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North Brazil Shelf Mangrove Project

Local community benefits from ecosystem services provided by mangroves on the North Brazil Shelf

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SUGGESTED CITATION

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EXECUTIVE SUMMARY

This analysis seeks to evaluate the size and distribution of the services the mangrove ecosystem is providing to local communities in Suriname and Guyana. The study involves three components: (i) the description, from the scientific and grey literatures, of the mangrove ecosystem services specific to local communities in Guyana and Suriname; (ii) identification of methods that could be used to estimate the economic values of these services, and estimation of the economic values for mangrove forests' fisheries support ecosystem service; and (iii) identification of local beneficiaries of these services.

Ecosystem services are defined as "the benefits of nature to households, communities, and economies". Ecosystem services are understood within a coupled socio-ecological system (SES) framework which consists of human and natural systems that interact in two directions. First, via human drivers where the human system influences environmental status and outcomes. Second, via ecosystem services that nature provides to human systems. In this study, the mangrove ecosystem is considered the natural system, the local beneficiaries and stakeholders the human system, and the ecosystem service flows from mangroves to people as the linkage between the two.

To describe the ecosystem services provided by mangroves in the project area, a literature review of the scientific and grey literatures was conducted. This literature search was complemented by a systematic search and analysis of the Marine Ecosystem Services database, which contains the ecosystem values from hundreds of scientific publications and reports on marine ecosystem services assessments. This preliminary list of ecosystem services that was subsequently refined and ground-truthed for relevance based on the focus groups and interviews conducted in Guyana and Suriname for stakeholder analysis and mapping.

The following ecosystem services were identified for Guyana and Suriname: Aesthetics, culture, heritage and social values, health impacts, species existence, wood products, non-timber forest products, fish abundance (commercial and subsistence), recreational values, flood damage mitigation, shoreline property damage mitigation, protection of peatlands, and climate mitigation.

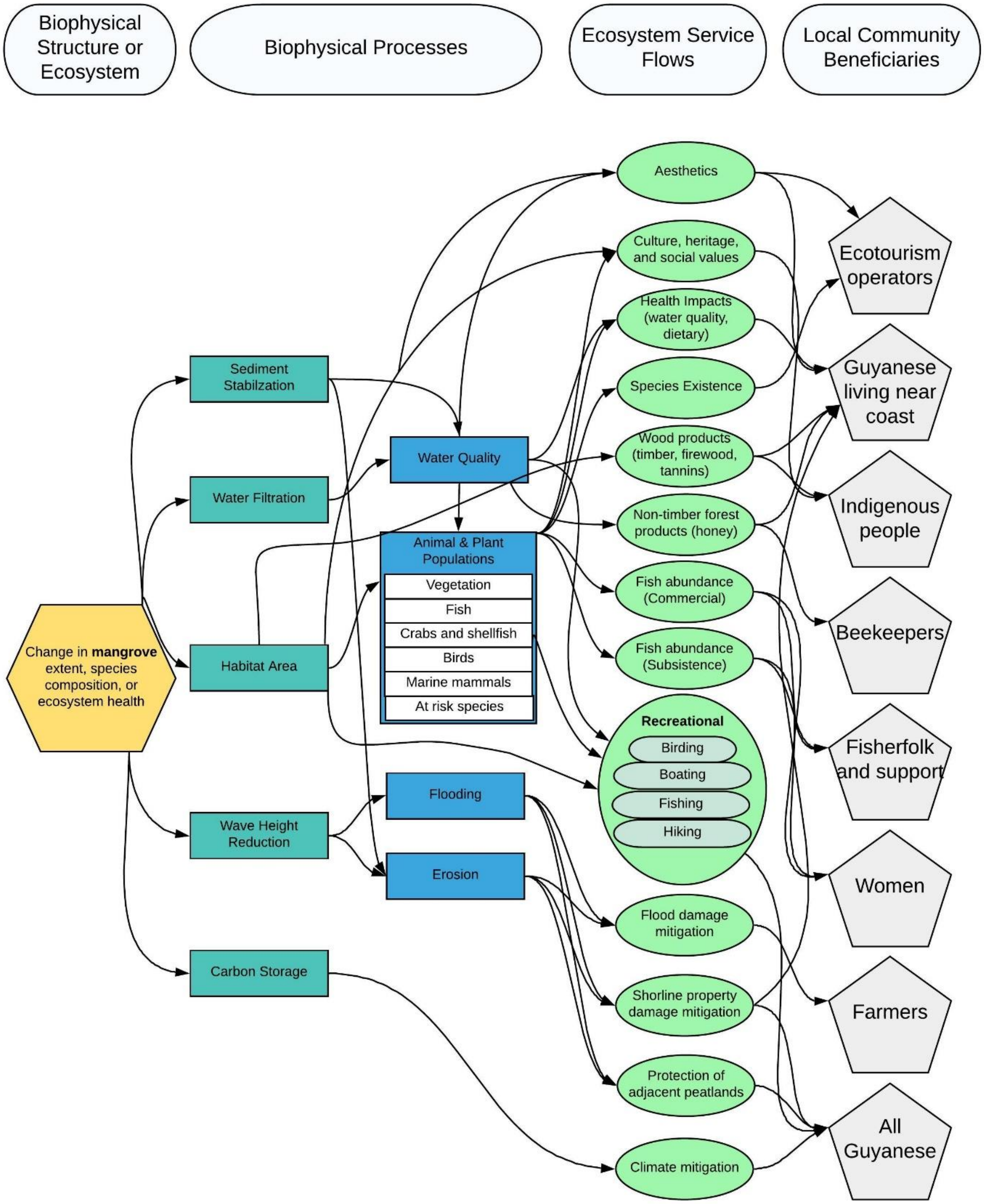
To facilitate future analyses, examples for benefit relevant indicators are provided as a first step toward economic valuation, and ecosystem services are matched to the appropriate economic valuation method from the literature. Using the ecosystem services conceptual model adopted to mangroves on the North Brazil Shelf (NBS), economic valuation methods are proposed from to literature to later estimate the marginal value of each ecosystem service produced based on the ecosystem services and the type of BRI example for each. Benefit relevant indicators for marketed ecosystem services include the number of fish caught, amount of honey produced, or timber harvested, among others. Indicators for non-marketed ecosystem services include avoided coastal storm damages, fish abundance indicators, amount of pollution reduction, or avoided construction and maintenance costs for gray infrastructure, among others.

As an example for an ecosystem service provided by mangroves, capture fisheries and aquaculture are on a steady growth trajectory in both Guyana and Suriname, making them the top two countries in the CARICOM region for fisheries production. Capture fisheries' contribution to GDP was calculated at 1.8 and 3.6% of total GDP of Guyana, and Suriname, respectively. As part of this project, a meta-analysis of scientific research together with benefit transfer was used to estimate the impact of changes in mangrove extent on fisheries.

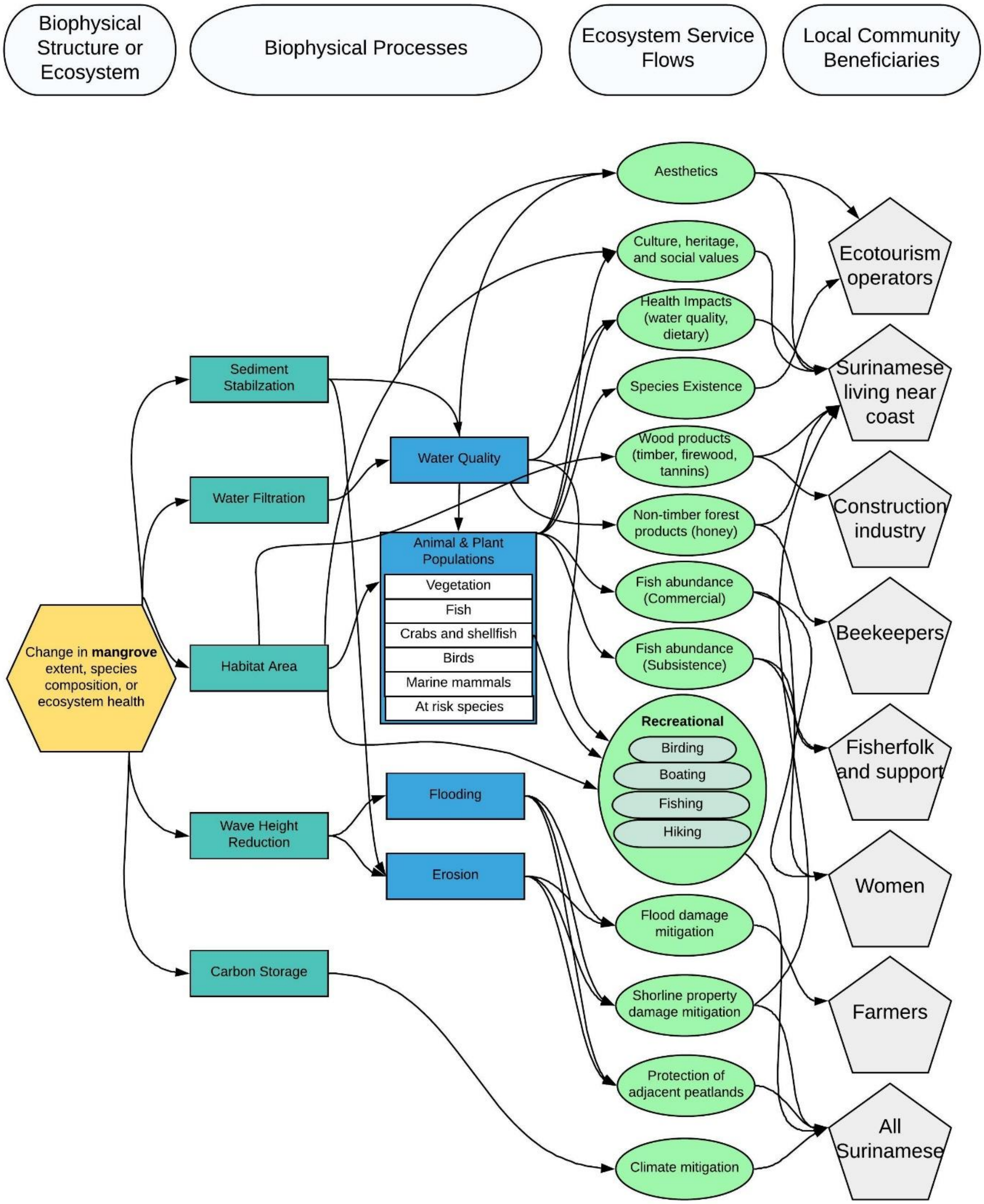
Using data assembled from multiple scientific publications on mangrove-fishery linkages, a regression model was estimated for finfish a shellfish catch, in which the shellfish, and abundance variables have positive regression coefficients that are statistically significant at a 0.01 significance level. The shellfish elasticity estimate was used in Guyana to illustrate changes in shellfish catch due to changes in mangrove cover. Therefore, a 1.68% loss in shellfish catch per year is expected in Guyana due to 1% mangrove loss. Similarly, a 0.38% loss in finfish catch per year is expected in Suriname due to a 1% loss in mangrove cover.

Based on the meta-analysis results, we estimated the monetary impact of mangrove loss on Guyanese and Surinamese fisheries. Using estimates from the meta-analysis, had the estimated loss in mangrove area not occurred, the expected increase in seabob landings priced at the international market price means that the Guyanese fishery would have gained $544,320 in a single year, or $1,389 per hectare. Similarly, had the estimated loss in mangrove area not occurred, the Surinamese fishery would have had an expected monetary gain of $30,780, or $81 per hectare.

To begin to understand the distribution of the NBS mangrove ecosystem services, an assessment of local community beneficiaries was performed in Guyana. Local community beneficiaries included those in fishing, agriculture, timber, and charcoal, leather, honey production, as well as tourism. In Guyana, local community beneficiaries of mangrove ecosystem services were identified to include fisher folk, those employed in the tourism, sugar, or rice industries or agriculture more generally, beekeepers, coastal ecotourism operators, indigenous communities, women, and communities that live along the coast. As a result of this analysis, the following mangrove ecosystem services model was developed, linking ecosystem services to the relevant beneficiaries.



Similarly, in Suriname, an assessment of local community beneficiaries was performed. In addition to the beneficiary groups identified in Guyana, communities also include people located in Weg naar Zee, Coronie, Nickerie, and Commewijne. For Suriname, the following the following mangrove ecosystem services model was developed.



In both Guyana and Suriname, local community groups were identified that may be affected disproportionately due to future mangrove loss. First, coastal small-scale fishers and the workers that support their operations in both countries rely most heavily on mangroves for their livelihoods, with limited alternatives available. Second, women participating in the fisheries supply chain are also potentially highly impacted in the case of mangrove loss, should it translate to loss of fish catch. Third, indigenous communities in Guyana derive significant cultural, social, and subsistence values from mangrove ecosystem services, and many of these values do not appear to have substitutes. Fourth, the focus groups from the local communities living near the coast reported large benefits from the coastal erosion mitigation, water quality, and flood damage protection services that can only be substituted by gray infrastructure. Finally, the broader national and regional communities benefit from the climate mitigation ecosystem service of these ecosystems.

