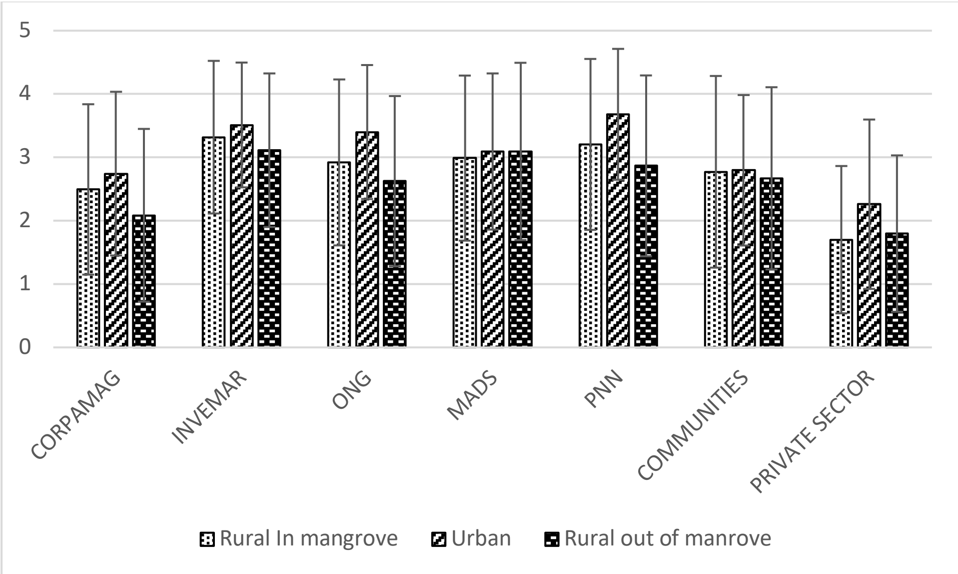

Figure 3-7. Perception of institutions as managers of restoration programs.

3.3.2 Preferences for mangrove ecosystem services

To analyse the preferences for mangrove ecosystem services the information reported prior to the choice experiment questions is analysed. Respondents were presented with a bundle of mangrove main ecosystem services (Barbier, 2017; de Groot et al., 2006) and they had to choose the most important for them. To model the probability to pick one ecosystem as most important a multinomial logit model was analysed. In this model, the dependent variable takes one of five possible values according to the type of ecosystem service chosen by the individual (i.e. provision, regulation, cultural, support). Initially, the ecosystem categories were organized as (de Groot et al., 2002; Kumar, 2010):

i) Provisioning ecosystem services: Fish and wood

ii) Regulating ecosystem services on a local scale: Coastal protection, water quality regulation, and local temperature regulation.

iii) Regulation ecosystem services on a global scale: Carbon sequestration and storage.

iv) Cultural ecosystem services: Opportunities for ecotourism.

v) Support: Biodiversity support (i.e. biodiversity of birds).

A set of independent variables were included in the model classifying the sites between close/far and rural/urban, resulting in four categories: close-rural (sites 1 and 4 in Figure 3-2), close-urban (site 3), far-rural (site 2) and far-urban (site 5); likewise sociodemographic variables like age and education levels were included. The empirical model is defined as:

$$Y_{ij} = \beta_0 + \beta_{Fish}Fisher_i + \beta_{CU}CU_i + \beta_{FR}FR_i + \beta_{FU}FU_i + \beta_{Age}Age_i + \beta_{Educ}Educ_i + \mu_{ij}$$

where Y is the preference indicator, this is, the choice of the *e*-est ecosystem service category made by the *i-est* individual, where *i*=1, 2,..,371, *j*=1,2,…,5, and j=1 represents the base category. *Fisher* is a dummy indicating if the respondent is a fisherman, *CU, FR, and FU* are dummies indicating if the respondent lives in an urban area close to mangroves, a rural area far from mangroves, or an urban area far from mangroves. *Age* and *Educ* are continuous variables indicating age and years of education respectively.

Table 3-2. Results of multinomial logit modelling preferences for ecosystem services.

Multinomial Logit Odd ratios				
	Regulation (no carbon reg)/ Provisioning	Carbon regulation/ Provisioning	Cultural/ Provisioning	Biodiversity/ Provisioning
Fisherman	0.40 (0.19 - 0.83)	0.30 (0.13 – 0.69)	0.55 (0.14 - 2.12)	1.56 (0.58 - 4.18)
Location: Close/Urban	2.00 (0.64 - 6.25)	8.14 (2.81 - 23.59)	1.30 (0.23 - 7.15)	9.87 (2.62 - 37.17)
Location: Far/Rural	1.72 (0.76 - 3.90)	0.86 (0.32 - 2.29)	0.00 (0.00 - 5.00)	4.77 (1.55 - 14.65)
Location: Far/Urban	0.82 (0.30 - 2.25)	4.95 (2.01 - 12.22)	0.75 (0.16 - 3.58)	1.73 (0.41 - 7.33)
Age	0.96 (0.94 - 0.98)	0.97 (0.95 - 0.99)	0.99 (0.96 - 1.03)	0.95 (0.92 - 0.98)
Years of Education	1.02 (0.94 - 1.09)	0.98 (0.91 - 1.06)	1.16 (1.05 - 1.36)	1.06 (0.95 - 1.17)
Constant	5.87 (1.66 - 20.73)	2.73 (0.76 - 9.81)	0.09 (0.01 - 1.03)	0.77 (0.14 - 4.34)
N	371			
Pseudo-R^2	0.12			
ll	-473			
Confidence intervals in parentheses				

Table 3-2 shows the results for the odd ratios from the multinomial logit regression. Overall, people are almost 6 times more inclined to prioritise regulating ecosystem services over provisioning ecosystem services. However, fishermen will prefer provisioning services (i.e. fish and wood) over regulating ecosystem services (including carbon sequestration), while there are no significant results for preferences of cultural (i.e. recreation) or supporting (i.e. biodiversity) over provisioning ecosystem services. On the other hand, regarding the location relative to mangroves and the type of population, compared with rural areas closer to mangroves, people living in urban areas closer to mangroves will be 8 times more likely to prioritize carbon regulation service (i.e. carbon sequestration and storage), and almost 10 times keener to prioritize supporting ecosystem services related to biodiversity, than provisioning ecosystem services. Likewise, individuals in rural areas far from mangroves will be almost five times more prone to prioritize supporting ecosystem services related to biodiversity than provisioning ecosystem services in comparison with people living closer to mangroves. Finally, when compared with people living in mangrove areas, those who live in urban areas far from mangroves are nearly 5 times keener to prioritize carbon regulation ecosystem services than provisioning ecosystem services.

As for sociodemographic characteristics, one additional year of age is associated with a decrease in the odds of prioritizing all types of ecosystem services versus provisioning ecosystem services (i.e. older people prefer provision ecosystem services like fish and wood from mangrove areas relative to other types of contributions from mangroves). Lastly, one more year of education is associated with an increase in the odds of prioritizing cultural ecosystem services (i.e. opportunities for ecotourism) versus provisioning ecosystem services.

3.3.3 Willingness to contribute to mangrove restoration

As people were presented with both contribution options, monthly payments and weekly hours for voluntary work, results show that most people were willing to contribute with voluntary work rather than with a monetary payment. 18% of the respondents choose the status quo, not contributing with either money or voluntary work. 23% choose not to contribute with a monetary payment but with voluntary work, while 4% choose not to contribute with their time for voluntary work but contribute with a monthly payment (see Table 3-3 and Figure 3-8).

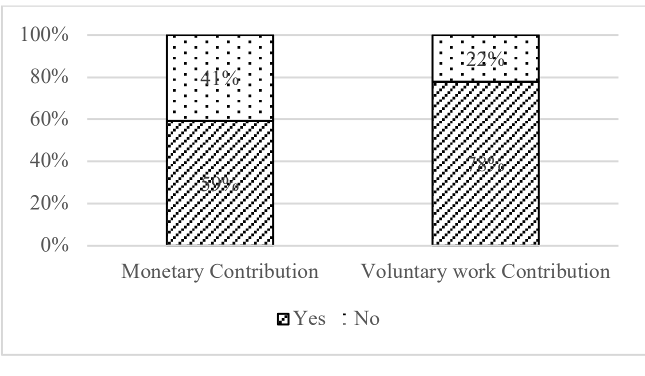

Figure 3-8. Distribution of willingness to contribute by type of payment vehicle.

Table 3-3. Distribution of willingness to contribute by type of payment vehicle.

N=371	Voluntary work Contribution			
		Yes	No	Totals
Monetary Contribution	Yes	55%	4%	59%
	No	23%	18%	41%
	Totals	78%	22%	100%

As one of the interests of this research is to analyse the preferences of beneficiaries for the possible environmental outputs of the improvement in restoration programs, the effect of attributes on the expected utility were also analysed. A conditional logit model (McFadden 1974), including an interaction to test the effect of the order in which the different types of contributions were presented (T) was initially tested.

$$Y_{itj} = \alpha_{asc0_i} + \beta_{Bio}Bio_{itj} + \beta_{Mang}Mang_{itj} + \beta_{Fish}Fish_{itj} + \beta_{Cont}Cont_{itj} + \beta_{asc0}asc0_{itj=1} * T_{it} + \mu_{itj}$$

where Y is the preference indicator, this means the choice of the j-est alternative made by the *i-est* individual in the *t-est* choice card, where *i*=1, 2,..,371, *t*=1, 2, …,8, and *j*=1,2,3, and j=1 represents the status quo. *Bio, Mang, Fish* and *Cont* are attributes that describe the alternatives presented, where *Cont* attribute can be monetary or voluntary work contribution. The alternative specific constant (ASC) for the status quo α_{asc0_i} (j=1) acts as a constant in this model capturing the average effect of unincluded factors of the "no contribution" alternative, relative to the alternative chosen. Finally, T represents the treatment of the order in which the contributions frames were presented, in this case, we define it as a dummy for presenting monetary contribution first.

The conditional logit assumes that preferences are homogenous, implying that the unobserved utility part of an alternative is not linked to the unobserved utility part of another alternative, this translates into the error terms being independent and identically distributed. This leads to the assumption of the Independence of Irrelevant Alternatives (IIA), stating that the introduction or removal of alternatives does not affect the probability of selecting a specific alternative (Cheng & Long, 2007). This assumption does not allow the identification of the effects of heterogeneity in the preferences. A solution for this can be the implementation of other models that relax these assumptions like the mixed logit (Train, 2009).

By using a mixed logit model, the model fitting is improved, and individual characteristics can also be captured. Mixed effects are included using ASC0 and *Cont* as fixed effects and *Bio, Mang, Fish and* $asc0 * T$ as random effects. Individual characteristics were also included as fixed effects interacting with ASC0 (see Table 3-4). As the payment vehicle and framing for each contribution were different, separate models were analysed to corroborate how the public responded to each contribution individually.

