Economic Valuation of Mangrove-Fishery Linkages in Guyana and Suriname

by

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Executive Summary

Mangroves are among the most productive ecosystems in the word. By providing valuable ecosystem services, mangroves enhance human well-being and contribute to biodiversity conservation in the tropical and subtropical regions where they are found. Mangroves provide nursery, feeding, breeding grounds, and shelter areas for many marine species, which in turn enhances the productivity of traditional and commercial fisheries.

The objective of the present study is to evaluate how mangrove ecosystems affect fisheries in Guyana and Suriname, as part of a collaborative project between the Nicholas Institute for Environmental Policy Solutions and Conservation International. The evaluation involved conducting a meta-analysis of information drawn from 21 mangrove-fishery linkage studies from around the world to estimate a general model relating fish catch to mangrove area. A benefit transfer method was then used to apply the results from the meta-analysis to recent and projected future changes in mangrove areas in Guyana and Suriname, and thereby predict the impacts on fish catch in the two countries.

The first section of this report provides an overview of mangrove ecosystems, definitions of the four types of ecosystem services identified by the Millennium Ecosystem Assessment, and an outline of the ecosystem services provided exclusively by mangroves. This section also highlights some of the main global drivers of mangrove loss. Lastly, it provides the main objectives of this project, an overview of Guyana and Suriname, and estimates of the areas and trends in mangroves in both countries. Mangrove area change was calculated using the average of estimates from two sources for each country. The estimated changes in mangrove area during 2000-2017 were -1.96% per year in Guyana and -0.76% per year in Suriname.

The second section of this report describes the methods used to determine how these trends have affected fisheries in Guyana and Suriname. After providing an overview of the meta-analysis and benefit transfer methods, this section explains the variables selected for the meta-analysis. Variables were selected to capture essential characteristics of the study sites and the studies themselves. Finally, the equation estimated by the meta-analysis is defined. This equation relates the impacts of mangrove area reported by the studies to the selected variables. Observations were included in the dataset for estimating this equation only if a study included sufficient information for calculating the reported impact as an elasticity, which can be explained

as follows: denoting the elasticity by Ɛ, a 1% increase in mangrove area increases fish catch by Ɛ%.

The third section of this report applies the results from the meta-analysis to calculate the benefit transfer estimates for each country. There are two final models: a shellfish model and a finfish model. The shellfish model was used to generate the estimate for Guyana, while the finfish model was used to generate the estimate for Suriname. For Guyana, the predicted elasticity (Ɛ**)** is 0.924, which implies a 1.81% loss in shellfish catch per year resulting from the recent loss of mangroves in that country. For Suriname, the predicted elasticity (Ɛ**)** is 1.77, which implies a 1.34% loss in finfish catch per year resulting from that country's recent loss of mangroves. These estimated losses in fish catch were calculated by multiplying each country's elasticity by the observed changes in mangrove area noted previously.

The fourth section of this study provides a discussion of the analysis and estimates the benefits of mangrove restoration in each country. If the estimated loss in mangrove area had not occurred in Guyana, the Guyanese fishery would have gained $586,440 in revenue net of costs. Similarly, if the estimated loss in mangrove area had not occurred in Suriname, the fishery in that country would have gained $180,900 in revenue net of costs. This section also provides a comparison to previous mangrove-fishery linkage studies. This is followed by a discussion of limitations of the present study, including the wide variation in mangrove area and mangrove area change estimates found in different sources. Lastly, recommendations for future data collection are provided.

The final section of this study provides an insight into mangrove-fishery linkages within the countries of Guyana and Suriname for specific fisheries as well as the associated monetary gains resulting from conserving mangrove area. These estimates are insufficient for determining the total value of conserving mangrove area, but a more complete estimate of total value could be determined by applying valuation methods, similar to those used in this study, to additional ecosystem services.

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1. Introduction

1.1 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).

While only accounting for less than one percent of the entire area of tropical forests in the world, mangroves are well known for their adaptations to survive in extreme environments (Duke *et.al*., 2014). Some of the extreme conditions that mangroves thrive in are environments of high salinity, low oxygen, high temperatures, and regular tidal inundation. One of the most important adaptations mangroves have developed are exposed breathing roots, known as pneumatophores (NOAA, 2019). When compared to other plants, mangroves have poorly developed underground roots because these tropical forests are located in sediments with low oxygen levels due to constant tidal inundations. Thus, specialized root structures like pneumatophores help mangroves to transport atmospheric gases to the underground roots. Additionally, root membranes act as effective water filters by excluding the salt while allowing the water to pass through. Moreover, some mangroves have glands on each leaf adapted to excrete salt from seawater (NOAA). Mangroves also have a unique reproduction method, where their seeds grow attached to the parental plant (seeds known as propagules). After a growing period, where the seed grows small roots, it reaches the water and travels in a vertical position until it finds a shallow region for the roots to further develop (Kathiresan and Bingham, 2001).