The present analysis provides four areas of application when developing or updating mangrove management plans. First, the conceptual framework developed helps determine the impact of policy and management changes on the amount of various mangrove ecosystem services flows. Second, the list of local community beneficiaries and their perceptions helps in determining the distributional impacts of changes in mangrove management, and highlights local beneficiary groups that are most highly dependent on mangroves. Third, the use of economic values estimated for the fisheries support ecosystem service can be used to improve management decisions by providing defensible positive values to better determine the relative costs and benefits of, and tradeoffs among alternative future scenarios. Fourth, to facilitate future mangrove ecosystem services valuation on the NBS, economic valuation methods are proposed for the ecosystem services relevant to Guyana and Suriname.

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Project Objectives

The main aim of the project “Setting the foundations for zero net loss of mangroves that underpin human wellbeing in the North Brazil Shelf LME (NBS-LME)” is to help establish a shared and multi-national process for Integrated Coastal Zone Management in the NBS. The first objective of the NBS-LME mangrove project is to generate the necessary baseline knowledge and technical assessments as inputs towards a collaborative vision and a coordinated well-informed management of NBS mangrove systems, with emphasis on the information needs of Guyana and Suriname. The second objective of the project is to support the development of transboundary coordination mechanisms between the countries of Guyana, Suriname, French Guiana, and Brazil (State of Amapa) towards the improved integrated coastal zone management of the extensive, ecologically connected yet vulnerable mangrove habitat of the NBS region.

To meet the overall objectives of the NBS mangrove project, this analysis seeks to evaluate the size and distribution of the services the mangrove ecosystem is providing to local communities in Suriname and Guyana. The study involves three components: (i) the description, from the scientific and grey literatures, of the mangrove ecosystem services specific to local communities in Guyana and Suriname; (ii) identification of methods that could be used in this context to estimate the economic values of these services, and estimation of the economic values for mangrove forests’ fisheries support ecosystem service; and (iii) identification of local beneficiaries of these services and description of their interaction with the mangrove ecosystem, including access to and distribution of the benefits provided by mangroves.

Mangrove Ecosystems

Mangroves are forest ecosystems located in the intertidal zone, i.e. the section between land and sea (Kathiresan and Bingham 2001). Consisting of trees and shrubs, these woody plants are distributed among 123 countries located between the tropical and subtropical latitudes (Figure 1, see Appendix). There are at least eighteen different mangrove plant genera distributed among these areas but only three genera are common to most regions: Avicennia, Acrostichum and Rhizophora (Duke et al. 2014).

Globally, mangroves are among one of the most biodiverse habitats (habitats with a variety of life forms) because of their unique location and adaptations which provide suitable ecosystems for all sorts of terrestrial, freshwater, and marine species (Duke et al. 2014). Among the species that can be found in mangrove ecosystems, there are a wide range of birds, mammals, insects, reptiles, fish, and crustaceans. Mangroves can serve as nursery areas to many important fishery species such as shrimp, fish, crabs, sharks, and rays. Additionally, some species use mangroves as breeding, nesting, and feeding grounds, as well as shelter areas (Duke et al. 2014). These tropical forests also sustain threatened and endangered species such as turtles, alligators, crocodiles, manatees, and snakes. Consequently, the biodiversity that depends on these ecosystems could be severely impacted by the loss of mangrove forest.

Introduction and Conceptual Framework Guiding Analysis

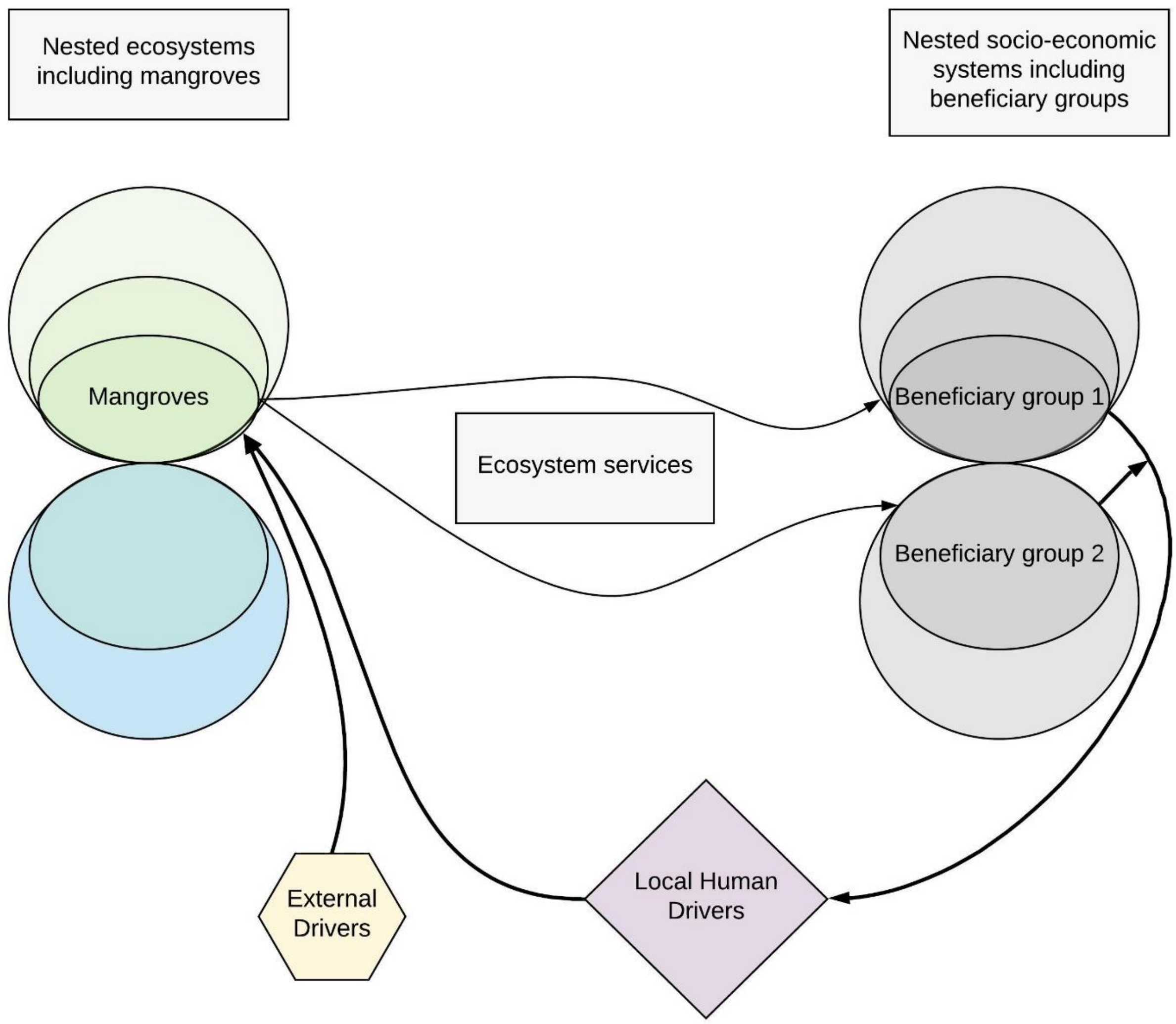
Ecosystem services are a way to address the value that humans place on natural resources and a method to evaluate the benefits individuals obtain from these resources (Costanza et al. 1997). Boyd and Banzhaf (2007) defined ecosystem services as “the benefits of nature to households, communities, and economies”.

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment (MEA) 2005), in an effort to enhance the sustainable use of natural ecosystems, evaluated how changes in ecosystems affect human well-being (Millennium Ecosystem Assessment (MEA) 2005). As a result, MEA classified natural ecosystems based on the services they provide to people, the benefits individuals gain from them, how human actions might change these environments, and the services they provide.

Ecosystem services are understood within a coupled socio-ecological system (SES) framework (McGinnis and Ostrom 2014). The SES framework consists of human and natural systems that interact in two directions. First, via human drivers where the human system influences environmental status and outcomes. Second, via ecosystem services that nature provides to human systems. In the specific case of this study, the mangrove ecosystem is considered the natural system, the local beneficiaries and stakeholders the human system, and the ecosystem service flows from mangroves to people as the linkage between the two. The conceptual framework for the human-nature interaction in coupled human-mangrove systems in Guyana and Suriname can be depicted as in (Figure 1).

The conceptual framework developed as part of this analysis is a coupled socio-ecological system framework with ecosystem service flows. It combines the ecosystem service conceptual model (Mason et al. 2017), and multiple published versions of socio-ecological system frameworks that includes the impact of humans on the environment directly or indirectly through anthropogenic drivers or policy (Ommer et al. 2011; Liquete et al. 2013; Patil et al. 2016).

Figure 1: Coupled socio-ecological system with ecosystem service flows to socio-economic systems



Source: (Ommer et al. 2011; Liquete et al. 2013; Patil et al. 2016; Mason et al. 2017)

Mangrove Ecosystem Services in Guyana and Suriname

As part of the NBS-LME project, the characterization of the mangrove ecosystem in Guyana and Suriname was undertaken by Silvestrum Climate Associates (Beers et al. 2019)[1], aiming to evaluate the potential of Guyana and Suriname's mangrove ecosystems to contribute to climate

[1] Presented in a report entitled "North Brazil Shelf Mangrove Project – Blue Carbon Feasibility Assessment"

change mitigation by exploiting their ability to sequester carbon and their role as important national carbon sinks.

Mangrove coverage and trends

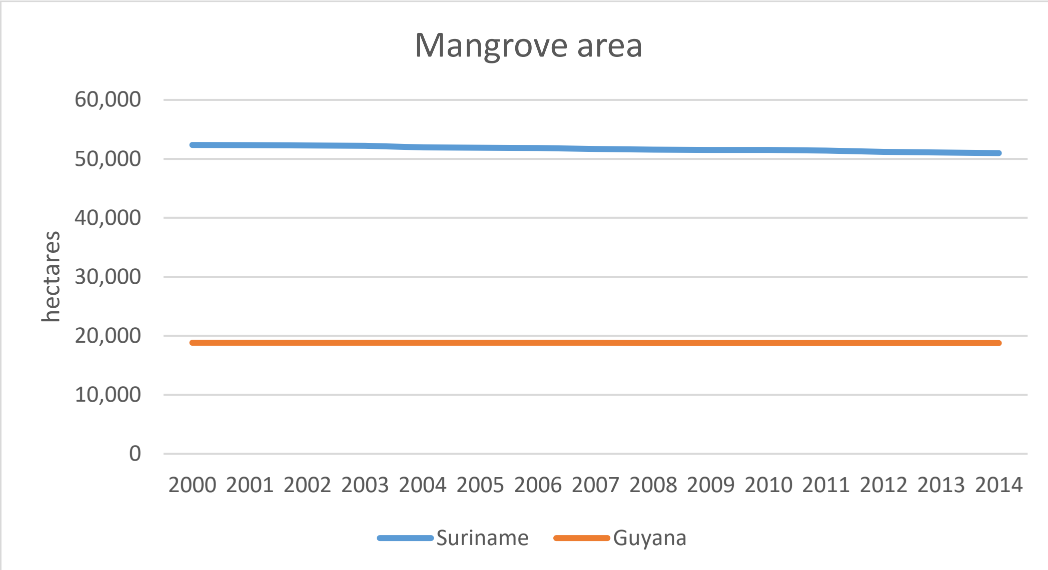
For the purposes of this analysis, an initial review of recent mangrove presence-absence data shows extensive mangrove coverage in Guyana and Suriname (Figure 2).

Figure 2: Distribution of mangroves along the coastlines of Guyana and Suriname

Source: (Giri et al. 2011) retrieved from the UNEP World Conservation Monitoring Centre, available at http://data.unep-wcmc.org/datasets/4

Recent reports provide conflicting estimates of mangrove extent for Guyana (Ter Steege 1999), and a recent study shows little or no loss of mangrove coverage for either Guyana or Suriname (Hamilton and Casey 2016) (Figure 3). Actual mangrove deforestation, degradation, and loss rates in the two countries, are, therefore, difficult to ascertain because of disparities in data quality or remote sensing technology used in the estimation.

Figure 3: Trends in mangrove cover in Guyana and Suriname



Source: (Hamilton and Casey 2016)

Even though there is a consensus that mangrove area is declining in Guyana and Suriname, there are large discrepancies between different studies regarding both mangrove area and the decline in mangrove area in each country (Hamilton and Casey 2016; Food and Agriculture Organization of the United Nations (FAO) 2019a; Food and Agriculture Organization of the United Nations (FAO) 2019b). For the purpose of this study the assumption was made that current mangrove area in Guyana is 20,000 ha and current mangrove area in Suriname is 50,000 ha (Hamilton and Casey 2016). This data set was chosen because it is the most recent data set available that used spatial analysis to estimate mangrove specific area.

Among the sources reporting different values for mangrove area are the FAO, Hamilton et al. 2017, and the Global Forest Watch. The FAO summary of trends in mangrove area for Guyana and Suriname from 1981 to 2000 showed that mangrove area is slightly decreasing in both countries. Moreover, in the year 2000, FAO stated that in Guyana there was around 76,000 ha of mangroves, whereas Suriname had 96,000 ha that same year. On the other hand, (Hamilton and Casey 2016) reported that in 2000 Guyana had around 20,000 ha of mangroves, while Suriname had around 50,000 ha.