Table 3-4. Individual-level variables included in the model.

Variable	**Description**	**Mean**	**SD**	**Max**	**Min**
CR	Living in rural areas close to mangroves	0.491	0.500	1	0
FR	Living in rural areas far from mangroves	0.170	0.375		
CU	Living in urban areas close to mangroves	0.159	0.366	1	0
FU	Living in urban areas far from mangroves	0.181	0.385	1	0
Restor	Know about restoration before this survey	0.334	0.472	1	0
Negative change	Perceive a negative change in mangroves in the last 20 years	0.415	0.493	1	0
Inc	Income per hour - US$ 2021 (self-reported)	0.872	0.662	4.557	0.390

3.3.3.1 Monetary payment vehicle

Regarding the monthly monetary payment vehicle, this was presented as a tax to be included in a household bill to pay monthly for at least 5 years, and 59% of the sample is willing to pay to improve the restoration program. Table 3-5 reports the results for the willingness to pay regression models.

In the conditional logit model, the biodiversity attribute is not significant for the choice made by individuals, while mangroves and fisheries attributes are. The payment attribute is also significant and negative as expected. This means that except for biodiversity, individuals will prefer scenarios where environmental attributes related to fisheries and mangrove extension are better and where the contribution is lower. The alternative specific constant for the no contribution or status quo (ASC0) was positive and significant, which means that on average this sample will prefer to stay in the current situation (holding everything else constant) as the magnitude for this coefficient is larger than the rest in this model. However, as discussed, the conditional logit model is restricted in terms of modelling heterogeneity in preferences.

Table 3-5. Regression models for monetary payment vehicle.

	(1) Conditional Logit	(2) Panel Mixed Logit	(3) SD	(4) Panel Mixed Logit + Covariates	(5) SD
Large change in Biodiversity	0.03	-0.394*	1.877***	-0.236	1.488***
	(0.092)	(0.238)	(0.386)	(0.226)	(0.379)
Mangrove area restored (km^2)	0.002**	0.004*	0.020***	0.004*	0.019***
	(0.001)	(0.002)	(0.004)	(0.002)	(0.004)
Annual fish catch (Ton)	0.001***	0.002***	0.006***	0.002***	0.005***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Payment (2021-US$)	-0.124***	-0.185***		-0.187***	
	(0.016)	(0.025)		(0.026)	
ASC0	0.526***	0.563**		1.702***	
	(0.139)	(0.243)		(0.500)	
Treatment*ASC0	-0.058	0.411	9.136***	0.523	7.598***
	(0.107)	(0.617)	(1.181)	(0.893)	(1.354)
CU* ASC0				1.410**	
				(0.701)	
FR* ASC0				1.588***	
				(0.518)	
FU* ASC0				-0.373	
				(0.592)	
Negative change*ASC0				-0.996**	
				(0.398)	
Restor*ASC0				-0.829**	
				(0.405)	
Income*ASC0				-0.963***	
				(0.348)	
Observations	4,452	4,452		4,452	
N	371	371		371	
ll	-1423	-1117		-1076	
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1					

Table 3-5 also reports results for the mixed logit model. First, including only attributes similar results as in the conditional logit model are obtained but we can observe a better model fit overall. Furthermore, adding individual's characteristics as covariates, improves the model as for the comparison between maximised Log-Likelihood. In this last model, although when asking people to contribute with a monetary payment, they are more willing to stay in the current situation, (i.e. the restoration programs as it is), as $\alpha_{ASC0} = 1.7^{***}$.

While biodiversity is again not significant for choosing an alternative, the standard deviation is showing that there is statistically significant variability (i.e. some people have a higher effect of the biodiversity attribute over their utility from the restoration scenarios, while others have lower or no effects). On the other hand, both mangrove and fisheries attributes, are significant and positive, meaning that people would prefer improved restoration scenarios where mangroves and fisheries have a positive change. Monetary contribution is significant and with the expected sign.

Regarding individual characteristics, these are presented as an interaction with the alternative specific constant for the status quo (ASC0). The variables representing the spatial distribution and the type of population were mostly significant, considering that the base category was the rural community living closer to mangrove areas. Here, the people living in urban areas closer to mangroves are keener to stay in the current situation instead of implementing an improved restoration program, versus people living in rural areas closer to mangroves. The same applied for people living in rural areas far from mangroves. Finally, the coefficient for urban areas far from mangroves resulted not significant. As for the attitude and knowledge variables, people that have any knowledge about the restoration process in the area prefer an improvement in the restoration programme. Likewise, those individuals that have perceived a negative change in the mangroves are also willing to move from the current restoration program and improve it, in contrast with those having a perception of positive change in mangrove areas in the last two decades, which is the reference category. Finally, people with the higher income are more willing to contribute than those with low income and change the current restoration program. Regarding the order in which the contribution types were presented, this treatment has no effect on the probability to favour an improvement scenario and on people's willingness to pay.

From the coefficients in Table 3-5, the willingness to pay and the aggregate value for each significant attribute is estimated. If the attention is just on the subsample of respondents willing to participate (59% of the sample), Table 3-6 reports the annual willingness to pay per household per attribute unit and the aggregate value for the total population in US$ 2021.

Table 3-6. Willingness to pay and value of mangroves and fish catch for direct beneficiaries.

Attribute	Annual mean WTP per household (2021 US$)	Annual value for all the beneficiaries (2021 US$/yr)	Present value for all the beneficiaries (5% discount rate - 2021 US$)
Mangrove area (km^2)	$0.256	$206,259	$1,031,295
Fish catch (Tons)	$0.128	$103,129	$515,647
Considering coefficients from mixed logit plus covariates results, and that 59% of beneficiaries in a 50km radius are willing to pay (550.296 households (DANE, 2018))			

On average respondents are willing to pay US$0.256 more for each additional km^2 of mangrove restored and an additional US$ 0.128 for an increase in one ton of fish catch. Considering the proportion of the sample that is willing to pay and aggregating for all beneficiaries in a 50km radius (550.296 households), the present value of an additional km^2 restored is US$ 1,03 million/km^2 or US$10,312/ha; this is equivalent to ~ US$2,062/ha/year. Similarly, the present value of an additional ton of fish caught as an output of the restoration program is US$515,647.62/ton or $568/kg, which is equivalent to ~US$113.6/kg/year.

3.3.3.2 Voluntary work payment vehicle

Most of the sample was willing to volunteer in restoration activities (78%). This contribution was presented as hours per week that people will be willing to volunteer to do restoration activities, inside mangroves or with the communities (i.e. sensitization), during a period of 6 months per year. Table 3-7 presents the results for the willingness to volunteer regression models.

Table 3-7. Regression models for voluntary work payment vehicle.

VARIABLES	(1) Conditional Logit	(2) Panel Mixed Logit	(3) SD	(4) Panel Mixed Logit + Covariables	(5) SD
Large change in Biodiversity	-0.02	-0.256	1.766***	-0.166	1.560***
	(0.080)	(0.186)	(0.321)	(0.17)	(0.294)
Mangrove area restored (ha/10)	0.002	0.003*	0.019***	0.004**	0.019***
	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)
Annual fish catch ton	0.001***	0.002***	-0.005***	0.002***	-0.005***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Hours per week	-0.078***	-0.124***		-0.123***	
	(0.011)	(0.019)		(0.019)	
ASC_SQ	-0.948***	-1.294***		-1.910***	
	(0.151)	(0.290)		(0.585)	
Treatment*ASC0	0.425***	-9.005***	23.946***	-6.400***	-21.991***
	(0.122)	(2.932)	(7.54)	(1.950)	(5.420)
CU* ASC0				1.772**	
				(0.819)	
FR* ASC0				2.442***	
				(0.606)	
FU* ASC0				0.553	
				(0.793)	
Negative change*ASC0				-0.325	
				(0.516)	
Restor*ASC0				-0.777	
				(0.555)	
Income*ASC0				0.043	
				(0.410)	
Observations	4,452	4,452		4,452	
N	371	371		371	
ll	-1527	-1175		-1137	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

From the environmental attributes presented, in the conditional logit model, only the fisheries attribute is significant for the choices between alternatives when asking people to work as volunteers in restoration activities. The time attribute is also significant and with the expected sign, which means respondents will prefer improved restoration scenarios where the fish harvest is higher, and the time spent as volunteers is lower. In contrast with the monetary contribution, on average people are willing to move from the status quo when asked to work as a volunteer; similarly, the coefficient for the treatment is also significant, however, considering the limitations of the conditional logit model, the interpretation of these coefficients might be omitting the heterogeneity in the sample. Hence, Table 3-7 also presents results for the mixed logit model, and its extended version, including individual characteristics.

In the complete version of the mixed logit model (column 4 in Table 3-7), mangrove cover restored and fish harvested are both significantly increasing the utility of the respondents, while the contribution of time for voluntary work is decreasing it, and people is indifferent to improvements in biodiversity. This means that people will prefer restoration programs that improve both, fish harvest and mangrove cover, while they can contribute with less voluntary work, and they do not consider biodiversity improvements. In contrast with the results for willingness to pay, in average people is willing to change from the current situation to a better restoration scenario ($\alpha_{ASC0} = -1.910^{***}$). As for the order in which the cards were presented, in this case presenting the monetary payment first does have a significant and positive effect over preferences for the current restoration program, this is, when people were presented with the monetary cards first, they were less keen to choose an alternative different from the current situation when asked to contribute with voluntary work. However, the standard deviation is significant too, thus the effect of showing first the monetary contribution over the election of alternatives in cards with volunteering as the payment vehicle, variates between individuals.

When including other individual-level variables, only spatial variables are significant, and here again, when comparing with individuals living in rural areas closer to mangroves, those living in urban areas close to mangroves are less keen to change to a different alternative from the current situation. Similarly, those respondents living in rural areas far from mangroves will be even less willing to move to a different alternative than those living closer to mangroves. A negative perception of change, knowledge about the current restoration programme and income are not significant but exhibit the expected signs.

Table 3-8. Willingness to volunteer and value of mangroves and fish catch for direct beneficiaries.

Attribute	Annual mean WTV per household (Hours)	Annual value for all the beneficiaries – Monetary approximation (2021 US$/yr)	Present value for all the beneficiaries (5% discount rate - 2021 US$)
Mangrove area (km^2)	0.78 hrs	$207,125 - $683,250	$1,035,628 - $3,416,251
Fish catch (Tons)	0.39 hrs.	$103,562 - $341,625	$517,814 - $1,708,125
Considering coefficients from mixed logit plus covariates results, and that 78% of beneficiaries in a 50km radius are willing to volunteer for mangrove restoration activities (723,840 households (DANE, 2018))			

As for the willingness to volunteer, table 6 presents a summary of findings. People are willing to volunteer for 0.78 more hours on average for an additional km^2 restored under an improved restoration program. Additionally, they are willing to volunteer for 0.39 more hours on average for an additional Ton of fish caught as an output of restoration in this area.