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.

1.2 Ecosystem Services

1.2.1 Definition of Ecosystem Services

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 (MA), in an effort to enhance the sustainable use of natural ecosystems, evaluated how changes in ecosystems affect human well-being (Millennium Ecosystem Assessment, 2005). As a result, MA 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 (Millennium Ecosystem Assessment, 2005).

1.2.2 Mangrove Ecosystem Services

MA describes four types of ecosystem services: *provisioning*, *regulating*, *cultural*, and *supporting* (Millennium Ecosystem Assessment, 2005). Among the *supporting services* provided by mangroves, coastal protection is the most well investigated. Due to its unique location mangroves protect shorelines from damaging storms, winds, waves, and floods (Duke *et.al.*, 2014). Moreover, mangroves enhance water quality by filtering pollutants derived from land and prevent shoreline erosion by trapping sediments within their root system (Duke *et.al.*, 2014). Mangroves' ability to sequester carbon can also help mitigate climate change (Kauffman *et.al.*, 2014).

Mangroves provide many *non-material values* to humans from spiritual enrichment and religious and cultural values, to enhancing recreational activities, aesthetics, education, and scientific research (Duke *et.al.*, 2014).

Among the *provisioning services*, these tropical forest ecosystems offer vital goods and services like food, fresh water, materials used for construction, and important medicines to cure certain illnesses (Abeysinghe, 2010). Additionally, it has been documented that mangroves enhance coastal fisheries by serving as shelter, feeding, and nursery grounds for many marine species (Chong, 2007 and Röhnback, 1999).

- *Feeding grounds*: mangrove habitats are considered to be highly productive. This productivity stems from the high concentration of organic matter resulting from the decomposition of falling leaves and detritus (Chong, 2007). This organic matter is used by marine fish, shrimp, crabs, and mollusks as food. The excess of nutrients also attracts other top predators (e.g. grouper, snapper, sharks) to the surrounding waters (Duke *et. al*, 2014). The high level of marine biodiversity that results from this function of the mangroves makes it an ideal location for local fishermen.
- *Shelter areas:* mangrove ecosystems provide shelter to marine species due to their intricate root systems, muddy floors, and turbid-shallow waters which help protect species from predators (Chong, 2007).
- *Nursery and breeding grounds:* Mangrove habitat characteristics enhance the early life stages of many marine species such as shrimp, prawns, and fish. By protecting early life stages and juveniles, mangroves provide effective nursery and breeding grounds where marine species have a higher rate of survival. Once these species reach the adult stage, some of them (like many fish and shrimp) migrate offshore and return later in life to deliver offspring. This dynamic flow helps to replenish marine species populations and sustain offshore fisheries (Aburt-Oropeza *et.al*., 2008).

Given this range of ecosystem services, human well-being could be severely impacted by the loss of mangrove forest. *Table 1* presents a comprehensive list of the ecosystem services provided by mangroves.

Table 1. Ecosystem services provided by mangroves. Adapted from *"The importance of mangroves to people: A call to Action"* by Duke *et.al*., 2014.

Provisioning Services	**Regulating and Supporting Services**	**Cultural Services**
Timber and construction materials	Coastal protection	Ecotourism
Food	Erosion control	Recreation
Medicine	Water quality maintenance	Aesthetics

Water	Climate regulation/carbon sequestration	Scientific research
Fuelwood	Nursery habitats	Spiritual enrichment
Fisheries	Nutrient cycling	Heritage and culture value
Tannins	Water cycling	Religious value
Fiber	Support to coral reef, seagrass beds, mud and sand flats	Education
Fodder		

1.3 Global Drivers of Mangrove Loss

Despite the valuable ecosystem services provided by mangroves, their existence is threatened by land use change (agriculture, aquaculture), pollution, coastal development, climate change, and overfishing (Global Mangrove Alliance). While uncertainty exists regarding the area of mangrove cover in some countries, including Guyana and Suriname, all agree that the original global area of these tropical forests has been reduced, perhaps by as much as 25% (Duke *et.al.*, 2014).