Given these discrepancies, for the purpose of this study the percentage change in mangrove area for each country was calculated using the average of the reported changes in mangrove area from (Hamilton and Casey 2016) and a second source, the Global Forest Watch. Global Forest Watch uses satellite data to monitor tree cover change around the world. This data is mapped across the globe and can be used to estimate the area of tree cover loss, gain, and change on a county level. The decision to use only the (Hamilton and Casey 2016) and Global Forest Watch to estimate mangrove area change for this study was made because both sources span similar time periods—2000-2014 for (Hamilton and Casey 2016) and 2001-2017 for Global Forest Watch.

In the case of (Hamilton and Casey 2016) the percent change in mangrove area was included in the data set. In Guyana this change is a 0.02% loss of mangrove area per year and in Suriname it is a 0.2% loss of mangrove area per year. Regions where mangroves are known to exist within each country were used to calculate the percent change in mangrove area (Global Forest Watch 2019) (Table 1).

Table 1: Percent in Mangrove Area Change per Regions in Guyana and Suriname

Country	% Mangrove Area Change
Guyana Regions	
N. 74	0.34%
N. 37	0.26%
N. 38	0.23%
Woodley	0.32%
Mahaica	0.39%
Nowvelle	0.16%
Sparta	0.63%
Banasika	0.28%
Essequibo	0.09%
Wakenaam	1.06%
Demerara	0.09%
Suriname Regions	
Galbi	0.05%
Margareta	0.41%
Kwatta	0.55%
Welgelegen	0.02%
Johanna	0.02%
Westelyke	0.08%

Source: (Global Forest Watch 2019)

It is important to highlight that this tool does not only analyze mangrove area change but instead examines tree cover change. Therefore, the percent in mangrove area change calculated for

Guyana (-3.84% /yr) and Suriname (-1.31% /yr) are expected to be overestimations since the analysis of tree cover is likely not limited to mangroves despite efforts to target mangrove habitats.

A value for percent change in mangrove area for each country was calculated as follows:

Guyana:

$$\frac{(-0.02\%\ /\mathrm{yr})\ +\ (-3.84\%\ /\mathrm{yr})}{2} = -1.96\%\ /\mathrm{yr}$$

Suriname:

$$\frac{(-0.2\%\ /\mathrm{yr})\ +\ (-1.31\%\ /\mathrm{yr})}{2} = -0.76\%\ /\mathrm{yr}$$

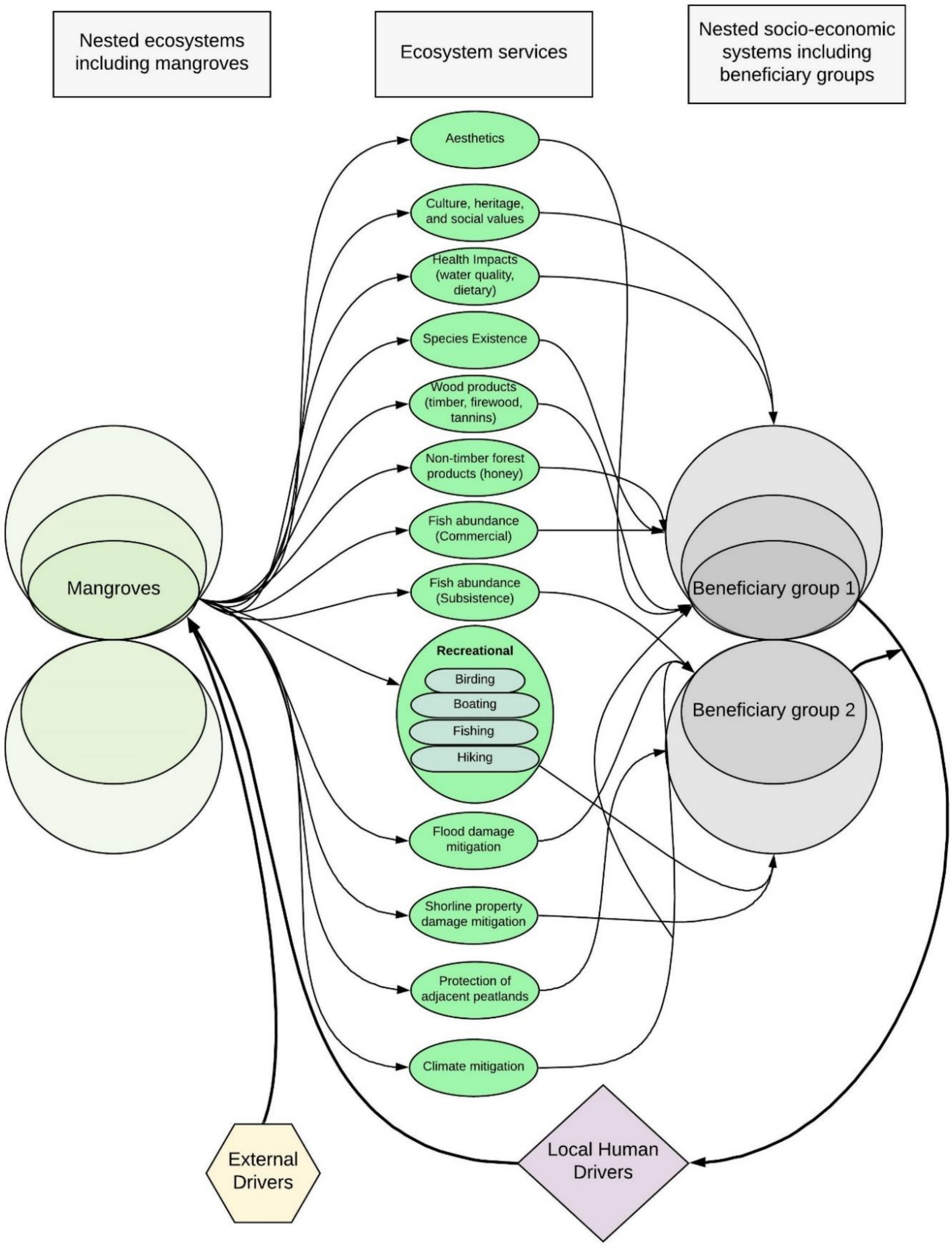
Characterizing the mangrove ecosystem services in Guyana and Suriname

Many of the ecosystem services provided by mangroves in Guyana have been identified in a recent report by (Environmental Resources Management and Environmental Management Consultants 2018). To build on this analysis and describe the ecosystem services (flows) provided by mangroves (stock of natural capital) in the project area, including descriptions of temporal and spatial distributions of services, mangrove species-specific services, and services that depend on a specific mangrove ecosystem community or species configuration, a literature review of the scientific and grey literatures was conducted (Annex 3). This literature search was complemented by a systematic search and analysis of the Marine Ecosystem Services database, also developed at Duke University (Marine Ecosystem Services Partnership 2019). The database contains the ecosystem values from hundreds of publications and reports on marine ecosystem services assessments. The ecosystem services that mangroves provide include coastal protection, fisheries support, among others (Liquete et al. 2013; Vegh et al. 2014). Coastal protection refers to the ability of mangroves to reduce incoming wave heights and thereby protect coastal properties and lives. Mangroves' fisheries support function refers to fish and nursery habitat provided by mangrove root systems.

To identify those services that are likely to be provided on the NBS region we started with the inclusive list from the literature, then narrowed down this list based on species present in the region, namely red, white, and black mangroves. Furthermore, the previously published scientific and grey literature was used to construct a preliminary list of ecosystem services that was subsequently refined and ground-truthed for relevance based on the focus groups and interviews conducted in Guyana and Suriname for stakeholder analysis and mapping. The ground-truthing involved consultations with local coastal communities that regularly interact with mangroves, as well as government agencies, research institutes, and non-governmental organizations. The final list of services are thus locally relevant or known to exist, based on the knowledge of regional experts, local stakeholders and local knowledge of beneficiaries.

The ecosystem services identified from the literature review are depicted using a conceptual model used to illustrate services from a range of ecosystems, including mangroves (Mason et al. 2017) as shown in Figure 4. The model is used here to enumerate the ecosystem services provided by NBS mangroves, and where possible, list quantitative benefit relevant indicators (BRI), defined as measures meaningful to people, to provide inputs into economic valuation. The models can also be used to show local community beneficiaries and link them to ecosystem services from which they benefit. The models can be considered as a “mental map” to depict the relationships between discrete variables linked to mangrove ecosystems in the two countries.

Figure 4: Mangrove ecosystem services conceptual model



Source: (Ommer et al. 2011; Liquete et al. 2013; Patil et al. 2016; Mason et al. 2017)

Economic Valuation of NBS Mangrove Ecosystem Services

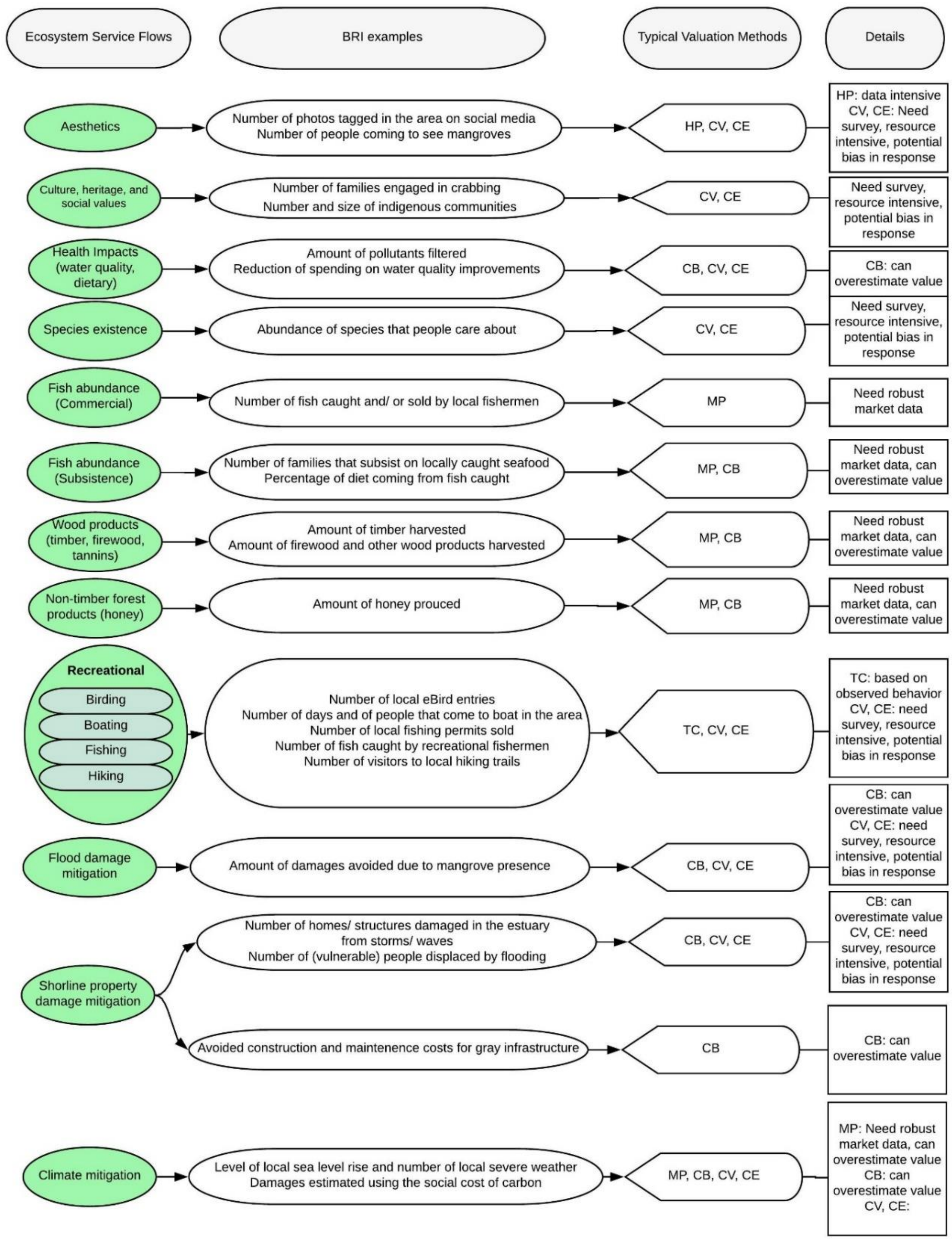
The value of ecosystem services can be described qualitatively, quantitatively, or monetized using economic valuation techniques if data allows. Economic valuation generally aims to provide monetary values for ecosystem services for better policy design, and evaluation of tradeoffs among various management options. An overview of economic valuation methods is found in Annex 4. In the literature reviewed, very limited data is available on the magnitude and distribution of mangrove ecosystem service values on the NBS. To facilitate future analyses, examples for benefit relevant indicators are provided as a first step toward economic valuation, and ecosystem services are matched to the appropriate economic valuation method from the literature (Champ et al. 2003 among others). Using the ecosystem services conceptual model adopted to mangroves on the NBS (Figure 4), economic valuation methods are proposed from to literature to later estimate the marginal value of each ecosystem service produced based on the ecosystem services and the type of BRI example for each (Figure 5).