Although there is no consensus in the literature on the best conversion rates to value time and the opportunity cost of time, here findings from Whittington and Cook (2019), were followed. They concluded that a feasible approximation for the value of time use outside the formal sector is to take 50% of the average wage rate after taxes. Assuming one person per household is doing the voluntary work and considering the proportion of the sample willing to volunteer, first, the average hourly wage rate self-reported by the sample (US$0.87/hr) can be considered. Alternatively, a second option is to take the minimum national wage rate for 2021 (US$2.8/hr). This allows to estimate present values for an additional km2 of mangroves restored between $ 1.03 million/km2 and $3.4 million/km2, or from US$10,356/ha to US$34,162.52/ha, which is equivalent to annual values of US$2,071/ha/yr to US$6,832/ha/year. On the other hand, following the same procedure an additional Ton of fish caught under an improved restoration program in the area has a present value between US$517,814/Ton and US$1.7 million/Ton, or between US$1,882/kg to US$570/kg. This is equivalent to annual values between US$376 kg/yr and US$114.16 kg/yr (see Table 3-8).

3.4 Discussion and Conclusions

In this chapter, the results of a choice experiment survey investigating the perceptions and preferences of direct beneficiaries for environmental outputs of a restoration program in CGSM are presented. The sample chosen is representative of direct beneficiaries in a 50km radius of mangroves and includes inhabitants from cities and rural areas in the surroundings of CGSM.

As for the preferences for mangrove ecosystem services in this area, overall, people prioritize regulating ecosystem services (coastal protection, water quality regulation, and local temperature regulation) over provisioning ecosystem services. However, the opposite occurs in the case of inhabitants whose livelihoods rely on natural resources (e.g. fishermen). In contrast, people living in urban areas give more priority to climate regulation through carbon sequestration and storage. People living outside of mangroves and whose livelihoods do not rely directly on natural resources in the area will also prioritize support for the biodiversity of bird species. Finally, older people prioritize the provisioning ecosystem services over the rest, while people with more years of education give more importance to cultural ecosystem services. This can be related to the traditional use and knowledge of the area supporting fisheries (Torres-Guevara et al., 2016), versus the access to new information about the importance of regulation and cultural services usually available for younger and more educated people.

People were presented with possible environmental outcomes of an improved restoration program plus a contribution that helps to support it. Although respondents were presented with two different possible payment vehicles (monthly payment and weekly time for volunteering) there are similar results in terms of preferences for better fishing and mangrove cover outputs, and the indifference towards biodiversity of birds outcome when bundled with the two first attributes. These results are related to the traditional use of the area as supporting livelihoods for the local people, especially through fishing and direct extraction of wood for domestic use, and less as an ecosystem offering other services like support of birds' biodiversity. This ecosystem service could be more relevant for more direct users of ecotourism activities or specialized birdwatchers (Maldonado et al., 2018), and for people living in areas with less biodiversity (i.e. urban areas).

On the other hand, respondents were more willing to contribute when asked to volunteer (e.g. giving part of their time) than when asked to pay, this is consistent with findings in the literature, where labour contribution reduces the proportion of zero bids (Asrat et al., 2004; Brouwer et al., 2009; Kamuanga et al., 2001), similarly, asking people to pay and then to volunteer had an effect over willingness to volunteer, as people prefer to stay in the current situation without contributing for improvements in the restoration program.

Additionally, there is also evidence on the effect of distance to mangroves (Far vs. Close) over willingness to contribute (with money or with time), as compared with people living within mangrove areas, people living just outside and far from mangroves are less keen to choose a different scenario of mangrove restoration and contribute, especially when asked to contribute with their time. On the other hand, there is not a significant difference regarding the type of population (Urban vs. Rural) other than their location in reference to mangrove areas. This can be interpreted as distance decay of value and how further away from the ecosystem its relevance for people decreases (Johnston et al., 2019). However, recalling results from the first preferences exercise in this study, the importance of the ecosystem for these populations is given through other services like regulation and cultural services (i.e. carbon regulation, erosion control, and ecotourism). Finally, although physical indicators show a net increase in mangrove cover, with a recovery of around 12,000 hectares between 2000 and 2021 (INVEMAR, 2022; Rodríguez-Rodríguez et al., 2021), the perception of change in mangrove cover is divided among the respondents, and it variates according to the zone the respondent has more interaction with. Thus, perceptions of positive change are especially predominant in the Palafitos zone, where most of the restoration actions have taken place (Rodríguez-Rodríguez et al., 2021). Perception influences the preferences for improved alternatives. Similarly, knowing about the restoration actions in the past influences the preferences for improving those actions in the future.

Regarding the estimation of willingness to pay and willingness to volunteer, although these payment vehicles were not directly related (i.e. the payment was not equivalent to the time volunteering), results were similar. Considering the part of the sample willing to contribute and taking a proportion of the self-reported salary in this sample as the shadow value of time, the results of both payment vehicles are very similar with values for an additional hectare of mangrove restored of US$2,062/ha/yr and US$2,071/ha/yr for monetary payment and volunteering respectively. These values are similar to those estimated by de Rezende et al. (2015), who using a choice experiment valued the mangrove restoration at US$1,837/ha/yr and US$2,375/ha/yr for moderate and complete restoration respectively

Conclusion

This dissertation contributes to assessing the value of Latin American mangroves presenting a combination of economic valuation methods for a case study in Colombia. Past restoration activities and future initiatives are assessed via meta-regression analysis, production function and choice experiment methods. While Latin American mangroves constitute approximately 14% of global coverage, they have been historically underrepresented in previous studies (Brander et al., 2006; Brander, Wagtendonk, et al., 2012; Ghermandi et al., 2011; Salem & Mercer, 2012)(Brander et al., 2006; Brander, Wagtendonk, et al., 2012; Ghermandi et al., 2009, 2011; Salem & Mercer, 2012).

For this reason, the research presents valuable insights into the role and ecosystem services provided by Latin American mangroves and helps to extend the research on the vital role of this ecosystem. The meta-regression in Chapter 1 has highlighted that food provision, recreation, and carbon regulation are the most frequently valued ecosystem services in Latin America, aligning with previous global analysis. At the same time, the research reveals the need for research around mangroves' coastal protection and biodiversity support.

Overall, findings from Chapter 1 (meta-regression analysis) support previous findings, emphasizing the high economic value associated with regulation services compared to provision services. This highlights the key role of mangroves in coastal protection, carbon sequestration, and water quality regulation. Results also confirmed the sensitivity of mangrove value to income levels and local population density, reflecting the direct benefits accrued by nearby communities. Additionally, the spatial analysis revealed nuanced relationships, indicating that the value of additional mangrove hectares varies based on the type of ecosystem service being valued. For instance, the effects of total mangrove area on economic value are contingent upon whether provision-type services like fisheries and wood are considered. These findings suggest to policymakers and stakeholders that restoration efforts should be prioritized especially if they support provisioning services since these play a key role in safeguarding direct benefits to local communities.

Chapter 2 dives into understanding the role of mangroves as fish nurseries and their contribution to local fisheries economies. These estimations offer an initial understanding of the economic importance of mangrove ecosystems for artisanal fisheries, especially in the Colombian Caribbean. The analysis partials out the role of fishing factors, such as gear type, effort intensity, and proximity to markets, on fish harvest and revenues and, consequently, identifies the role of mangroves on economic benefits for local communities. Findings emphasize the importance of restoration initiatives that have enhanced mangrove cover and provided economic benefits of at least US$938,759 for the past two decades to the small-scale artisanal fisheries in CGSM.

Finally, the stated preferences survey provides valuable insights into the preferences and priorities of direct beneficiaries for future environmental mangrove restoration options helping to gain priority among actions and ecosystem services to value. Results highlight a general preference for regulation of ecosystem services, except for those whose livelihoods are directly relying on natural resources, like fishermen, who prioritize provisioning services. This emphasizes the importance of coastal protection, water quality regulation, and local temperature regulation for the population in and around mangrove areas. Additionally, the study distinguishes preferences based on factors such as age, education level, and proximity to mangroves. Findings stress the need for tailoring restoration strategies to accommodate the diverse perspectives and needs of different beneficiary groups. Furthermore, the choice experiment results revealed that individuals were more inclined to volunteer their time rather than make monetary contributions towards restoration improvements. The distance from mangroves had a notable effect on willingness to contribute, with those living further from the ecosystem being less inclined to support restoration efforts, particularly when asked for their time. On the other hand, there was not a clear distinction between urban and rural populations regarding their willingness to contribute, signaling an overall interest in preserving and restoring mangroves, conditioned to their proximity to the ecosystem.

Findings from this case study are crucial to signal the fundamental role that local communities hold in designing restoration programs that are not only ecologically effective but also socially sustainable. By prioritizing outcomes like improved fishing opportunities and increased mangrove cover, restoration efforts can be tailored to align with the needs and livelihoods of local communities, promoting a sense of ownership and engagement (Coelho-Junior et al., 2021). Moreover, the preference for volunteering over monetary contributions suggests an opportunity for community involvement that can be used to mobilize resources and labour for restoration initiatives, even in resource-constrained settings (Valenzuela et al., 2020). Additionally, the study's assessment of the influence of distance from mangroves on willingness to contribute highlights the importance of considering spatial factors in restoration planning, which can guide the targeting of interventions to areas where they are likely to be most effective and welcomed by the local population. These insights provide practical guidance, especially for Latin American countries that aim to implement successful mangrove restoration programs and provide environmental and social benefits for communities that depend on mangroves.

Values here estimated can be used in environmental management to design financial strategies that support conservation and restoration initiatives helping to achieve global restoration and conservation goals (UNEP, 2022) including informing the development and implementation of Integrated Coastal Zone Management (ICZM) policies (Forst, 2009), the design and implementation of Payments for Ecosystem Services (PES) programs involving the compensation of communities for maintaining or restoring mangrove ecosystems to ensure the continued provision of valuable services like carbon sequestration, coastal protection, and habitat for commercial fish species (Maniatis et al., 2019; Pagiola et al., 2004) as well as to justify the establishment and expansion of Marine Protected Areas (MPAs) that include mangrove habitats (Dabalà et al., 2023; Siikamäki et al., 2012).

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Appendix

Appendix A. Mangrove meta-analysis and benefit transfer

A.1 Primary studies for mangrove meta-analysis

Table A.1-1. Primary studies used in mangrove meta-analysis.