Damage and loss of the ecosystem services provided by mangroves impact human well-being by reducing incomes, threatening food security, reducing water quality, increasing pollution and eutrophication, and impacting the overall health of communities (Duke *et.al.*, 2014). Additionally, the loss of mangroves will have detrimental effects on coastal communities by increasing their susceptibility to the effects of sea level rise, severe and frequent storms, and coastal erosion (Duke *et.al.*, 2014).

1.4 Study Objective

The ecological aid that mangroves provide to several marine species has been well documented (Röhnback, 1999; Kathiresan and Bingham, 2001; Islam and Haque, 2004; Duke *et.al.* 2014, Chong, 2007). Moreover, numerous studies around the world have found a significant contribution of mangrove-dependent fish to important commercial fisheries, including prawn and shrimp fisheries (Lavanya and Kumar, 2017; Martosubroto and Naamin, 1977; Pauly and Ingles, 1999; Turner, 1977; Barbier and Sathirathai, 2001; Manson *et.al.*, 2005; Sathirathai, 2003; Gilbert and Janssen, 1998).

While a few studies have documented mangrove-fishery linkages in Latin America (Barbier and Strand, 1998; Aburt-Oropeza *et.al*., 2008; Carrasquilla-Henao *et.al*. 2013; Vazquez-Gonzalez *et.al*., 2015; Serafy *et.al*., 2015; Bassirou *et.al*., 2016), there is a lack of studies that evaluate the benefits of mangroves for fisheries in the North Brazil Shelf (NBS). The North Brazil Shelf, considered one of the most productive Large Marine Ecosystems (LME) in the world, includes northeastern Brazil, French Guiana, Suriname, Guyana, Venezuela, Trinidad and Tobago (Isaac and Ferrari, 2017). It is estimated that mangrove forest covers approximately 8900 km^2 of the total area of this region. Demersal fish ("species that live in close relation with the bottom of the sea/lake and depend on it", NOAA Fisheries Glossary) and shrimp are the most profitable fisheries in this region (Isaac and Ferrari, 2017).

The Nicholas Institute for Environmental Policy Solutions (NIEPS) at Duke University in collaboration with Conservation International (CI) are working together on the NBS Mangrove Project which is funded by the Global Environment Facility (GEF). The objectives of this project are 1) to generate the necessary baseline knowledge that would contribute to well-informed management of NBS mangrove systems, with emphasis on the information needs of Guyana and Suriname; and 2) to support the development of transboundary coordination mechanisms in NBS region countries.

The objective of the present study is to evaluate how mangrove ecosystems contribute to fisheries in Guyana and Suriname. This contributes to the NBS Mangrove Project by conducting an economic valuation of one of the ecosystem services provided by mangroves, namely fisheries support, and creating a benefit transfer and meta-analysis framework for NIEPS to apply towards subsequent economic valuations of other ecosystem services.

1.5. Research Area

The research area for this analysis is the countries of Guyana and Suriname, and the marine waters under their jurisdiction.

1.5.1 Guyana

The nation of Guyana is bordered by Venezuela, Brazil, Suriname, and the Atlantic Ocean. Mangroves are found along most of the Atlantic Coast (FAO 2005). The government of Guyana, with the help of the European Union, set up the National Mangrove Management Action Plan in 2010 to begin to address mangrove loss and coastal erosion issues. The plan sets out standards for conserving mangroves, preventing net-loss, and preparing environmental impact assessments (MAP, 2010), and it expired in 2012. There has not been an update since the plan was released. Some of the leading causes of mangrove loss include extracting the mangroves to produce a variety of products such as charcoal, fishing poles, tanning bark, and domestic fuel wood (Allan et al., 2002). Aquaculture on a commercial scale has expanded greatly in Guyana over the past two decades. Some of this aquaculture is occurring in brackish waters and is likely a contributor to recent mangrove loss (FAO Aquaculture).

The open-sea 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 (Guyana Demographic Profile). Shrimp and other shellfish species dominate the fish catch (FAO Fish). In Guyana, trawlers 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 prawn trawlers to land 15 tons of finfish bycatch per year (FAO 2005). 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).

1.5.2 Suriname

The country of Suriname is located just southeast of Guyana between Brazil and the Atlantic Ocean. Suriname has been recognized as the country most threatened by sea level rise in the Caribbean and South America, which has been a major motivator in implementing shoreline and mangrove protection plans (Cete et al., 2018). The Mangrove Project, which is the newest plan to conserve mangroves in the country, was rolled out in May of 2018. The loss of mangroves in Suriname is commonly attributed to the activities of fishers and farmers, however a study conducted between 2009-2011 in three different regions of Suriname found that ecological factors were the driving force in mangrove loss (Nijbroek, 2014). Mangroves are particularly dependent on thick mudbanks to stabilize their roots. Rising sea levels have led to an erosion of these mudbanks and exposed mangroves to stronger waves. The combination of these effects has led to the natural loss of mangroves (Nijbroek, 2014).