Market price-based economic valuation approaches could be used to value, for instance, fisheries support, beekeeping, carbon sequestration, and firewood provision; while services such as cultural, social, or spiritual values, would need to be measured by estimating monetized welfare changes using survey-based techniques such as contingent valuation. For the ecosystem services conceptual model, each BRI was matched to a valuation method based on the type of service the BRI is describing. Where possible, multiple methods were proposed, and some key details were noted.

The scope of this analysis was restricted to the identification of relevant valuation methods to be used in future work, but where possible, initial economic valuation were attempted. As part of the NBS-LME project, the estimation of the economic value of the climate mitigation ecosystem service provided by the mangroves in Guyana and Suriname was undertaken by Silvestrum Climate Associates and presented in a report entitled “North Brazil Shelf Mangrove Project – Blue Carbon Feasibility Assessment” (Beers et al. 2019). The report is based on a desk review of carbon sequestration and storage, and loss rates, and uses carbon values from the literature to estimate climate mitigation value of mangroves in these two countries.

Mangroves reduce the height and energy of wind and swell of waves passing through them, reducing their ability to erode sediments and to cause damage to structures such as dikes and sea walls (Spalding et al. 2014; Beck and Lange 2016; Beck et al. 2018). Mangroves also reduce winds across the surface of the water and this prevents the propagation or reformation of waves. For the coastal protection benefit of mangroves, we reviewed of the relevant scientific literature (Annex 2) to assess the feasibility of conducting a meta-regression analysis, based on the comparability of units of the outcome variables used in the original studies. Meta-regression analyses require that the outcome variables of interest be comparable so that estimates from multiple sources could be combined into a single value estimate. However, our review found that this is not possible for the body of literature on the coastal protection service provided by mangroves. Future analyses could employ spatially explicit analyses of changes to property damages based on an evaluation of storm surge mitigation, such as in (Blankenspoor et al. 2016). The authors estimate the coastal population and GDP at risk due to loss of coastal protection from mangroves, and the potential for adaptation. This approach overlays predicted wave height and inundation from state of the science models and spatially explicit data on property values to determine property damages under various scenarios. Specifically, the storm surge inundation zones and wave heights with and without mangroves were calculated first. Then to assess the vulnerability of population and GDP, data was used that contained information on the number of people from Landscan (Bright et al. 2006) and GDP for from the World Bank / UNEP databases available from the biennial The Global Assessment Reports on Disaster Risk Reduction (United Nations 2011).

Figure 5: Typical valuation methods for ecosystem services provided by mangroves on the NBS



Note (methods): CB: cost-based, CE: choice experiment, CV: contingent valuation, HP: hedonic pricing, MP: market price, TC: travel cost

Source: (Garrod and Willis 1999; Champ et al. 2003)

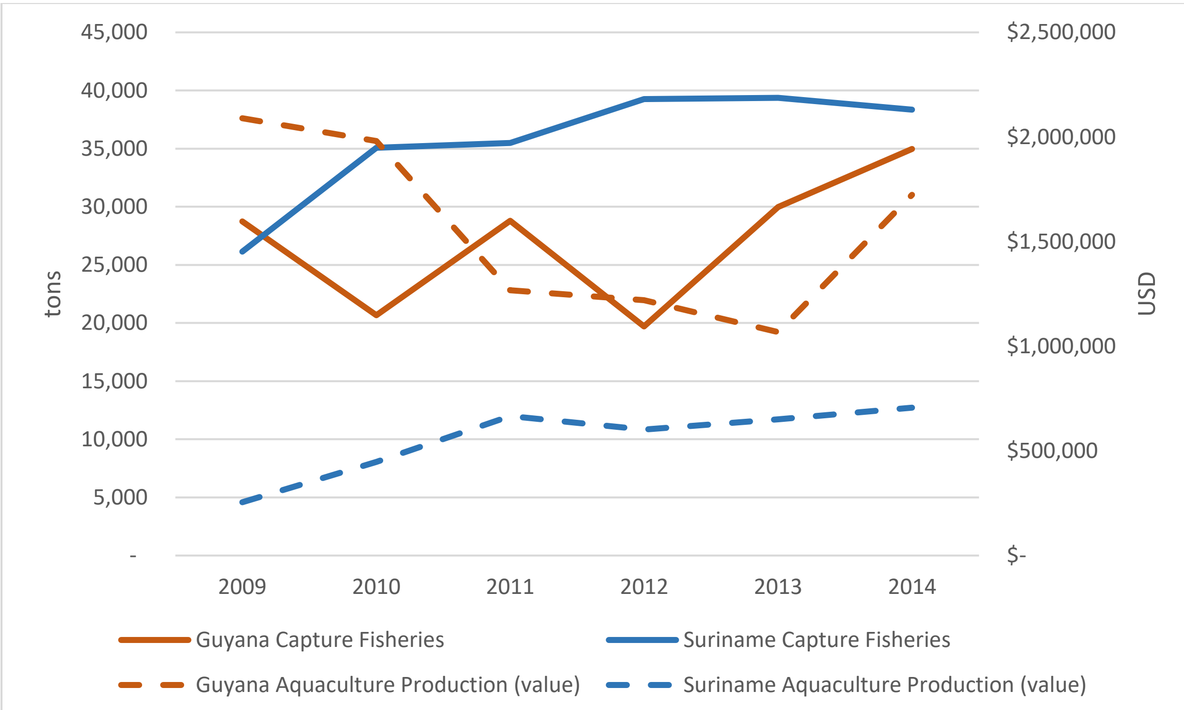
Economic valuation of fisheries support

Capture fisheries and aquaculture are interlinked with mangroves and are on a steady growth trajectory in both Guyana and Suriname according to the FAO (Figure 6). Guyana and Suriname are the top two countries in the CARICOM region for fisheries production, and are in the top-5 in terms of aquaculture production (FAO 2014). The most recent data available from 2017 indicate that the fisheries sector contributed over USD 100 million towards exports in both countries (OEC 2018a; OEC 2018b). Capture fisheries' contribution to GDP was calculated at 1.8 and 3.6% of total GDP of Guyana, and Suriname, respectively (Bank of Guyana 2017; ABS Suriname 2018). In terms of percentage of total GDP, this contribution may not be significant, however at the local level along the coast this would be expected to be more significant.

The ocean-based fishing industry accounts for 1.84% of Guyana's total GDP and employed 7,370 people in 2014 which is around 2% of the total workforce (Index Mundi 2018). Shrimp and other shellfish species dominate the fish catch (Food and Agriculture Organization of the United Nations (FAO) 2019c). In Guyana, trawl vessels are registered and licensed by type. In response to the increasing levels of finfish bycatch being discarded in the 1980s, a regulation was put in place that requires shrimp trawlers to land 15 tons of finfish bycatch per year (Food and Agriculture Organization of the United Nations (FAO) 2005). According to the FAO, the fish stock in Guyana was held constant until around the year 2000 when the status of the fish stocks appears to have shifted abruptly from 97% at or below maximum sustainable yield (MSY) to only 43% at or below MSY. It should be noted that this sharp change may be at least in part due to a change in the methods used to analyze the stocks. By the year 2014, only 2.8% of the total fish stock fell into the developing or rebuilding categories. This trend in fish stock was reflected in a decrease in fish catch in recent years (Sea Around Us Project 2019).

Fisheries account for 3.55% of Suriname's GDP. The fishing industry is highly export-oriented and accounts for 4.8% of total exports (Food and Agriculture Organization of the United Nations (FAO) 2019c). In 2016, total landings were 47,013 tons with the majority of the landings being finfish (Food and Agriculture Organization of the United Nations (FAO) 2019c). The fishing industry in Suriname is regulated through the requirement to obtain licenses to operate all types of fishing vessels. However, the number of licenses are only restricted for the seabob shrimp vessels and the bottom trawlers. Additionally, Suriname has fishing operation zones which limit the type of fishing activity that can occur in specific locations (Food and Agriculture Organization of the United Nations (FAO) 2008). According to the FAO, the percentage of fish stocks estimated to have a status at or below MSY in Suriname has hovered around 60% since 1985 aside from a few outlying years. This relatively stable aggregate fish stock status has coincided with fairly stable catch numbers over time. The catch did grow rapidly in the late 1990s and early 2000s which coincides with the outlying years of decreased stock status. In 2014, 44% of Suriname's fish stock fell into the developing or rebuilding categories.

Figure 6: Capture fishery production volume and value of aquaculture production over time



Source: (FAO 2019)

Methodology

Meta-Analysis overview

A meta-analysis is a quantitative synthesis of a large number of studies on the same topic whose results are combined and analyzed as if they were the results from one study (Borenstein et al. 2011). A benefit transfer study uses information from one or more valuation studies to estimate the value of an environmental change not previously studied (Champ et al. 2003). The benefit transfer method was used to apply the results from the meta-analysis to Guyana and Suriname. Because there are no known studies to date on mangrove-fishery linkages in Guyana or Suriname, this was the most appropriate method for the economic valuation.

To identify studies with useful data for the meta-analysis, a literature search was performed. The search terms "mangrove", "fish*", "valu*", and "link*" were used to identify studies using Google Scholar, and Web of Science. The list of studies was then cross checked and expanded using two databases that contain economic valuation studies or data: the Marine Ecosystem Services database, and the Environmental Valuation Reference Inventory. Finally, snowball searches were performed beginning with (Salem and Mercer 2012) and (Himes-Cornell et al. 2018). When selecting studies for the meta-analysis, the scope of the search was originally circumscribed to countries located in South America as well as Mexico and the Caribbean. This region was selected because of its proximity to Guyana and Suriname. This yielded very few studies, so the scope was expanded to include all countries located between the latitudes of 0 and 10 degrees. Once again it was determined that there were insufficient studies in this small latitude band, so study collection was expanded to include studies conducted throughout all regions of the world. The final database for the meta-analysis included 21 separate studies (Annex 1).

Once the values of the independent variables were extracted from the studies mentioned above, different regression models were run (Table 2). The resulting regression models were then used to predict elasticities (Ɛ). This elasticity is a measure of the sensitivity of fish catch to a change in mangrove area, expressed in percentage terms. The predicted elasticity was multiplied by the percentage change in mangrove area for each country (%M), which yielded the predicted percentage change in fish catch for Guyana or Suriname resulting from a change in mangrove area:

$$Percent\ change\ in\ fish\ or\ shrimp\ catch\ in\ Guyana\ or\ Suriname\ =\ \varepsilon \times \%M$$

Table 2: List of dependent and independent variables used in the meta-analysis.

Dependent variable	Independent variables
Elasticity	Year of publication
	Observations
	Period of data collection
	Country
	Fish species
	Catch location
	Type of fisher
	Average mangrove area
	Average fish catch

Model description

After selecting the studies for the meta-analysis, the data were entered into a database. Aside from recording the mean values of x and y (where x is mangrove area and y is the fishery response variable), reported impacts **($\frac{dy}{dx}$)**, elasticities **($\frac{dy}{dx} \times \frac{mean\ x}{mean\ y}$)**, and a variety of explanatory variables were also included. Examples of explanatory variables include dummy variables for shellfish and finfish studies, whether fishing was on a small or large scale, if fish were caught in the open ocean or within the mangrove, and the percent of the fish stock that was improving. The finfish and shellfish variables were further broken down into demersal finfish, pelagic finfish ("fish that live in the open ocean at or near the water's surface and usually migrate long distances", NOAA Fisheries Glossary), prawn/shrimp shellfish, lobster/crab shellfish, mollusk shellfish, and unspecified. The fish stock improving variable was constructed using the Sea Around Us fish stock status plots (Sea Around Us Project 2019). Sea Around is a project that that assesses the impact of fisheries on the marine ecosystems of the world, and offers mitigating solutions to a range of stakeholders. As it relates to this report, it attempts to reconstruct catch time series starting in 1950, and related series (e.g., landed value and catch by flag state, fishing sector and catch type), by estimating discards, and unreported catch, and supplementing the official data by FAO.

For each study included in the final model, the percent of the fish stock that fell into the developing or rebuilding categories was extracted from the stock status plot for the country in which the data was collected. In the case of panel and time series analysis, the median year of data collection was used, i.e. if data collection from a study spanned from 2000 to 2004, the fish stock improving variable was based on data from 2002. Annex 6 describes the explanatory variables collected or calculated from the studies included in the meta-analysis.

Once the data were extracted and checked for accurate coding, the model was estimated in Stata. There were high levels of inconsistency in the units used between studies to measure the fishery and mangrove variables. To avoid the difficulty of equating terms, the elasticity of each observation was used as the dependent variable in this model. In some cases, the elasticity was presented within the study itself and in other cases it was calculated using the following equation:

$$\varepsilon = \frac{dy}{dx} \times \frac{mean\ x}{mean\ y}$$

The compilation of reported and calculated elasticities had a right-skewed distribution. Outliers with values below the 5th percentile or above the 95th percentile were removed. Once the final models were chosen, regression equations were estimated. These equations were then used to complete the benefit transfer for Guyana and Suriname by predicting their elasticity values.

A benefit transfer method was subsequently used to apply the results from the meta-analysis, expressed as elasticities, to recent and projected future changes in mangrove areas in Guyana and Suriname, and thereby predict the impacts of mangrove loss on fishery productivity in the two countries.