Reference	Type of publication	Country	Obs.
(Windevoxhel, 1994)	Thesis	Nicaragua	3
(Barton, 1995)	Thesis	Costa Rica	6
(Farber, 1996)	Paper	US	4
(Gammage, 1997)	Report	El Salvador	2
(Barbier & Strand, 1998)	Paper	Mexico	1
(Cabrera et al., 1998)	Article	Mexico	3
(Milon et al., 1999)	Paper	US	1
(Wilson, 2001)	Thesis	Colombia	1
(Castiblanco, 2002)	Paper	Colombia	3
(Dharmaratne et al., 2000)	Report	Trinidad y Tobago	1
(MARN, 2002)	Report	El Salvador	3
IUCN, 2004 (ESVD (Brander et al., 2023))	Report	Costa Rica	1
(Sanjurjo Rivera et al., 2005)	Conference proceedings	Mexico	27
(Lozano Torres, 2007)	Paper	Colombia	1
(Charcape, 2007)	Thesis	Peru	4
(Aburto-Oropeza et al., 2008)	Paper	Mexico	1
(Fajardo, 2009)	Thesis	Colombia	4
(Daza & Maldonado, 2009)	Thesis	Colombia	2
(Cooper et al., 2009)	Working paper	Belize	3
(De la Peña et al., 2010)	Paper	Colombia	3
(Carbal Herrera, 2010)	Paper	Colombia	4
(Ituarte, 2010)	Report	Ecuador	1
(Oliva Posada & Londoño Diaz, 2011)	Report	Colombia	1
(Souza & Ramos e Silva, 2011)	Paper	Brazil	3
(Poce-Diaz et al., 2011)	Book-section	Mexico	2
(Beltre, 2011)	Thesis	Dominican Republic	2
(IIAP, 2012)	Report	Colombia	1
(Vargas-Morales et al., 2013)	Report	Colombia	2

Reference	**Type of publication**	**Country**	**Obs.**
(Farah, 2013)	Thesis	Colombia	1
(Maldonado et al., 2013)	Working paper	Colombia	3
(Herrera & Vargas-Morales, 2014)	Report	Colombia	3
(Zárate & Maldonado, 2014)	Working paper	Colombia	3
(Chacon, 2014)	Report	Panama	4
(Pupo García & Parada Corrales, 2015)	Paper	Colombia	2
(Carbal Herrera & Muñoz Carbal, 2015)	Paper	Colombia	4
(Maldonado et al., 2015)	Report	Colombia	3
(de Rezende et al., 2015)	Paper	Brazil	3
(Duque-Estrada et al., 2015)	Paper	Brazil	3
(Arguedas, 2015)	Thesis	Costa Rica	3
(Contreras, 2016)	Paper	Colombia	4
(Guillen-Oñate et al., 2016)	Report	Colombia	3
(Leon Gonzalez et al., 2016)	Paper	Colombia	1
(Solá Defranc, 2016)	Thesis	Ecuador	5
(Diaz et al., 2016)	Paper	Cuba	3
(Romero & Cardenas, 2017)	Report	Colombia	2
(Bravo, 2017)	Thesis	Ecuador	1
(Rojas-Villeda, 2017)	Thesis	Honduras	3
(Cuervo-Sánchez et al., 2018)	Paper	Colombia	1
(Rojas et al., 2019)	Paper	Colombia	6
(Tanner et al., 2019)	Paper	Ecuador	2

A.2 Graphic analysis of values reported, and context variables used in the meta-analysis.

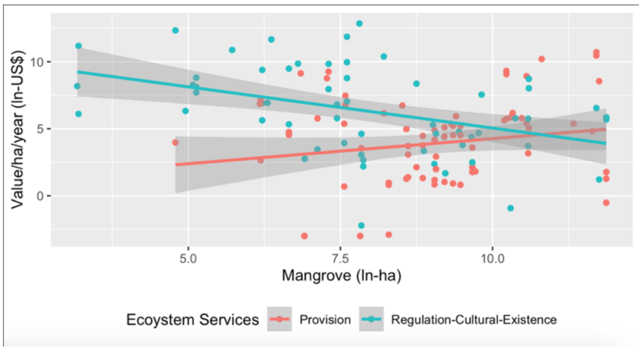


Figure A.2-1. Mangrove area and values.

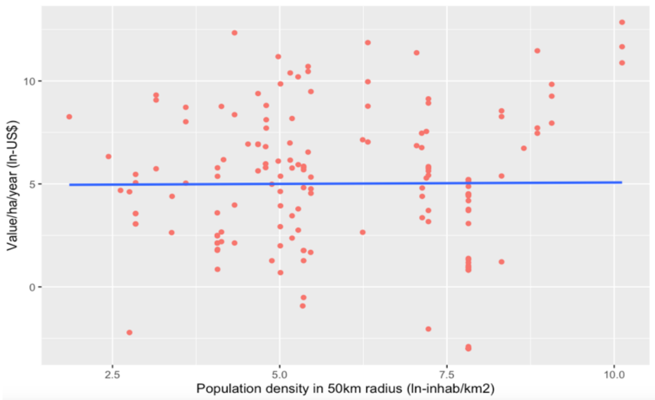


Figure A.2-2. Population density and values.

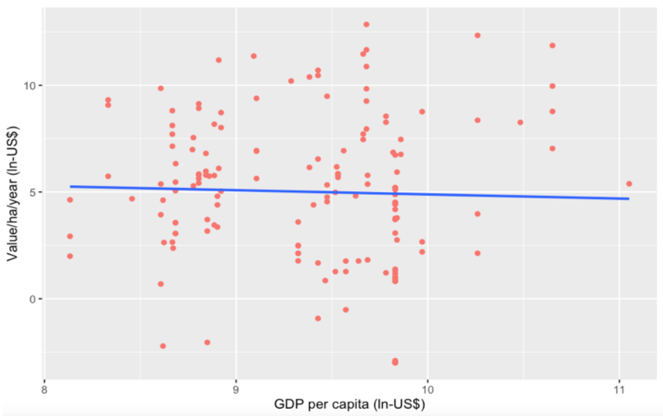


Figure A.2-3. GDP per capita and values.

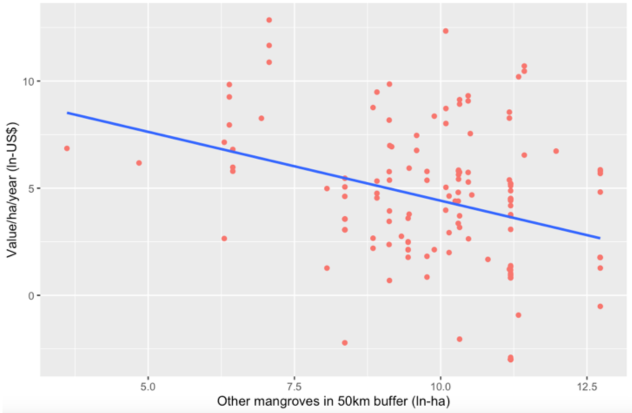


Figure A.2-4. Other mangroves patches and values.

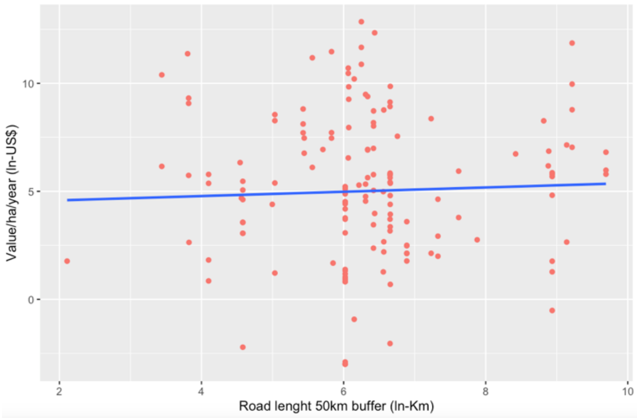


Figure A.2-5. Roads and values.

A.3 Linear mixed model regression results

Table A.3-1 Results for linear mixed model – Meta-regression model.

Linear Mixed Model: value per hectare per year (ln)	
Fisheries	−11.40 (2.91)∗∗∗
Wood extraction	−10.22 (6.51)
Carbon Regulation	3.53 (1.02)∗∗∗
Coastal protection	2.89 (1.45)∗∗
Water quality	2.13 (1.34)
Multiple ES	0.06 (1.25)
Non-use value	2.37 (1.49)
Mangrove Area (ln)	−0.44 (0.23)∗
Total Mangrove Area: Fisheries	1.40 (0.32)∗∗∗
Total Mangrove Area: wood	1.23 (0.77)
Population Density (Ln)	0.54 (0.30)∗
GDP per capita (ln)	1.77 (0.98)∗
Other mangroves areas (ln)	−0.18 (0.12)
Roads (ln)	−0.78 (0.44)∗
Paper	0.63 (1.17)
Report	2.30 (1.49)
Intercept	−3.21 (8.14)
Year: 1997	0.33 (3.71)
Year: 1998	−6.93 (4.16)∗
Year: 1999	4.54 (4.85)
Year: 2001	−0.77 (4.50)
Year: 2002	0.02 (3.07)
Year: 2004	−2.81 (4.45)
Year: 2005	−7.17 (4.08)∗
Year: 2007	−1.21 (3.12)
Year: 2008	−0.92 (4.50)
Year: 2009	−2.50 (3.17)
Year: 2010	−2.47 (3.00)
Year: 2011	−1.45 (3.20)
Year: 2012	−4.28 (4.76)
Year: 2013	−3.42 (3.31)
Year: 2014	−4.14 (3.54)
Year: 2015	−3.28 (2.95)
Year: 2016	−2.38 (2.97)
Year: 2017	−2.35 (3.11)
Year: 2018	−11.76 (5.31)∗∗
Year: 2019	−2.14 (3.43)
AIC	699.45
BIC	826.73
Log Likelihood	−307.73
Num. obs.	153
Num. groups: Study	50
Var: Study (Intercept)	4.12
Var: Study Fisheries	7.52
Cov: Study (Intercept) Fisheries	−2.53
Var: Residual	4.35
∗∗∗p < 0.01; ∗∗p < 0.05; ∗p < 0.1	
Standard errors in parentheses	

A.4 Mean Absolute Percentage Error (MAPE) for meta-regression

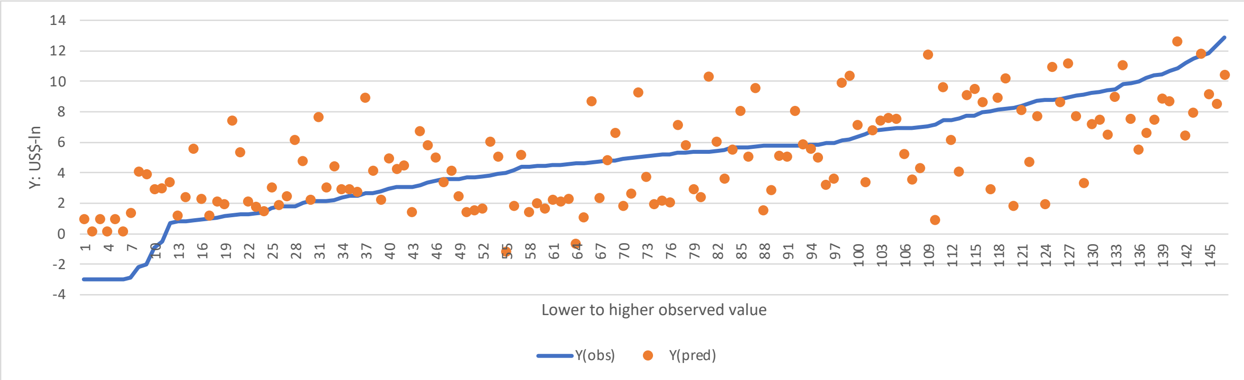


Figure A.4-1. Observed vs. predicted values and Absolute Error.