Fisheries account for 3.55% of Suriname's GDP. The fishing industry is highly export oriented and accounts for 4.8% of total exports (FAO Fish). In 2016, total landings were 47,013 tons with the majority of the landings being finfish (FAO Fish). The fishing industry is not heavily regulated in Suriname, aside from required licenses to operate all types of fishing fleets. Only the number of seabob shrimp and bottom trawler licenses are restricted. Additionally, Suriname has fishing operation zones which limit the type of fishing activity that can occur in specific locations (FAO Suriname, 2008). The percentage of fish stocks with 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.

1.5.3 Mangrove areas and trends

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 (FAO mangrove Guyana; FAO mangrove Suriname; Hamilton *et. al.* 2017). 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 et al. 2017). 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 (*Figure 2*), whereas Suriname had 96,000 ha that same year (*Figure 3*). On the other hand, Hamilton *et. al.* (2017), reported that in 2000 Guyana had around 20,000 ha of mangroves, while Suriname had around 50,000 ha (*Figure 4*).

To account for these discrepancies, the percentage change in mangrove area for each country was calculated using the average of the reported changes in mangrove area from Hamilton *et. al.* (2017) 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 *et al*. (2017) 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 *et al.* (2017) and 2001-2017 for Global Forest Watch.

In the case of Hamilton *et.al.* (2017) 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.

When using the Global Forest Watch source (Global Forest Watch), regions where mangroves are known to exist within each country were selected to calculate the percent change in mangrove area (*Table 2*). 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:

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

Suriname:

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

The result is a 1.96% loss of mangrove area per year for Guyana, and a 0.76% loss of mangrove area per year for Suriname.

2. Methods

2.1 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 (Romm *et. al*. 2010). The benefit transfer method was used to apply the results from the meta-analysis to Guyana and Suriname. 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.*, 2017). Seeing as there are no known studies to date on mangrove-fishery linkages in Guyana or Suriname, this was felt to be the most appropriate method for extracting results.

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. Guyana and Suriname sit between the latitudes of 5.8-8.4 degrees so it was rationalized that countries with similar latitudes would be more similar in fish species and mangrove type than countries outside of this range. Once again it was determined that there were insufficient studies in this small latitude band, so study collection was expanded to include studies conducted in all regions of the world. The final database for the meta-analysis included 21 separate studies (*Table 3*).

Once the values of the independent variables (*Table 4)* were extracted from the studies mentioned above, different regression models were run. 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 (Kenton, 2019). 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:

$$\% \text{ change in fish catch in Guyana/Suriname} = \mathcal{E} \times \%M$$

Table 4: 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

2.2 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 **(**$\frac{dy}{dx} * \frac{mean\ x}{mean\ y}$**)**, 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). 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 the data was collected in. In the case of panel and time series analysis, the median year of data collection was used. What this means is that if data collection from a study spanned from 2000 to 2004, the fish stock improving variable was based on data from 2002. Table 5 describes the explanatory variables collected or calculated from the studies included in the meta-analysis (*see Appendix*).

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:

$$\mathcal{E} = \frac{\mathbf{dy}}{\mathbf{dx}} * \frac{mean\ x}{mean\ y}$$

The compilation of reported and calculated elasticities had a right-skewed distribution. Outliers with values 0.1 < and > 10 were removed and the variable was log-transformed. These adjustments resulted in a more normal distribution (*Figure 5)*. No other variables were transformed so the final result was a log-linear model**.** 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.

3. Results

3.1. Meta-analysis

After building the database for this study, two different regression models were run: a finfish model and a shellfish model. These models were used in the subsequent analysis and were estimated using robust standard errors. The decision to use these two models was based on the inconsistency in classification of the catch in the studies selected for this meta-analysis. Not all of the studies specified the species of finfish or shellfish that were caught. 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.

3.2.1 Shellfish Regression

The meta-regression output for the shellfish model, by the standards of a meta-analysis, fit the data well with an R-squared of 0.393. The shellfish, location at open sea, and fish stock improving variables have positive regression coefficients that are statistically significant at a 0.05 significance level, whereas the number of observations variable has a negative regression coefficient that is statistically significant at a 0.05 significance level (*Table 6*). The number of observations refers to the number of data points reported in each study.