Given the availability of satellite data on mangrove cover, fishery impacts of mangrove changes were estimated in specific regions of the two countries, rather than at the aggregate national level. Impacts would be expected to be larger in locations where: (i) the relative change in mangrove cover is larger, and (ii) the size of the fishing industry relative to the area of mangrove cover is larger. Relevant literature to inform the valuation of fisheries support is located in Annex 1.

Meta-analysis results

First, a parsimonious set of variables was identified that explained the variance in the elasticity estimates, then a maximum likelihood random effects model with clustered robust standard errors[2] was estimated to determine which variables were significant at a reasonable level ($p<0.2$). A single regression model was run for finfish and shellfish (specifically, crustacean, i.e. lobsters, crabs, shrimp, and prawns) catch, using robust standard errors, despite the fact that not all of the studies specified the species of finfish or shellfish that were caught (Table 3). Consequently, the broad categories of "shellfish" and "finfish" were used to avoid excluding studies that did not report species at a more disaggregated level. Additional models controlling for the dates of data collection had no effect on elasticity size in either the shellfish or the finfish model.

Table 3: Regression output from maximum likelihood mixed effects model

Observations = 41	Clusters = 15	Wald Chi^2 = 68.48	Prob > Chi^2 = 0.000
Log pseudolikelihood = -32.969			

[2] Clustered robust standard errors are known to be downward biased, thus overstating significance, when the number of clusters (studies in this case) is small. A common technique for correcting this bias, i.e. "wild" bootstrapped t-statistics, has recently been found to overcorrect, thus understating significance. In random effects models, uncorrected clustered robust standard errors can yield more accurate estimates of significance than the corrected t-statistics generated by this technique.

Variable	**Coefficient**	**Robust standard error**	**P> |z|**
Abundance	0.446	0.070	0.000
Finfish	0.494	0.309	0.110
Crustaceans	0.855	0.320	0.008
Cross-section	-0.360	0.169	0.033
Constant	0.113	0.290	0.699

In the maximum likelihood mixed effects model no traditional goodness-of-fit measure like the r^2 is available. The log pseudolikelihood is -32.97, and the Wald chi-squared is 68.5 ($p<0.0001$). An ordinary least squares (OLS) regression with the same variables but no random effects has an r^2 of 0.22. The shellfish, and abundance variables have positive regression coefficients that are statistically significant at a 0.01 significance level, while the finfish variable is statistically significant at a weaker significance of 0.11. No assumptions were made regarding the expected sign on the shellfish coefficient but the known importance of mangroves for shrimp likely explains why shellfish would have larger elasticities than finfish (Rönnbäck 1999; Chong 2007). Also, no assumptions were made regarding the signs of the finfish coefficient. A potential explanation for the smaller yet still positive finfish coefficient is that shrimp are more dependent than most finfish species on mangroves, resulting in smaller estimated elasticities for finfish. As possible explanations for these findings, shrimp are known to feed in the mangroves and use the areas protected by mangrove roots as shelter, and therefore are spatially and temporally directly connected to the ecosystem. On the other hand, finfish spawns depend of mangroves with a delayed response, and larger fish tend to feed farther from the shore.

Benefit transfer

When conducting the benefit transfer portion of the analysis, the finfish model was used to predict the elasticity for Suriname, since finfish account for most of the catch in that country. On the other hand, the shellfish model was used when predicting the elasticity for Guyana because shrimp are the largest portion of catch in the country. Site measures, which are the predicted values of the data at the study site, were used to estimate the final elasticity.

The shellfish elasticity estimate was used in Guyana to illustrate changes in shellfish catch due to changes in mangrove cover. In order to obtain the expected percentage change in fish catch, Ɛ is multiplied by the percentage change in mangrove area (%M) in Guyana,

$$0.855 \times (-1.96\%) = 1.68\% \text{ loss in shellfish catch per year in Guyana due to mangrove loss}$$

Suriname's main fishery is finfish so the finfish elasticity was used. In order to obtain the expected percentage change in fish catch, Ɛ is multiplied by the percentage change in mangrove area (%M) in Suriname,

$$0.494 \text{ x } (-0.76\%) = \ 0.38\% \text{ loss in finfish catch per year in Suriname due to mangrove loss}$$

Discussion

Economic benefits of mangrove restoration for the fisheries

When estimating the potential economic benefits of mangrove restoration to the fisheries, the dominant species of fish catch and corresponding market prices were used. In the case of Guyana this was the Atlantic seabob shrimp, and in the case of Suriname this was the weakfish (Sea Around Us Project 2019). When estimating the benefits, the assumption was made that all seabob and all weakfish are dependent on mangroves. While it is true that both species depend on mangroves as part of their life cycle (Ferreira et al. 2016; Willems et al. 2016), the following benefit estimates could be biased upwards if this dependence is incomplete with respect to mangrove ecosystems generally, or in terms of the fraction of these species life-cycles spent in or around mangroves.

The estimated loss in shellfish catch due to mangrove area loss in Guyana is 1.68%. Atlantic seabob accounts for the largest share of fish catch in the country. In 2014, the seabob catch was estimated to be 1.8 million kg (Sea Around Us). If the estimated loss in mangrove area had not occurred, the expected result would have been an increase in seabob landings of 30,240 kg (1.68% of 1.8 million kg). At the international market price of \$18 kg-1 (Federal Reserve Bank 2019), the Guyanese fishery would have gained \$544,320, all else the same.. The expected monetary gain can be divided by mangrove area change to determine the value per hectare of mangroves for the shellfish fishery:

$$\frac{\$544{,}320}{1.96\% \ \times 20{,}000 \text{ ha}} = \$1{,}389 \text{ per ha per year}$$

The estimated loss in finfish catch in Suriname due to mangrove area change is 0.38%. Weakfish are the most common type of fish caught in Suriname, totaling 2.7 million kg in 2014. The market price for relevant fish species at this time was \$3 kg-1 (Tridge 2019). If the 0.76% loss in mangrove area had not occurred, the fishery would have gained 10,260 kg of weakfish, resulting in an expected monetary gain of \$30,780. To determine the value of one hectare of mangroves to the Surinamese weakfish fishery, the estimated monetary gain was divided by mangrove area change:

$$\frac{\$30{,}780}{0.76\% \ \times 50{,}000 \text{ ha}} = \$81 \text{ per ha per year}$$

Comparison to previous mangrove-fishery linkage studies

The estimated elasticity for shellfish was 0.855, which compares well to the results from shellfish studies included in the meta-analysis. The mean reported elasticity for shellfish studies was 1.35, with a standard deviation of 1.48, and the median was 0.886. The estimated elasticity for finfish is 0.494. The mean of the reported elasticities for finfish from studies included in the meta-analysis was 0.916, with a standard deviation of 0.744, and median of 0.716. The similarity between the reported elasticity medians and the results of our benefit transfer increase confidence in the accuracy of the estimated value.

Limitations

One of the most significant limitations of this analysis is the wide variation in mangrove area and mangrove area change estimates in Guyana and Suriname across different studies. Having an accurate number for percent mangrove change is key to being able to estimate the effect of mangrove change on local fisheries. This analysis was also limited by the relatively small number of available studies focusing solely on mangrove-fishery linkages as opposed to a variety of mangrove ecosystem services. This could be partly due to publication bias, which is the result of journals prioritizing studies with highly statistically significant results. It is possible that some studies conducted on mangrove-fishery linkages that did not find a statistically significant relationship between the variables were not published, making them difficult to identify. This also implies that our elasticity estimates could be biased upward due to the exclusion of these insignificant estimates.

Another limitation is the inconsistency in methods used between the studies included in the meta-analysis. Because there is such a variety of research methods and units of measure, this study is limited in the way it can compare results between observations. An additional inconsistency between studies is the level to which authors reported fish type. Some studies named specific species of shrimp, making it very easy for the data to be coded precisely, but others just listed "shellfish". In these cases, shellfish could mean a variety of species of shellfish or it could mean just one species of shrimp; either way it would be coded as shellfish: non-specific. These coding limitations are another reason why finfish and shellfish models were preferred over more specific fish descriptions.

A final limitation is omitted variable bias. Some of the studies included in the meta-analysis controlled for seasonality and temperature effects. While some studies found these variables to be statistically significant, too few studies reported these variables for them to be included in the final models of this study. Seasonality could play a significant role in reported fish catch, since all fish species have breeding seasons which determine the number of fish available to be caught at a given time (Ahmed 2017). In the face of a changing climate, rising ocean temperatures could be playing a role in fish productivity. Some sources estimate an observed decrease in marine productivity of up to 30% over the last few decades due to rising ocean temperatures (Cheung et al. 2009; Union of Concerned Scientists (UCS) 2011; Cheung et al. 2013; Watson et al. 2013). Including these seasonality and temperature effects would provide a more holistic view of the environmental dynamics of mangrove ecosystems. An additional variable that could enhance the accuracy of this meta-analysis is a control for adjacent ecosystems such as seagrass and coral reefs. Seagrass and coral reefs are commonly found in tandem with mangroves and exhibit similar feeding, nursery, and shelter functions (MacNeil et al. 2015; Nordlund et al. 2018). It is possible that part of the observed impact of mangrove area on fish catch is a combination of mangrove area and seagrass or coral reef presence. This study originally tried to control for these adjacent ecosystems, but few studies in the meta-analysis sample reported information on seagrass and coral presence, so it was eventually removed.

The distribution of NBS mangrove ecosystem services

To begin to understand the distribution of the NBS mangrove ecosystem services identified in Figure 6, and specifically who the key stakeholders and beneficiaries that rely on mangroves are, what their incentives are, and what benefits they derive from interacting with mangroves, stakeholder and beneficiary mapping was conducted. Stakeholder mapping is a collaborative process that lists relevant groups based in part on past or current initiatives. It relies on local and in-country knowledge, and networks, and seeks diversity among groups identified. Stages of mapping include identification, analysis, mapping, prioritization of stakeholders, and updating an initial list if necessary. The process aims to understand interests and incentives, determine relationships to goals and other stakeholders, and prioritizes stakeholders for each ecosystem service of interest. In this case, the process aimed to understand the human component of the mangrove SES and to fill a gap in the understanding of beneficiaries of ecosystem services (Cete et al. 2018).

Initial results from the literature showed that local beneficiaries included those in fishing, agriculture, timber, and charcoal, leather, honey production, as well as tourism (Allan et al. 2002; Cete et al. 2018). The lists of local community beneficiaries and regional and national stakeholders were compiled based on input from experts in Guyana and Suriname, and the relevant scientific and grey literature. The lists were further developed based on in-country field visits, discussions with relevant government agencies, for example, the National Agricultural Research and Extension Institute (NAREI) in Guyana.

Methodology for primary data collection on local community beneficiaries

The aim of the focus groups and interviews was to understand in the NBS context (1) the perceived benefits that mangroves provide to various stakeholders and beneficiaries, (2) the perceived value of these ecosystem services, and (3) the perceived threats that these ecosystems face. The questionnaire design used was based on Schaeffer and Presser 2003; Park 2006; Gill et al. 2008; Turner 2010. The short focus group discussions or interviews began and were facilitated through, neutral, open ended, and clearly worded questions. In Guyana, the focus groups and interviews were conducted in English, and in Suriname, in Dutch. Participants were not compensated for their involvement, including their time, in the research project, except for reimbursement for travel related expenses to meeting locations.

In Guyana, to ensure full representation from all the coastal regions 1-6, three separate sessions were held in Region 1 & 2, Region 3 & 4 and Region 5 & 6. Due the logistics involved in accessing Region 1, a joint session for Regions 1 & 2 was hosted in Region 2. Region 1 stakeholders included indigenous communities that required collaboration with the Ministry of Amerindian People's Affairs in Guyana. Local stakeholder groups were invited through working with local community volunteers and the Neighborhood Democratic Councils in the regions.

Field visits were organized by CI-Guyana in partnership with NAREI, and CI-Suriname, for the weeks of April 8th, and April 22-29th in Guyana and Suriname, respectively. During the field visits in Guyana, local fisher folk, as well as communities in all six coastal regions were engaged. Specifically, three meetings were organized to capture the knowledge and perceptions of local community beneficiaries of mangrove ecosystem services. A meeting was held in Anna Regina, Guyana to perform a focus group based primary data collection for local communities in Regions 1 and 2. Two additional meetings in Fort Wellington, and Cove and John, Guyana were held with the same objective for regions 5 and 6, and 3 and 4, respectively.

In Suriname, field data collection using the same approach were conducted by CI-Suriname, in partnership with university undergraduate and graduate students from Anton de Kom Universiteit Suriname, based in Paramaribo. The data collection in these regions took place after a training workshop on interview and focus group based data collection, during the weeks of April 29th and May 6th.The team performed focus groups in Nickerie, Coronie, Commewijne, and Weg naar Zee, to include a wide range of local community beneficiaries.

Focus group based data collection brought together members of the local coastal communities to interactively discuss benefits derived from mangroves. The interactions were typically seeded, driven, and moderated by a trained moderator or interviewer. In addition to focus groups, several in-depth, semi-structured interviews were used to interact directly with community members. The main advantage of focus groups is that they are more efficient in obtaining detailed information about personal and group feelings, perceptions, and opinions, can provide a broader range of information, and can save time and money, compared to interviews. The questionnaire used to structure interviews or focus group discussions, limited to an hour each, can be found below in Annex 5.