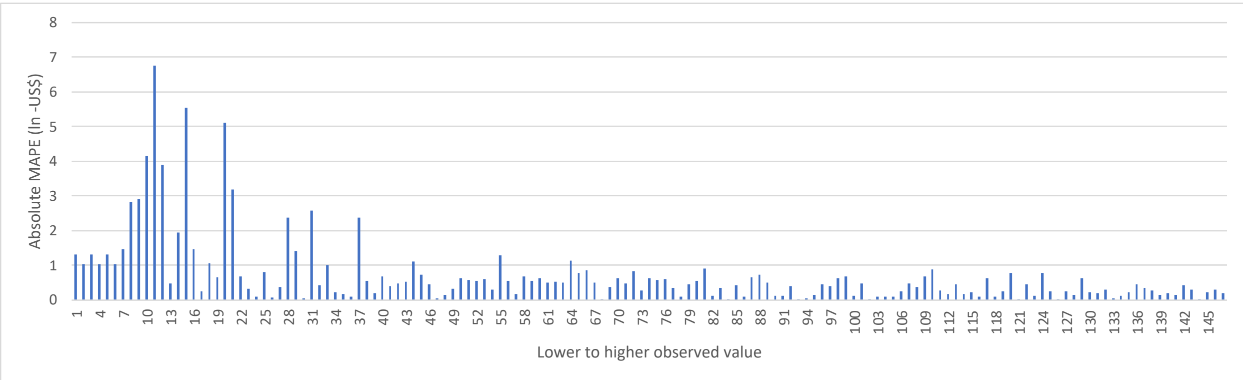


Figure A.4-2. Absolute MAPE.

A.5 Values per hectare per year for Marine Protected Areas in Colombia

Table A.5-1. Values per hectare per year for Marine Protected Areas in Colombia (2019 US$;000s).

No.	Coast	Marine Protected Area	Mangrove Area (ha;000s)	Fisheries	Wood	Carbon Regulation	Coastal Protection	Water Quality Regulation	Recreation	Non-use values
1	Caribbean	Bahia Portete - Kaurrele	1.20	0.87	0.85	130.11	68.60	32.08	3.81	4.05
2	Caribbean	Musichi	0.01	0.01	0.01	598.00	315.32	147.47	17.52	18.61
3	Caribbean	Delta del Rio Rancheria	0.09	0.03	0.04	153.62	81.00	37.88	4.50	4.78
4	Caribbean	Los Flamencos	0.18	0.03	0.05	70.08	36.95	17.28	2.05	2.18
5	Caribbean	Refugio Guajiro	0.01	0.00	0.00	340.40	179.49	83.94	9.98	10.59
6	Caribbean	Tayrona	0.06	0.02	0.03	213.74	112.70	52.71	6.26	6.65
7	Caribbean	La Esperanza	0.04	0.01	0.01	144.01	75.94	35.51	4.22	4.48
8	Caribbean	Rivello	0.04	0.01	0.01	144.73	76.32	35.69	4.24	4.50
9	Caribbean	Vigo	0.04	0.01	0.01	136.56	72.01	33.68	4.00	4.25
10	Caribbean	Hacienda El Cequion	0.02	0.00	0.01	177.21	93.44	43.70	5.19	5.51
11	Caribbean	Sierra Nevada de Santa Marta	0.02	0.01	0.02	341.88	180.27	84.31	10.02	10.64
12	Caribbean	Isla de Salamanca	10.78	3.43	2.30	23.62	12.46	5.83	0.69	0.74
13	Caribbean	Cienaga Grande de Santa Marta	12.97	3.84	2.50	20.43	10.77	5.04	0.60	0.64

No.	Coast	Marine Protected Area	Mangrove Area (ha;000s)	Fisheries	Wood	Carbon Regulation	Coastal Protection	Water Quality Regulation	Recreation	Non-use values
14	Caribbean	Palmar del Titi	0.02	0.01	0.02	370.53	195.38	91.37	10.86	11.53
15	Caribbean	Los Corales del Rosario y de San Bernardo	0.27	0.03	0.03	30.88	16.28	7.62	0.91	0.96
16	Caribbean	El Corchal El Mono Hernandez	2.15	0.30	0.26	19.73	10.40	4.87	0.58	0.61
17	Caribbean	Sanguare	0.15	0.01	0.02	37.71	19.89	9.30	1.11	1.17
18	Caribbean	Del Sistema Manglarico del Sector de la Boca de Guacamaya	1.26	0.09	0.08	11.86	6.25	2.93	0.35	0.37
19	Caribbean	Ecosistema de Manglar y Lagunar Cienaga de la Caimanera	1.41	0.09	0.09	11.08	5.84	2.73	0.32	0.34
20	Caribbean	Manglar de la Bahia de Cispata	9.48	1.04	0.72	8.59	4.53	2.12	0.25	0.27
21	Caribbean	Ensenada de Rionegro	0.36	0.04	0.05	31.36	16.53	7.73	0.92	0.98
22	Caribbean	Lago Azul los Manaties	0.30	0.02	0.03	23.12	12.19	5.70	0.68	0.72
23	Pacific	Cabo Manglares Bajo Mira y Frontera	5.96	0.72	0.53	11.37	5.99	2.80	0.33	0.35
24	Pacific	Sanquianga	40.15	14.21	7.63	15.54	8.19	3.83	0.46	0.48
25	Pacific	El Comedero	0.70	0.29	0.31	92.02	48.52	22.69	2.70	2.86
26	Pacific	Isla Aji	1.51	0.47	0.44	50.44	26.60	12.44	1.48	1.57
27	Pacific	Rio Anchicaya	6.91	2.40	1.74	30.86	16.27	7.61	0.90	0.96
28	Pacific	La Sierpe	1.12	0.08	0.08	13.74	7.24	3.39	0.40	0.43
29	Pacific	Uramba Bahia Malaga	0.65	0.02	0.02	6.26	3.30	1.54	0.18	0.19

No.	Coast	Marine Protected Area	Mangrove Area (ha;000s)	Fisheries	Wood	Carbon Regulation	Coastal Protection	Water Quality Regulation	Recreation	Non-use values
30	Pacific	Consejo Comunitario de la Comunidad Negra de la Plata	0.78	0.02	0.02	4.88	2.58	1.20	0.14	0.15
31	Pacific	Encanto de los manglares del Bajo Baudo	23.71	4.09	2.40	9.34	4.93	2.30	0.27	0.29
32	Pacific	Golfo de Tribuga Cabo Corrientes	2.16	0.26	0.23	17.23	9.08	4.25	0.50	0.54
33	Pacific	Utria	0.10	0.04	0.05	174.66	92.09	43.07	5.12	5.43
34	Caribbean Island	Old Providence Mc Bean Lagoon	0.03	0.33	0.59	7,005.97	3,694.19	1,727.65	205.31	218.00
35	Caribbean Island	Old Point Regional Park	0.22	5.00	6.52	240.92	4,334.97	2,027.32	240.92	255.82

Appendix B. The economic value of mangrove contributions to artisanal fisheries in CGSM

B.1 List of commercial species ecologically linked to mangroves in CGSM.

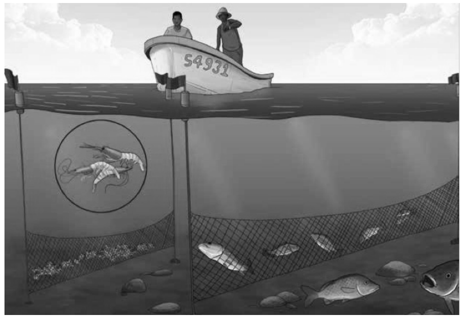
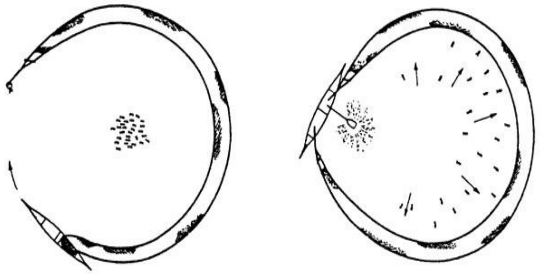
Table B.1-1. Species included in the estimation of catch and revenues for two landing points in CGSM, following INVEMAR (2022) and Carrasquilla-Henao et al. (2022).

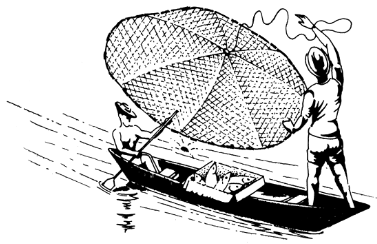
Species	Common Name (Colombia)	Main aquatic habitat
Achirus lineatus	Lenguado	Marine-Estuarine
Anchovia clupeoides, Cetengraulis edentulus	Bocona	Marine-Estuarine
Ariopsis canteri	Chivo cabezon	Marine-Estuarine
Bairdiella ronchus	Carrurra	Marine-Estuarine
Callinectes bocourti	Jaiba roja	Marine
Callinectes sapidus	Jaiba azul	Marine
Caquetaia kraussii	Mojarra peña	Freshwater
Caranx hippos	Jurel	Marine
Cathorops mapale	Mapale	Marine-Estuarine
Centropomus ensiferus	Robalo pipon	Marine-Estuarine
Centropomus undecimalis	Robalo largo	Marine-Estuarine
Crassostrea rhizophorae	Ostra	Marine-Estuarine
Ctenolucius hujeta	Agujeta	Freshwater
Curimata mivartii	Vizcaina	Freshwater

Species	Common Name (Colombia)	Main aquatic habitat
Diapterus rhombeus, D. auratus, Gerres cinereus	Mojarra blanca	Marine-Estuarine
Elops smithi	Macabi	Marine-Estuarine
Epinephelus sp	Mero	Marine
Eugerres plumieri	Mojarra rayada	Marine-Estuarine
Hemibrycon sp, Astyanax fasciatus, Cyphocharax magdalenae	Viejita	Freshwater
Lutjanus spp	Pargo	Marine
Megaleporinus muyscorum	Cuatro ojos	Freshwater
Megalops atlanticus	Sabalo	Marine-Estuarine
Melongena melongena	Caracol	Marine-Estuarine
Micropogonias furnieri	Coroncoro	Marine-Estuarine
Mugil curema	Anchoveta	Marine-Estuarine
Mugil incilis	Lisa	Marine-Estuarine
Mugil liza	Lebranche	Marine-Estuarine
Oligoplites saurus, O. palometa	Meona	Marine-Estuarine
Oreochromis niloticus	Mojarra lora	Freshwater
Pimelodus blochii	Barbul	Freshwater
Prochilodus magdalenae	Bocachico	Freshwater
Stellifer venezuelae	Bobito	Marine-Estuarine
Strongylura marina	Chonga	Marine-Estuarine

B.2 Gears used in the estimation of fish catch and revenue in CGSM.

Table B.2-1. Gears used in the estimation of fish catch and revenue in CGSM.

Gear	Description	Graphic reference
Set Gillnets	A set gillnet is a long rectangular netting anchored or otherwise fixed to the seabed to catch fish when they encounter it. This fishing gear works because fish and other organisms are entangled in the net; The construction material of gillnets is monofilament nylon; The network can have one or several cloths, each of a variable length (typically between 100 and 180 meters) and a height of between 1.5 and 2.4 meters. The holes in the net are known as eye or light mesh, usually measured in inches, their size is proportional to the calibre of the nylon (He et al., 2021; Ross Salazar, 2014).	
Encircling gillnets	Encircling gillnets are gillnets set vertically, in shallow waters, encircling fish. After the fish has been encircled by the net, noise or other means are used to force them to gill or entangle themselves in the netting. It is a technology commonly used by groups of small-scale fishermen (or women). They are generally operated by more men (around 10) than the other gears. The negative impact on the environment is low (Arias Arias, 1988; He et al., 2021).	

Castnets	A cast net is constructed from a series of tailored netting sections joined together to produce a cone-shaped net with weights and a drawstring attached to the perimeter and cast by a fisher. These nets are thrown from the shore of the beach or from the boat. In its descent by the column of water, the net, catches the fish by confinement. Generally, they are used in little waters deep (Arias Arias, 1988; He et al., 2021).	

B.3 Graphic relationship between mangrove and effort with fishing outputs (catch and revenue) by gear.

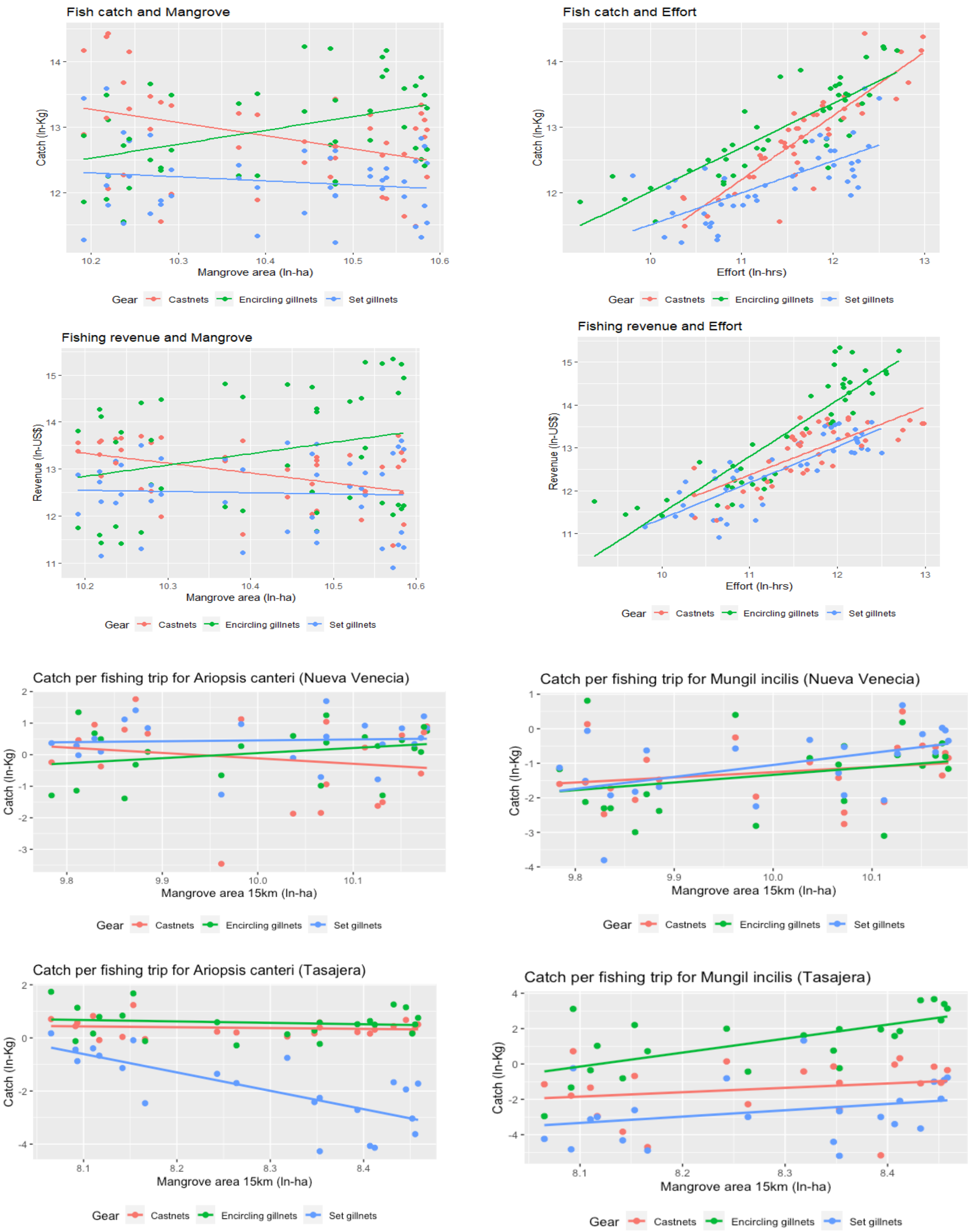


Figure B.3-1. Graphic relationship between mangrove and effort with fishing outputs (catch and revenue) by gear.

B.4 Regression results for a log-linear form of Cobb Douglas production function of fishing in CGSM.

Table B.4-1. Regression results for a log-linear form of Cobb Douglas production function of fishing in CGSM.

	OLS Total Catch (ln- Kg)	Panel FE Total Catch (ln- Kg)	OLS Ariopsis canteri – Catch/fishing trip. (ln-Kg)	OLS Mugil incilis – Catch/fishing trip. (ln-Kg)
Intercept	0.48 (0.85)	0.43 (0.07)***	-0.41 (2.21)	1.65 (2.48)
Costs (ln-US$)	0.40 (0.07)***	0.45 (0.07)***		
Costs/trip (ln-US$)			1.33 (0.31)***	0.54 (0.35)
Effort intensity (ln-Hrs)	0.36 (0.09)***		-0.65 (0.17)***	1.15 (0.62)*
Effort/trip (ln-Hrs)			0.88 (0.55)	-0.68 (0.20)***
Gear castnets	0.04 (0.09)		1.94 (0.43)***	0.88 (0.48)*
Gear set gillnets	-0.42 (0.09)***		0.48 (0.35)	-1.29 (0.39)***
Mangrove 15km (ln -ha)	0.44 (0.06)***	0.66 (0.23)***	0.25 (0.13)**	0.58 (0.14)***
Year: 2001	-0.59 (0.18)***		0.61 (0.57)	-0.81 (0.64)
Year: 2002	-0.45 (0.18)**		0.91 (0.58)	-0.20 (0.65)
Year: 2003	-0.15 (0.19)		0.97 (0.60)	0.15 (0.67)
Year: 2004	0.12 (0.19)		0.64 (0.60)	0.45 (0.67)
Year: 2005	0.12 (0.19)		0.86 (0.60)	-0.12 (0.68)
Year: 2006	0.23 (0.20)		0.95 (0.61)	-0.35 (0.68)
Year: 2007	0.07 (0.20)		0.71 (0.61)	-0.42 (0.68)
Year: 2008	-0.18 (0.19)		0.92 (0.61)	-0.16 (0.68)
Year: 2009	-0.28 (0.19)		1.20 (0.60)**	-2.20 (0.68)***
Year: 2010	-0.07 (0.19)		0.69 (0.61)	0.08 (0.68)
Year: 2011	-0.15 (0.19)		1.11 (0.61)*	0.45 (0.69)
Year: 2012	-0.14 (0.19)		0.93 (0.61)	0.19 (0.69)
Year: 2013	-0.12 (0.19)		1.16 (0.62)*	-0.29 (0.69)
Year: 2014	-0.05 (0.20)		1.03 (0.63)	-1.19 (0.70)*
Year: 2015	0.01 (0.19)		0.53 (0.62)	0.75 (0.70)
Year: 2016	-0.09 (0.20)		0.57 (0.64)	0.23 (0.72)
Year: 2017	-0.02 (0.20)		0.32 (0.64)	-1.04 (0.72)
Year: 2018	0.12 (0.19)		0.45 (0.60)	-0.34 (0.68)
Year: 2019	0.18 (0.19)		-0.11 (0.61)	-0.72 (0.68)
Year: 2020	0.18 (0.19)		-0.60 (0.58)	-0.01 (0.65)
Year: 2021	0.36 (0.09)***		-0.53 (0.59)	-0.50 (0.66)
R^2	0.85	0.72	0.51	0.65
Adj. R^2	0.82	0.7	0.38	0.56
Num. obs.	132	132	132	132

∗∗∗p < 0.01; ∗∗p < 0.05; ∗p < 0.1. Standard errors in parentheses

Appendix C. Preferences for mangroves restoration survey and materials

C.1 Choice experiment survey (translated from Spanish)

ECONOMIC VALUATION OF MANGROVE RESTORATION IN THE COLOMBIAN CARIBBEAN

B.	**SURVEY DATA**	
B.1.	Indicate your initials and the number of this survey (Enumerator)	
B.2.	Form code (CE bloke)	
B.3.	Date	
B.4.	Start time	
B.5.	Place	