Preliminary list of regional and national stakeholders and local community beneficiaries

In Suriname the following National and regional level stakeholders were engaged based discussions with experts in-country, and subsequently cross validated by comparing to a list of stakeholders identified in a recent report on "Stakeholder Analysis for Suriname: Promoting Integrated Ocean and Participatory Governance in Guyana and Suriname". The list of stakeholders are:

- Ministry of Agriculture, Animal Husbandry and Fisheries
- Ministry of Spatial Planning, Land and Forest Management
- Ministry of Natural Resources
- National Institute for Environment and Development in Suriname
- Foundation for Forest Management and Production Control
- Green Heritage Fund Suriname
- Fishermen of The Commewijne and Paramaribo Fisher Collective
- Anton de Kom University of Suriname
- WWF – Guianas
- SUNFO (Suriname National Fishersfolks Organization)

In Guyana the following National and regional level stakeholders were engaged:

- Central Planning and Housing Authority (CHPA)
- Environmental Protection Agency Guyana (EPA)
- Guyana Forestry Commission (GFC)
- Guyana Ministry of Public Works (MPW)
- National Agricultural Research & Extension Institute (NAREI)
- Guyana Sugar Corporation (GuySuCo)

In addition to national-level stakeholders, beneficiaries of local community mangrove ecosystem services were identified to include fisher folk, those employed in the tourism, sugar, or rice industries or agriculture more generally, beekeepers, coastal ecotourism operators, indigenous communities, women, and communities that live along the coast. In Suriname local communities are similar to the ones identified for Guyana, except for indigenous communities, and include communities located in Weg naar Zee, Coronie, Nickerie, and Commewijne.

Local community beneficiaries of NBS mangrove ecosystem services

Guyana

Based on the preliminary list of local community beneficiaries in Guyana, local fisher folk were engaged during field visits. Fisherfolk in La Grange, Zeeburg, Ogle, Hope Beach, Goed Fortuin, and the Georgetown Fish Market were contacted. Most of the fishermen catch the same finfish species, including catfish, trout, banga mary, mackerel, kingfish, gilbaka, curras, hardhead, snook, basha, paku, as well as seabob, shrimp, and sherriga crabs. They sell most of the catch to wholesalers or middlemen, or to women who clean and resell the fish and can make a profit. Several support workers aid in the fishing industry, including net menders, and boat repair workers.

Catch volumes and species are very important to all employed or involved in the fisheries sector because catch is directly tied to pay. As most trips are self-funded, the livelihoods of fishermen as well as other workers is heavily dependent of fish and shrimp catch. Fishing was commonly described as a lucrative industry that can “make a person rich”. Even with such promising outcomes, the hard work does not draw young men. Those fishermen who have been in the industry for a long time derive all of their income from fishing. In some areas (e.g. La Grange) some of the fishermen were not full-time fishers, bur made money from construction, masonry, or other labor. Fishermen said that women that are involved in the fish cleaning, processing, and reselling typically work close to full time as well.

From a social and cultural ecosystem value perspective, the mudcrab season (July-August) every year is described as a time to build and maintain inter-generational connections within one's family. Crabbing was mentioned as a common activity both among fishermen, as well as the indigenous communities in Region 1, as described below. Fishermen tend to keep some of the catch for their own and families' consumption, amounting to about 5-10% of total catch, according to one of the fishermen. The responses collected on fishermen are not sufficient to estimate the percentage of mangrove dependent fish catch as a fraction of local households' subsistence, however, interviews indicate this to be important source of food for fishermen and their relatives.

> "Fishing Can Make Someone Rich"
>
> A Fisherman at Georgetown Fish Market told the story of a fisherman who started out on a small boat, and over time worked his way up to larger vessels.
>
> Many years later, he is the owner of three large boats, and continues to generate a profit from fishing.
>
> *A Fisherman in Georgetown, Guyana*
>
> *April 7th, 2019*

Regarding future potential of the sector, fishing driven ecotourism was described by fishermen as a potentially successful endeavor, with large tarpon and other sport fish farther away from the coast, in the "blue water". Still, to this day, none of the fishermen have heard about ecotourism operators focusing on taking domestic or foreign tourists out on fishing trips. One of the stakeholders, the operator of the Mangrove Tour out of Cove and John, described the culinary and cultural components of the tour, but fishing is currently not included among the activities that visitors can participate in. Aquaculture is only present in Regions 6, and could potentially yield high volumes of fish and shrimp, such as cockabelly, or black shrimp, but the impact on mangroves must be mitigated.

Most fishermen described a recent decline in water quality, and in catch per unit of fishing effort, meaning they usually have to take the boats out farther than they used to, which is more costly. Catch of seabob and shrimp did not appear to be affected based on the discussions with fishermen at Zeeburg and Ogle. According to some fishermen, these changes were only moderately tied to changes in mangrove ecosystems. Others described this connection as direct and strong, and understood the critical importance of mangroves to fisheries and their coastal communities. Coastal protection due to reducing wave heights, and control of coastal erosion were specifically mentioned as important services that mangroves provide to these fisher groups.

Some long-time fishermen in Anna Regina and Hope Beach see mangroves as a challenge to overcome. Specifically, they have noticed an increase in sedimentation rates with the expansion of some mangrove areas, making it more challenging to catch fish and shrimp close to shore as they were able to do in the past. Also, they need to take their boats out farther; some fishermen estimated they had to go out almost one mile as compared to a quarter mile or less, from years ago.

Local community beneficiaries identified in Region 1 and 2 include indigenous peoples, women, families engaged in seasonal crabbing, fisher folk and supporting workers, communities exposed to the sea, farmers, and the general population deriving other environmental benefits, such as cleaner water and air, from mangrove ecosystems. Indigenous communities have medicinal uses for the mangroves, use the tannins extracted from the wood to color leather and other products, eat mangrove honey, and derive cultural and social benefits from mangroves. Similar to the fishermen, indigenous communities describe the mud crab season as one of the most important series of events during the year.

> "Christmas in July"
>
> Indigenous communities view the July-August crab season as one of the highlights of the year. Families, children and great-grandparents alike look forward to this annual event of community, culture, food, and celebration.
>
> *An indigenous person in Anna Regina, Guyana*
>
> *April 8th, 2019*

Mangrove ecosystem services are widely recognized among local communities in Regions 1 and 2, including fish abundance, carbon sequestration, species existence (e.g. birds), coastal protection, wood and non-timber forest products, water quality, as well as culture, heritage, and social values. Local communities clearly see the threats to mangroves as being coastal erosion, cutting, sea level rise, storm surges, oil exploration, and pollution. Having the largest extent of mangrove forest in these two regions, local communities regularly interact with mangroves and appear eager to be part of sustainability, monitoring, and forest health efforts in the future. Some of the issues raised by local communities require solutions. These include insects and africanized bees in the mangroves, as well as boating accidents and loss of life due to collision with mangrove branches in narrow bodies of water where cutting is not allowed.

Local community beneficiaries engaged in Regions 3, 4, 5 and 6 include fisher folk and supporting workers, such as net menders, women, coastal populations generally, crabbers, beekeepers, tour operators, and farmers. As emphasized by local communities in Regions 5 and 6, private cutting for aquaculture of mangroves is still occurring, mostly for aquaculture, causing tension among those that live near the coast. By cutting down mangroves, private entities effectively prohibit others in the local community to continue derive benefits from mangrove services, and convert this public benefit to a private one. Unique to these regions are some particular threats to mangroves, such as diebacks due to sawdust from coastal sawmills, an issue that has not been resolved.

Farming is common in these regions, and thus mangrove ecosystem services are closely linked to farming activity. Garden posts, stakes, fences, or pig pens are often made out of mangrove wood, and livestock grazing often occurs in close proximity to mangroves. Also, farmers growing cash crops, and coconut estates, are often located near the coast, making the coastal protection ecosystem service of mangroves more critical.

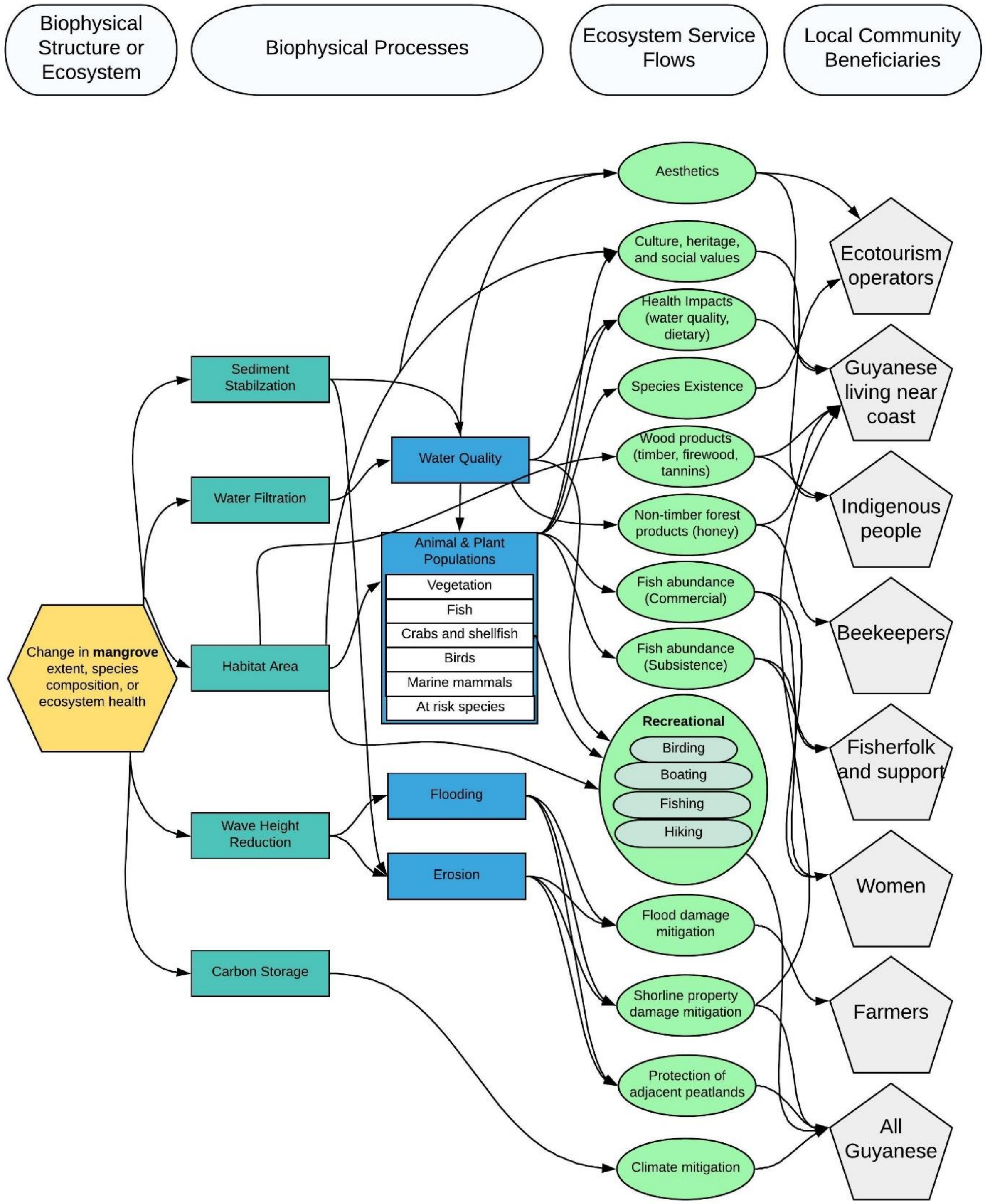
Beekeeping was described as a potentially lucrative activity, and as one that can provide alternative livelihoods to local communities. The honey from mangroves is known to contain medicinal compounds, and could be marketed domestically or abroad. The mangrove ecotourism operator in Cove and John has been able to showcase the culinary aspect of mangrove ecosystems to visitors by making honey tasting, and other food-related experiences part of their popular tours. These interview data indicate there might be potential to scale up mangrove ecotourism operations. Other places where mangrove ecotourism has been successfully scaled up could serve as models for Guyana. A few examples operations in Vietnam[3], Indonesia[4], and Bangladesh[5].

Ecotourism and tourism operators could, in principle, be deriving more ecosystem services from mangroves, but this potential has not been explored widely in this area or others in Guyana. Many Guyanese and others enjoy nature walks near the mangroves, simply due to their aesthetics. Some large beaches draw local, and sometimes foreign, tourists to coastal areas, and bird watching has been widely recognized as a coastal ecotourism related activity. Local community members described the reactions of some visitors who came to the coastal area to engage in bird watching. These tourists were amazed by the beauty of the birds: scarlet ibis, herons, among others.

Based on the data collected in interviews and focus groups in Guyana, we developed an ecosystem services model that links local community beneficiaries and ecosystem services that they derive benefits from. After ground-truthing these linkages, and validating them through the network of regional and national stakeholders in Guyana, we finalized the model and arrived at the mapping below (Figure 7).