C. I.	**EXPERIENCE, KNOWLEDGE AND PERCEPTION**				
C.1.	Do you know the mangrove of the Ciénaga Grande de Santa Marta?				
	Yes			No	
	(Show the map indicating the place where the survey is being applied and the delimited area of the CGSM)				

C.2.	Which of the following activities best describes your interaction with mangroves in the CGSM?	
to.	Fishing in mangrove areas	
b.	Tourist in mangrove areas	
c.	Tour guide in mangrove areas	
d.	Resident in mangrove areas	
e	Resident in urban areas near mangroves	
f.	Other work or activity in mangrove areas	
f.1	Which activity?	
g.	Do not interact with mangroves	

C.3.	How long have you been doing this activity? *for example how long you have been fishing or living in mangrove areas.*	
to.	Less than a year	
b.	Between 1 and 5 years	
c.	Between 5 and 10 years	
d.	Between 10 and 20 years	
e	More than 20 years	

C.4. How frequent is your interaction with the mangrove in the CGSM? For example, how often you can see, touch, or be surrounded by these mangroves:		
a	Between 1 and 7 days per week	
b.	Between one and three times a month	
c.	Between one and three times a year	
d.	Other:	

C.5.		With which of the following zones of mangrove in the CGSM have you had the most contact? Contact is understood as being able to see, touch or be surrounded by mangroves. *You can check more than one option (show the map with the zones)*
Zone A		Road area (Cienaga or Pueblo Viejo town)
Zone B		Farming Zone
Zone C		Salamanca Natural Park Area (VIPIS)
Zone D		South Zone/ Flora and Fauna Sanctuary (SFF)
Zone E		Water communities area

C.6.	Do you consider that in the zone you mentioned above the condition of mangroves has (read options)					
	Made much worse	Worsened	Stayed the same	Improved	Greatly improved	Don't Know
	-2	-1	0	1	2	

C.7.	What do you think are the main reasons why these changes have occurred? **(Only if you answered differently from "Remains the same" and "doesn't know" in the previous question) You can choose more than one option.**				
Negative			Positive		
a.	Indiscriminate logging		d.	Mangrove planting	
b.	Little connection to rivers		e	Cleaning of water channels	
c.	Contamination		f.	Proper disposal of garbage	
g.	Other:				

C.8	Of the following benefits of the Ciénaga Grande de Santa Marta, which do you consider to be the most important? (*choose only one option)*	
a	Carbon capture: that is, the ability of the mangrove to absorb carbon from the environment helping to regulate the global climate.	
b.	Diversity of animals including birds	
c.	Coastal protection	
d.	Improving water quality	
e.	Fisheries support	
f.	Wood for domestic use	
g.	Shade and cool in local areas	
h.	Opportunities for ecotourism	
i.	Other:	

D.	**MANGROVE RESTORATION PREFERENCES**

During the last 20 years some restoration activities such as dredging and reforestation have been developed, but these have not been 100% successful. Mangrove coverage has increased in some years and decreased in others. To this are added the effects of climate change that together with human activities deteriorate the mangrove. In 2019 there were approximately 35,000 hectares of mangroves, think that a soccer field measures almost one hectare.

It is expected to improve restoration programs, including activities such as work with machinery, manual works within the mangrove, community awareness and monitoring. It is also expected to involve local communities and the public more actively.

1

These restoration initiatives will require greater economic resources and greater participation of local communities and populations surrounding the Lagoon.

GO TO CARD WITH EXPLANATION OF THE ELECTION EXERCISE

D.1.	Do you have any questions about this exercise?	
Yes		Which one:______________________
No		

D.2.

No	Card	Scenario 1	Scenario 2	Maintain current situation
1				
2				
3				
4				
5				
6				
7				
8				

D.3.	Why do you think it is important to continue restoring the mangrove? (Choose only one option)	
a.	Benefits the preservation of other ecosystems and the animals that live there	
b.	Because it benefits local communities living in CGSM	
c.	Because it benefits the populations around the CGSM	
d.	Because it benefits future generations	
e.	Because mangroves must exist, even if they do not benefit us directly.	

If you always chose the current situation in one of the subgroups or in both (none of the options presented) ask the following question

D.4.	Why are you not willing to contribute to the restoration programs at CGSM? (*wait for him to answer and check the nearest option*)	
a.	Limitation of income and/or free time	
b.	Considers it the government's responsibility to fund these programs	
c.	He does not believe that restoration programs will improve mangrove conditions in the CGSM	
d.	Does not trust the institutions that manage these programs	
e.	You need more information to make your decision	
f.	Other:	

D.5.	For the following institutions or groups, rate your level of trust in them for the management of the collected resources for restoration and the volunteer program, with 1 being the lowest level of trust and 5 total confidence in this institution.					
a.	County Environmental Authority such as CORPAMAG	1	2	3	4	5
b.	Research Institutes, such as INVEMAR	1	2	3	4	5
c.	Charities or NGOs	1	2	3	4	5
d.	Ministry of Environment	1	2	3	4	5
e.	National Natural Parks	1	2	3	4	5
f.	Local communities	1	2	3	4	5
g.	Private companies	1	2	3	4	5

C. II.	EXPERIENCE, KNOWLEDGE AND PERCEPTION				
C.9	Did you know about the activities that have been carried out in the CGSM to improve mangrove conditions and cover previous to this survey?				
Yes		(Go to C.10)	No		(Skip to E)

C.10	Which ones did you know?	Knew (C.10)	Did you participate in any of these activities? (C.11)
a.	Mangrove planting	Yes/No	Yes/No
b.	Nurseries	Yes/No	Yes/No
c.	Cleaning of water channels	Yes/No	Yes/No
d.	Monitoring and follow-up to the environmental conditions of the mangrove	Yes/No	Yes/No
e.	Other:	Yes/No	Yes/No

C.12	Do you think restoration programs need to be improved?				
Yes		Go to C.13.	No		Skip to E

C.13.	Of the following options, which do you think would contribute the most to improving restoration programs? (Select only one option)	
a.	More strict control on activities that deteriorate the mangrove.	
b.	Greater participation of people living in the mangrove in restoration activities.	
c.	Greater participation of the public.	
d.	Increased frequency of restoration activities, such as pipe cleaning and reforestation.	
g.	Other:	

E	SOCIOECONOMIC QUESTIONS			
	Now I will ask you some socioeconomic questions, remember that the survey is anonymous so I won't ask for any information that might be used to identify you.			
E.1.	Are you a resident of this municipality/city/village?			
	Yes		No	
E.1.1.	If you don't live here, what city in Colombia do you live in?			
E.1.2.	If you don't live in Colombia, what country do you live in?			
E.2.	What is the last educational level completed?			
to.	None			
b.	Primary			
c.	Secondary			
d.	Technician			
e.	University / Undergraduate			
f.	Graduate			
E.3	What year were you born?			
E.4.	Are you the head of your household?			
	Yes		No	
E.5.	If you are not the head of household, what relationship do you have with the head of your household?			
a.	Spouse or partner			
b.	Son / Daughter			
c.	Grandson / granddaughter			
d.	Brother / Sister			
e.	Other:			

E.6.	What is your marital status?					
a.	Single			d.	Separated (a)	
b.	Married			e.	Widower	
c.	With a partner			f.	Other:	

E.7.	Do you have dependents?			
	Yes		How many?	
	NO			
E.8.	In total how many people make up your household including you?			
E.9.	What is your occupation?			

E.10.	Are you the person who contributes the most income in your household?					
	Yes		Skip to E.12.	No		Skip to E.11
E.11.	What does the person contributing the most income in your household do? (occupation)					
E.12.	Approximately how much is your monthly income? (or the income of the person contributing the most) Remember that the survey is anonymous.					
a.	Under COP$600,000					
b.	Enter COP$600.001 and COPS$1.000.000					
c.	Enter COP$1.000.001 and COP$2.000.000					
d.	Enter COP$2.000.001 and COP$3.000.000					
e.	Between COP$3.000.001 and COP$4.000.000					
f.	More than COP$4,000,000					
The interviewer completes the following						
E.13.	Respondent's gender					
	Male		Female			
B. 6.	End Time					
Check that all answers are filled out correctly						
FEEDBACK AND COMMENTS:						

C.2 Survey and choice experiment materials

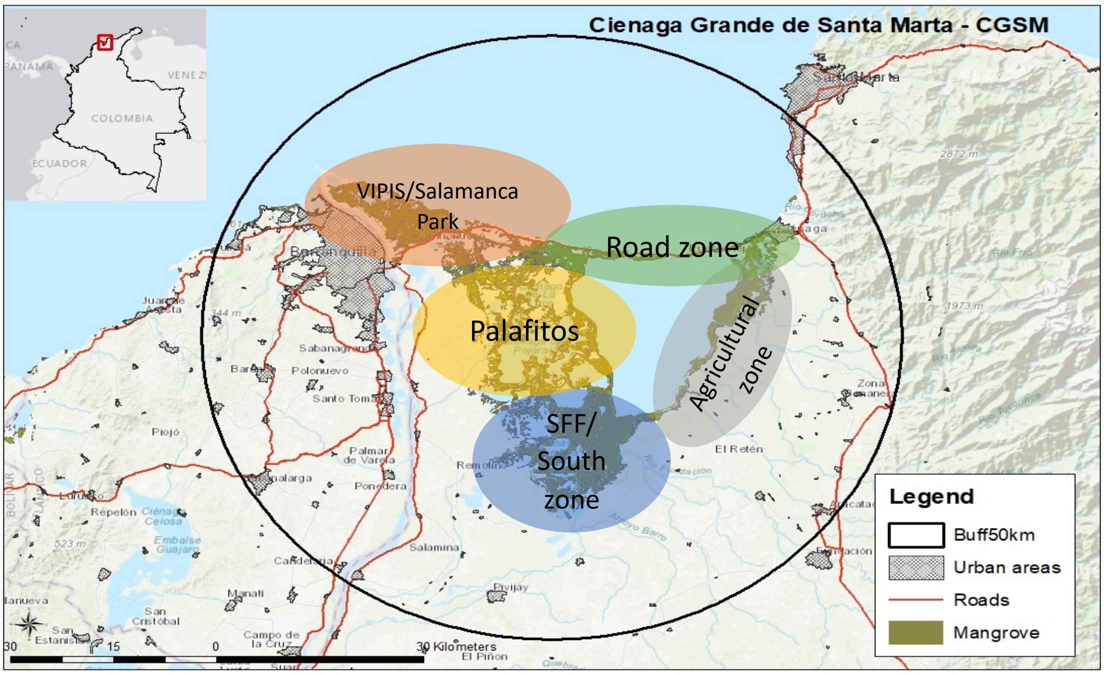


Figure C.2-1. Map for question C.5. in Choice experiment survey

Choice Question

We will conduct a choice exercise to evaluate your preferences and your willingness to contribute to new and improved restoration scenarios in CGSM.

In this exercise, you must choose between three alternatives that correspond to two possible scenarios for restoration and a third in which the current conditions are maintained. All alternatives would be developed over a period of 10 years and are independent of each other. In each scenario, changes in characteristics associated with the restoration of the CGSM are described, these characteristics are:

1. Changes in biodiversity at the end of the period, represented through the bird species that can inhabit the CGSM

2. Changes in mangrove cover restored at the end of the period

3. Changes in the annual catch of some commercial fish in the lagoon at the end of the period

4. Each scenario also has a contribution in the form of a monthly payment that your home would make initially for 5 years through a house bill. And a contribution in hours a week of your free time to carry out restoration activities as a volunteer, these activities can be within the mangrove or with the surrounding communities for up to 6 months a year and for 5 years initially.

In total, I will present to you 8 cards and in each one you must make a choice. Please consider your income and expenses when deciding if you want to contribute a monthly payment, as well as your free time if you want to participate in the volunteer program since both the pay scheme and the volunteer program could be developed in the future.

Figure C.2-2. Description of choice experiment to participants

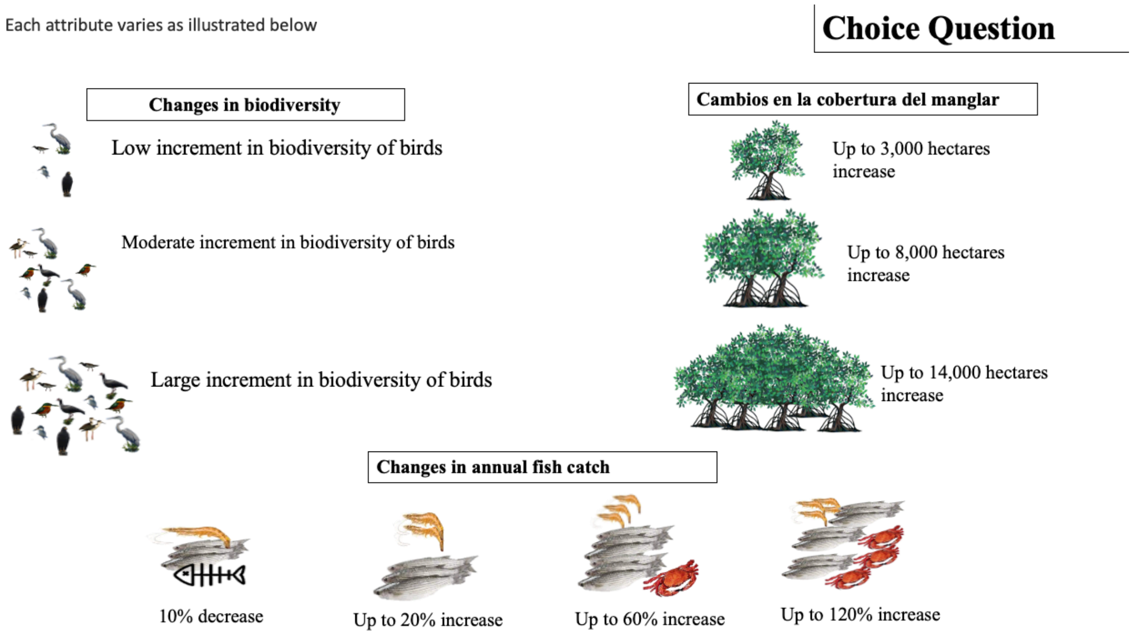


Figure C.2-3. Illustration of restoration attributes

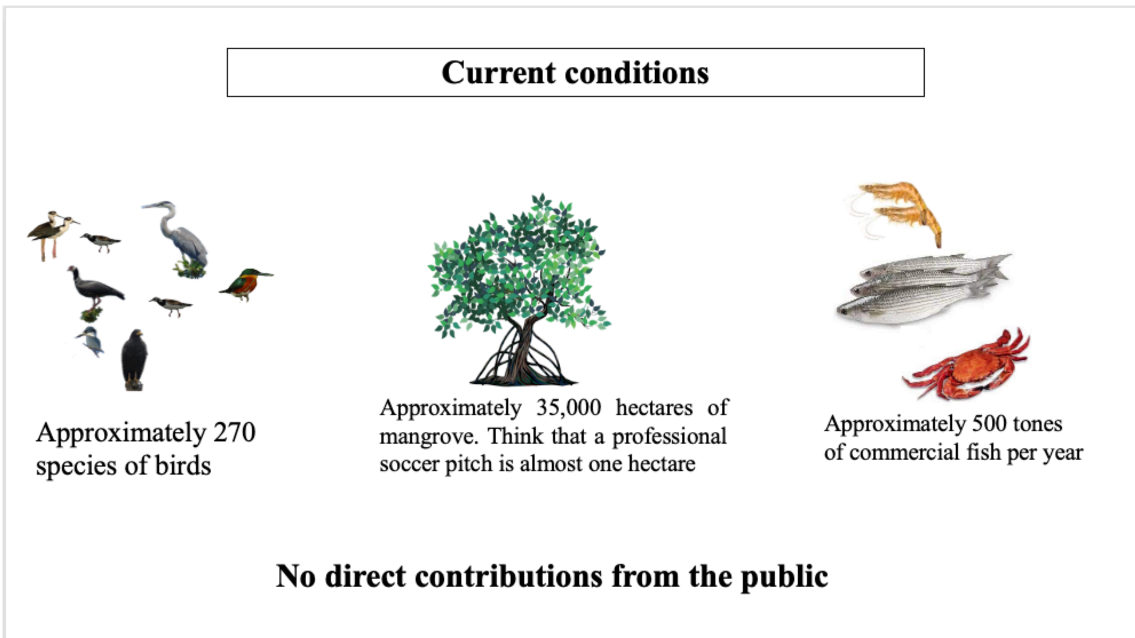


Figure C.2-4. Description of current conditions in CGSM.

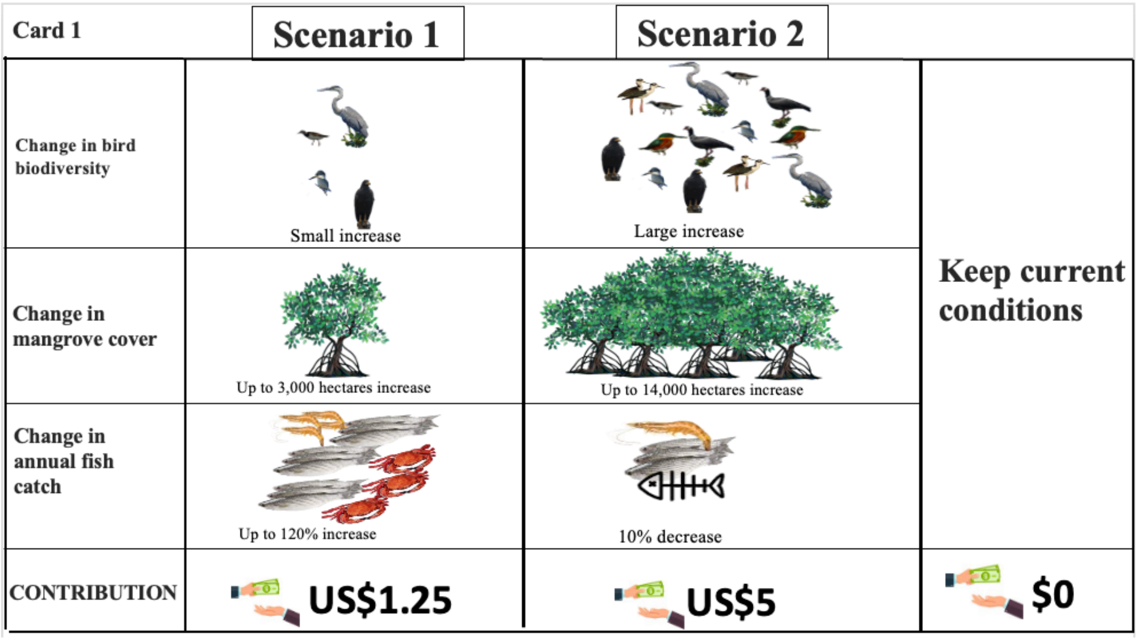


Figure C.2-5. Example of choice card with monetary payment.

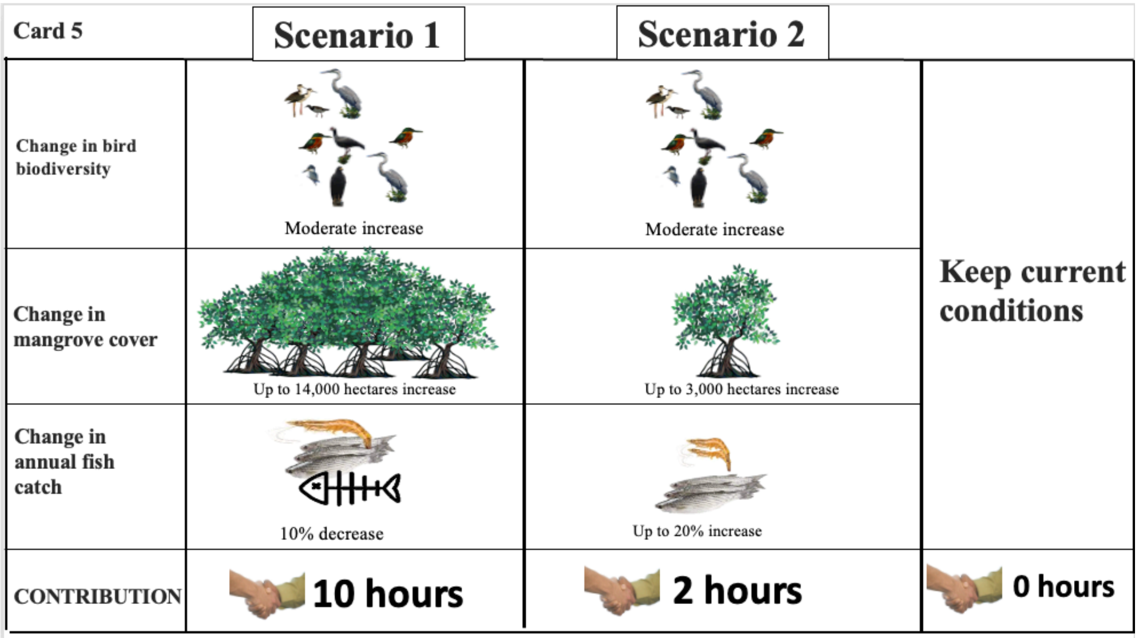


Figure C.2-6. Example of choice card with time contribution.