[3] http://wwf.panda.org/?291130/World-Wetlands-Day-Mangrove-Ecotourism-Protects-Vulnerable-Vietnam-Delta
[4] https://iopscience.iop.org/article/10.1088/1742-6596/953/1/012174/pdf
[5] https://www.tandfonline.com/doi/abs/10.1080/13032917.2000.9686983

Figure 7: Guyana mangrove ecosystem service model with local community beneficiaries



Source: (Ommer et al. 2011; Liquete et al. 2013; Patil et al. 2016; Mason et al. 2017) and primary data collected during field visits in Guyana

Suriname

At the national level mangrove ecotourism has potential, but is has not been explored yet. In Coronie, there is a Mangrove Educational Center, where guided tours are offered. Regarding other future opportunities related to mangroves, beekeeping is starting to grow at scale on the national level, and it is already widespread at the local and subsistence levels. Also, the local community seeks to continue their engagement in the restoration economy, as in Weg naar Zee, and even expand their involvement in the future.

Regarding threats, the focus groups reported that little agriculture is taking place near mangroves, but cutting for agriculture related reasons can occur. Similarly, grazing has had minimal impacts around mangroves because animal husbandry takes place mainly south of the main coastal road. Some of the regional and national level stakeholders stated that salinity changes have not mattered to coastal farms and productivity, although this could be in part due to the erosion control ecosystem service of the mangroves which reduces the likelihood of salt water intrusion or inundation. Potential threats to mangroves listed by the focus groups are the absence of a policy to prohibit or limit mangrove cutting as well as limited data and knowledge on the actual values that they provide to local communities.

> "Mangrove is a Priority"
>
> Mangrove breaks the waves. Sometimes the waves [would] come all the way where we are [standing].
>
> Mangrove forests offer more: forests, crabs, birds, fish. […] Also filters salt water and then produces fresh water. Shrimp also come to eat there.
>
> *Member of the local community in Weg naar Zee, Suriname*
>
> *April, 2019*

Local community beneficiaries in Weg naar Zee include fisher folk and those engaged in crabbing, farmers (e.g. poultry), hunters, and local community deriving identity, cultural, aesthetic, or clean air and water related environmental benefits from mangroves. People engaged, or participating, in tourism were also identified as a group of local beneficiaries since these groups often engage in bird watching, hunting, or other recreational activities in or around the mangroves. These local communities have experienced reduced flooding and coastal erosion due to the recent mangrove restoration efforts that have taken place in the area. Regarding fisheries, local communities in Weg naar Zee clearly described the linkage between mangroves and fish catch. As they describe it, shrimp and small fish eat between the roots, and subsequently go back into the deep sea and be eaten by bigger fish. Thus, from their perspective the mangroves directly impact small fish and shrimp, and indirectly impact larger fish.

Before restoration began, mangrove cover was decreasing and as a result, damages to property were larger, and fish catch was in decline. Also, as mangroves were declining, many farmers experienced devastating floods and many had to abandon their original line of work, and traditional livelihoods, completely. With respect to restoration efforts, local communities in Weg naar Zee expressed a desire to have this work continue, and are hopeful that different organizations would continue to support these efforts.

In the Commewijne region, hunters, fisher folk and workers in supporting jobs, and workers in the construction industry were identified ad beneficiaries, in addition to local community members that derive environmental benefits from mangroves, including oxygen, coastal protection, or cooling impacts that make coastal living more enjoyable. This group of beneficiaries, as a whole, recognizes the food provision, fisheries support, coastal erosion mitigation, water quality, recreational, biodiversity habitat, cultural and social ecosystem services of mangroves.

In the Coronie region, beekeepers, tour operators, farmers, charcoal producers, workers in the construction industry, fisherfolk and workers in fish processing and smoking, farmers and recreationists, such as those interested in birding, were identified. It was also mentioned that mangroves protect coastal communities from strong winds and the charcoal made from the wood can be used in cooking or smoking fish. In addition, mangrove use was mentioned in connection with the construction industry where it serves multiple purposes.

> "Construction"
>
> […] The fishermen mainly cut them, and the people who are building houses. They use the young ones as a reinforcement in construction.
>
> So when you cut, you don't just cut a piece. […] You can selectively cut.
>
> *Member of the local community in Coronie, Suriname*
>
> *April, 2019*

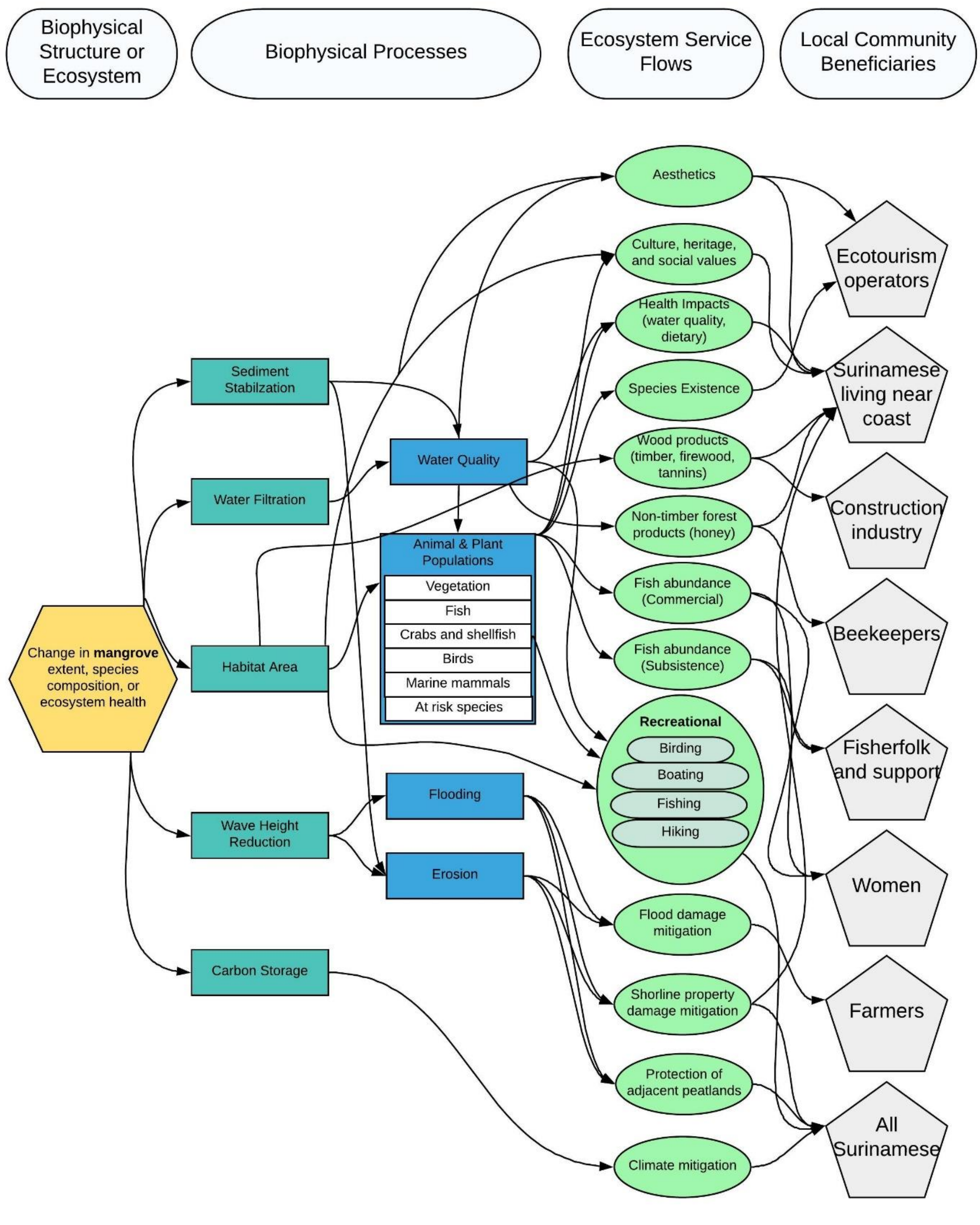
Mangroves are also understood to play a key role in, and benefit the local community, in coastal water management, including the protection of coastal properties, salt water and fresh water management, and sea level rise related issues. Water quality benefits were mentioned explicitly as one of the most important benefits that mangroves provide; other include cultural and social values, marine biodiversity habitat, and habitat for birds. To illustrate the intimate linkage between local communities and mangroves, a local beneficiary described mangroves as being important "for all of life in Coronie". As a collective response to this dependence, local community members expressed the desire to continue to manage mangrove forests in the area for their own benefit, and the benefit of others as well.

In Nickerie, the general coastal population deriving coastal protection benefits was engaged, in addition to fisher folk and workers in supporting jobs, market vendors, and charcoal producers. Fishermen catch multiple species, including koepila, lompoe, tilapia, and grangmorgu, among others, which are often dried using charcoal from mangroves. Also, they tend to use trees for "jagi jagi" to support the nets, while others use longer branches for "djoek", another form of support, but now they must pay a fine if they cut down a tree.

The coastal protection, recreation, water quality, and social and cultural values of mangroves are widely recognized by the local community beneficiaries. A member of the local community described the importance of mangroves to fisheries, including crabs, shrimp, and finfish, as well as their coastal erosion mitigation benefit. Local communities believe they benefit from the shoreline stabilization service of mangroves, whereby they stabilize mudbanks that migrate along the coastline. They also believe that mangrove trees are better than artificial “dams” and that “it is good that there is a dyke and the mangrove”. The roots of mangrove trees are known as “water purification so that the water does not become too salty or too sweet in the rainy season. A kind of natural filter system.”

Based on the data collected in interviews and focus groups in Suriname, we developed an ecosystem services model that links local community beneficiaries and ecosystem services that they derive benefits from. After ground-truthing these linkages, and validating them through the network of regional and national stakeholders in Suriname, we finalized the model and arrived at the mapping below (Figure 8).

Figure 8: Suriname mangrove ecosystem service model with local community beneficiaries



Source: (Ommer et al. 2011; Liquete et al. 2013; Patil et al. 2016; Mason et al. 2017) and primary data collected during field visits in Suriname

From the perspective of local community beneficiaries in Guyana and Suriname, the ecosystems services they derive benefits from are summarized in the table below, and ranked by importance, based on the interviews and focus groups (Table 4). Indigenous peoples, fisherfolk and supporting workers, people living near the coast, and women participating in the fisheries supply chain depend highly on the ecosystem services supplied by mangroves, meaning that if ecosystem service flows change due to changes in mangrove ecosystem health, these groups are especially vulnerable.

Table 4: Importance of ecosystem service flows to local community beneficiary groups

Local community group	**Ecosystem services**	**Importance**
Fisherfolk and supporting	Fish abundance (commercial and subsistence)	High
Guyanese and Surinamese living near coast	Aesthetics, culture, heritage, and social values, health impacts, non-timber forest products, shoreline property damage mitigation, wood products	High
Indigenous peoples	Aesthetics, culture, heritage, and social values, wood products	High
Women	Fish abundance (commercial and subsistence)	High
Beekeepers	Non-timber forest products	Medium
Ecotourism operators	Aesthetics, species existence	Medium
Farmers	Flood damage mitigation	Medium
Construction industry	Wood products	Medium
All Guyanese and Surinamese	Climate mitigation, shoreline property damage mitigation, protection of adjacent peatlands, recreational	Medium

Summary and application

Analysis of local community beneficiaries

The residents of the local communities that participated in the focus groups in both Guyana and Suriname are generally well informed, and are knowledgeable about, the ecosystem services that mangroves provide them. In both countries, a handful of local community groups were identified that may be affected disproportionately due to future mangrove loss. First, coastal small-scale fishers and the workers that support their operations in both countries rely most heavily on mangroves for their livelihoods, with limited alternatives available. Second, women participating in the fisheries supply chain are also potentially highly impacted in the case of mangrove loss, should it translate to loss of fish catch. Third, indigenous communities in Guyana derive significant cultural, social, and subsistence values from mangrove ecosystem services, and many of these values do not appear to have substitutes.

Fourth, the focus groups from the local communities living near the coast reported large benefits from the coastal erosion mitigation, water quality, and flood damage protection services that can only be substituted by gray infrastructure. They also value the indirect social benefits provided by mangroves during the annual mud crab harvest, widely thought of by the focus groups in both countries as one of the highlights of the year. Finally, the broader national and regional communities benefit from the climate mitigation ecosystem service of these ecosystems. Other local community groups also derive benefits from mangrove ecosystems, but the values they derive may have locally available substitutes, decreasing the level of dependence on mangroves. Without knowing the direction and rate of change of mangrove cover over time, the magnitude of change in the supply of these ecosystem services remains uncertain.

Tenure issues for mangroves and stakeholders in Guyana were analyzed in a recent report by (Johnson-Bhola 2018). A recent report on institutional and legal issues related to mangrove management also served as an important resource (Government of Guyana 2013). The report "Stakeholder Analysis for Suriname" provided the background for the analysis of local communities and how they relate to mangroves in Suriname. There appear to be few barriers in the two countries to derive benefits from mangrove ecosystem services. Except for the resources harvested directly from these forests, ecosystem services provided by mangroves are available to all members of the local community. Most of the mangroves in Guyana and Suriname occur on public lands, and provide benefits to the entire community. Rules to mangrove use are a combination of state legislation and customary tenure. For example, cutting of mangroves in Guyana requires a permit, while in Suriname it does not. Where mangroves occur on privately owned land, such as titled or transported property, state rules still apply, but owners may restrict access to these mangrove plots, therefore disallowing other community members to benefit from ecosystem service flows in those areas.

Extractive resources derived from mangroves, such as timber, honey, tannins, or firewood could have limited accessibility, especially in Guyana where cutting of mangroves is unlawful without a permit. Some of these resources are of high relative value and importance to groups of the local community, and their having continued access to these services may be prioritized in the future, to ensure that the well-being of these groups is not reduced unnecessarily. Alternative future mangrove management scenarios such as no net loss, mangrove reforestation, should use the results in this analysis to predict the impact on the distribution of ecosystem services provided over time and space (Koch et al. 2009). Changes in the distribution of ecosystem services in time and space also affects the sustainability of the mangrove SES, and is of key relevance to sustainability and adaptation to rapid global and local changes (Janssen et al. 2007).

Areas of application

The present analysis provides four areas of application when developing or updating mangrove management plans. First, the conceptual framework developed for the NBS mangrove SES helps determine the impact of policy and management changes on the amount of various mangrove ecosystem services flows relevant to Guyana and Suriname. Second, the ground-truthed list of local community beneficiaries and their perceptions helps in determining the distributional impacts of changes in mangrove management, and highlights local beneficiary groups that are most highly dependent on mangroves. Third, the use of economic values estimated for the fisheries support ecosystem service can be used to improve management decisions regarding mangroves by providing defensible positive values to better determine the relative costs and benefits of, and tradeoffs among alternative future scenarios. Fourth, to facilitate future mangrove research on the NBS, economic valuation methods are proposed for the ecosystem services relevant to Guyana and Suriname. Valuation of mangrove ecosystem services in addition to fisheries support can provide a more complete picture of the total values by this ecosystem, which in turn allows for making well-informed decisions about the potential welfare gains or losses expected under alternative management scenarios.

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Annexes

Annex 1: List of studies used in the mangrove-fishery support meta-analysis.

Study	Title	Country	Catch Type
Abdul *et al.* (2015)	The Correlation between Mangrove and the Increasing Capture Fisheries and Sea Farming Products in Coastal Waters (The Case Study in Sinjai Regency Coastal Waters)	Indonesia	Finfish, Shellfish

Bassirou *et al.* (2016)	The role of mangrove for the French Guiana shrimp fishery	French Guiana	Shellfish
Cesar Vasquez-Gonzalez (2015)	Trade-offs in fishery yield between wetland conservation and land conversion on the Gulf of Mexico	Mexico	Finfish, Shellfish
Barbier (2003)	Habitat Fishery Linkages and Mangrove Loss in Thailand	Thailand	Finfish, Shellfish
Manson *et al.* (2005)	A broad-scale analysis of links between coastal fisheries production and mangrove extent: A case-study for northeastern Australia	Australia	Shellfish
Gatot Yulianto *et al.* (2016)	The role of mangrove in support of coastal fisheries in Indramayu Regency, West Java, Indonesia	Indonesia	Finfish, Shellfish
Gilbert and Janssen (1998)	Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes	Philippines	Shellfish
Joseph E. Serafy (2015)	Mangroves Enhance Reef Fish Abundance at the Caribbean Regional Scale	Caribbean	Finfish

Lavanya *et al.* (2017)	Economic analysis of mangrove and marine fishery linkages in India	India	Shellfish
Mauricio Carrasquilla-Henao *et al.* (2013)	Mangrove forest and artisanal fishery in the southern part of the Gulf of California, Mexico	Mexico	Shellfish
Loneragana *et al.* (2004)	Prawn landings and their relationship with the extent of mangroves and shallow waters in western peninsular Malaysia	Malaysia	Shellfish
Aburto-Oropeza *et al.* (2007)	Mangroves in the Gulf of California increase fishery yields	Mexico	Shellfish
Pauly & Ingles (1996)	The relationship between shrimp yields and intertidal vegetation (mangrove) areas: A reassessment	Worldwide	Shellfish
Paw & Chua (1991)	An assessment of the ecological and economic impact of mangrove conversion in Southeast Asia.	Philippines	Finfish
Martosubroto & Naamin (1997)	Relationship Between Tidal Forests (Mangroves) And Commercial Shrimp Production in Indonesia	Southeast Asia	Shellfish
Sathirathai (2003)	Economic Valuation of Mangroves and the Roles of Local Communities in the Conservation of Natural Resources: Case Study of Surat Thani, South of Thailand	Indonesia	Finfish, Shellfish

Sathirathai and Barbier (2001)	Valuing Mangrove Conservation in Thailand	Thailand	Finfish, Shellfish
Sopheak & Hoeurn (2016)	An Estimation of the Production Function of Fisheries in Peam Krasaob wildlife sanctuary in Koh Kong Province, Cambodia	Cambodia	Finfish, Shellfish
Turner (1977)	Intertidal vegetation and commercial Yields of Penaeid Shrimp	Worldwide	Shellfish
Yanez-Arancibia *et al.* (1985)	Ecology of control mechanisms of natural fish production in the coastal zone.	Mexico	Unknown
Barbier (1998)	Valuing Mangrove-Fishery Linkages	Mexico	Shellfish

Annex 2: Literature reviewed on the valuation of the coastal protection ecosystem service

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Annex 4: Background on economic valuation methods

Most ecosystem services lack markets and thus their values may not be taken into consideration when managing human interactions with nature, or failing to manage them. Economic valuation aims to provide accurate and defensible values for these services, to help make tradeoffs more explicit (Champ et al. 2003). Two groups of primary economic valuation exist: revealed and stated preference methods. Revealed preference methods estimate economic value based on the behavior of people using ecosystem services; these methods include market price, cost-based (i.e. avoided damages, replacement cost, or substitution cost), hedonic pricing, and travel cost methods. The more complex, and resource-intensive stated preference methods include contingent valuation and choice experiments. Benefit transfer is an alternative to the primary valuation methods and uses existing values estimated through primary methods elsewhere, and adjusted to match conditions in the area of interest. The choice of method depends on the objectives of the study, research area and population of interest, resource and time availability, and the existence or access to existing data.

Based on a review of the economic valuation literature (Garrod and Willis 1999; Bateman et al. 2002; De Groot et al. 2002; Champ et al. 2003; Wilson and Hoehn 2006; Bockstael and McConnell 2010; Carson 2012, among others), we provide an evaluation of the strengths and weaknesses of each methodology, as well as details on their application to help guide further efforts to manage uses of mangrove ecosystems in Guyana and Suriname.

Revealed preference methods

Measures the economic benefits from marketed ecosystem services such as timber or non-forest wood products, based on prevailing market prices. The method is used to calculate the marginal value of changes in the quantity or the quality of the services supplied. The strengths of the approach are availability of price data for observed transactions and thus individual preferences, and that standard economic principles are employed. Some of the key weaknesses of the market price method are that generally, prices are only available for a few marketed ecosystem services, and that the value of other factors necessary for the production of ecosystem products is not deducted from the estimate which leads to overestimation of the ecosystem benefit that contributed to their production.

These methods are used to value improved environmental (e.g. water, air) quality derived from nature by estimating the cost of damages to property or human life avoided due to their presence, the cost to replace ecosystems that produce them, or the cost to provide substitutes for them. As such, these methods are often referred to avoided damage cost, replacement cost, or substitution cost methods, respectively. The strengths of these methods are that they are easy to estimate, not data intensive, and can often be used when other methods are inappropriate. The weaknesses are that the accuracy of the estimates depend on the similarity of the ecosystem service to be measured, and its human-made equivalent. replacement, or substitute.

This method is mainly used to estimate the value of economic services related to environmental quality (e.g. air, water) or aesthetics. Hedonic pricing assumes that the price differential between two goods (e.g. properties) is dependent, on their characteristics, including environmental factors. The main strengths of this method are readily available data on property records, and economic values estimated based on actual market transactions or preferences. The main weaknesses of the method are limitation to housing-related environmental attributes as perceived by people, and its resource and data intensive nature.

Typically used to estimate values related to recreational benefits under the assumption that the total cost of a non-business related trip reflects people's willingness to pay for the ecosystem services supplied at the destination. Travel cost based valuation can rely on primary (e.g. survey) or secondary (e.g. park entrance fees) data and are similar to the market price method because of its reliance on actual price paid for a service. The strengths of the method are low resource requirements, and reliability of estimated values due to reliance of revealed preferences of individuals. The main weakness of the method is its restriction to estimate values based only on current conditions.

Stated preference methods

A survey-based valuation method, contingent valuation directly asks people about their willingness to pay for a given improvement in and environmental quality or attribute, or their willingness to accept compensation for their loss or degradation. Survey questionnaires can be designed to provide data on the perceived values of the entire range ecosystem services, including those that the respondent is not directly interacting with. The strength of this method is that hypothetical changes in the value of environmental services can be detected, and that other relevant data can be collected in the surveys that help with interpretation of the results. The main weakness of this method is the risk of highly biased responses which lead to inaccurate value estimates. Also, questionnaire development, survey administration, and data analysis are highly resource intensive.

A survey-based valuation method, choice experiments seek to estimate the value of environmental services by having respondents rank various alternative scenarios described by several characteristics. Respondents are assumed to rank the alternatives based on their positive impact on them, allowing for the estimation of relative values of ecosystem services. The strengths and weaknesses of choice experiments are similar from the perspective of application.

Annex 5: Questionnaire used to assess local community mangrove ecosystem services

Section 1: Background

1. If you are employed, what type of organization do you work for?

Self-employed, Government agency/department, Sub-national level of government (e.g. local authority, municipality etc.), Private sector, Research institution, Academia, Non-governmental organization, Non-profit organization, Other (please specify)

2. Do you work in some occupation or derive livelihood related to one of these benefits?

Climate regulation/carbon storage, Raw material, Benefits related to mariculture, Fisheries/ Fish nursery habitats, Recreation e.g. recreational fishing, diving, photography, Provision of habitat for natural biodiversity and protected species, Coastal protection/sediment stabilization, Water quality regulation (e.g. diseases, nutrient cycling), Sense of place and cultural connections, Spiritual value, Other (please specify)

3. How much of your work or livelihood relates to mangroves?

Less than 25%, More than 25% but less than 50%, More than 50% but less than 75%, More than 75%, Other (please provide an estimate)

4. In relation to your mangrove-related occupation or livelihood from the question above, please provide as much detail as possible.

Site / Region:

Locations:

Section 2: Mangroves and their benefits

1a.What values are provided by mangroves in your region to you or the community as a whole (open ended)?

1b. Please indicate which values are provided by mangroves in your region to you or the community as a whole?

Raw materials, Aquaculture (e.g. shrimp ponds), Fisheries/ Fish nursery habitats, Recreation e.g. recreational fishing, diving, photography, Provision of habitat for important species, natural biodiversity and protected species, Coastal protection/sediment stabilization, Water filtering and water quality regulation (e.g. diseases, nutrient cycling), Sense of place and cultural connections, Spiritual value, Other (please specify)

2. How much of your livelihood depends on mangrove ecosystems?

Less than 25%, More than 25% but less than 50%, More than 50% but less than 75%, More than 75%, Other (please provide an estimate)

3. Please indicate how much you agree with the following statements about the benefits that mangroves in your region provide to you:

Strongly disagree Disagree Neither agree or disagree Agree Strongly Agree
Unsure

Mangroves are important for food provision.

Mangroves provide food and shelter for young fish.

Mangroves can help prevent coastal erosion.

Mangroves provide important habitats for marine animals etc.

Mangroves improve water quality.

Mangroves are important for societal health and wellbeing.

Mangroves are a valuable environment for recreation and tourism

Mangroves are important to inspire culture, art and design.

Mangroves are important for a sense of place.

4. Are there other services or benefits provided by mangroves that have not been mentioned? If yes, please provide details below and give an indication of their importance using the same scale used in the previous question.

Section 3: Mangroves and their management

1. In your opinion, what do you think are the main threats to the mangroves in your region where you live or work? Please rank them and say why.

2. Are their rules for using the mangroves? If so, who is responsible for enforcing them?

3. What are the main things affecting mangroves in your region? For example, tradition, policy, financial resources.

4. Overall, how would you rate the effectiveness of mangrove management in your region? For example: Are mangroves being lost or not? Is fish catch related to mangroves changing and if so, how? Are coastal areas getting impacted by storms or waves due to mangroves? Please explain your answer.

Not Effective, Somewhat Effective, Neither Effective nor ineffective, Effective, Very Effective

Annex 6: Initial list of variables used in the meta-analysis of fisheries support.

Variable	Variable definition
Dependent	Elasticity (ln)
Finfish	Dummy variable for finfish (presence of finfish =1; absence of finfish =0)
Shellfish	Dummy variable for shellfish (presence of shellfish =1; absence of shellfish =0)
Location at Open Sea	Dummy variable for catch location (catch location at open sea= 1; catch location not at open sea=0)
Observations	Number of observations in the meta-analysis
Fish Stock Improving	Percentage of stock that is rebuilding or developing