The observations coefficient was expected to be negative because the assumptions were made that studies with more observations are more representative and more representative studies have smaller elasticities. The fish stock improving variable was expected to have a positive coefficient because studies with higher percentages of improving fish stocks signal a well-managed fishery which likely means larger fish populations than studies with lower percentages of improving fish stocks. In this case, the elasticity may be a combination of the effects of mangrove area and fishery management, resulting in a greater observed elasticity. No assumptions were made regarding the location open sea coefficient because of uncertainty about the species of fish caught and therefore the dependence of the catch on mangroves. Similarly, 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 (Chong, 2007 and Röhnback, 1999).

Table 6. Meta-regression output for the Shellfish model.

N. Obs	36
F (4,31)	13.22
Prob > F	0.0000
R-squared	0.3929

Variables	**Coefficients**	**p-values**
Shellfish	0.561	0.015*
Observations	-0.005	0.026*
Location Open Sea	1.068	0.002*
Fish Stock Improving	0.029	0.000*
constant	-1.727	0.000

* statistically significant at $\alpha = 0.05$

3.2.2 Finfish Regression

Like the shellfish model, the meta-regression output for the finfish model, by the standards of a meta-analysis, fits the data well with an R-squared of 0.402. The finfish and observations variables have negative regression coefficients that are statistically significant at a 0.05 significance level while the location at the open sea and fish stock improving variables have positive regression coefficients that are statistically significant at a 0.05 significance level (*Table 7*).

As was the case for the shellfish model, no assumptions were made regarding the signs of the finfish and location open sea coefficients. A potential explanation for the negative finfish coefficient follows the logic used in explaining the positive shellfish coefficient: shrimp are more dependent than most finfish species on mangroves, resulting in smaller estimated elasticities for finfish. The explanations stated in the shellfish regression discussion for the expected negative coefficient for observations also hold. This is true too for the positive coefficient of the fish stock improving variable.

Table 7. Meta-regression output for the Finfish model.

N. Obs	36
F (4,31)	18.45
Prob > F	0.0000
R-squared	0.4015

Variables	Coefficients	p-values
Finfish	-0.636	0.033*
Observations	-0.005	0.019*
Location Open Sea	1.021	0.004*
Fish Stock Improving	0.026	0.001*
constant	-0.926	0.088

* statistically significant at $\alpha = 0.05$

3.3 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.

3.3.1 Guyana

Guyana's main fishery is shellfish so a value of 1 was assigned to the shellfish dummy variable. This signals that if a study had been conducted in Guyana, then it would have focused on shellfish. Similarly, since most of the catch happens in the open sea, a value of 1 was assigned to the location open sea variable. The fish stock improving value for Guyana was calculated by using the Sea Around Us website (calculated for the most recent year available, 2014). The estimate for observations at the study site is more difficult to predict. In this case, the median of the reported observations of the studies included in the meta-analysis was used.

Variable	**Regression Coefficients**	**Guyana site measures**
Constant	-1.73	1
Shellfish	0.561	1
Location Open Sea	1.07	1
Fish Stock Improving	0.0295	2.8
Observations	-0.00521	12

The predicted elasticity (Ɛ) was calculated from the model by multiplying the regression coefficients by the site measures for each variable and summing them:

$$-1.73 + 0.561\,\mathbf{(1)} + 1.07\,\mathbf{(1)} + 0.0295\,\mathbf{(2.8)} - 0.00521\,\mathbf{(12)} = -0.0789,$$

Since the meta-regression is a log-linear model, the resulting value was then untransformed,

$$\boldsymbol{\varepsilon} = e^{-0.0789} = \mathit{0.924},$$

In order to obtain the expected percentage change in fish catch, **Ɛ** is multiplied by the percentage change in mangrove area **(%M)** in Guyana,

0.924 x (-1.96%) = **-1.81% loss in shellfish catch per year in Guyana**

3.3.2 Suriname

Suriname's main fishery is finfish so a value of 1 was assigned to the finfish dummy variable. Similarly, since most of the catch happens in the open sea, a value of 1 was assigned to that variable. The fish stock improving value for Suriname was calculated by using the Sea

Around Us website (calculated for the most recent year available, 2014). As was the case with Guyana, the median of reported observations from the studies included in the meta-analysis was used to predict the observations value for the benefit transfer.

Variable	**Regression Coefficients**	**Suriname site measures**
Constant	-0.926	1
Finfish	-0.636	1
Location Open Sea	1.02	1
Fish Stock Improving	0.0265	44
Observations	-0.00457	12

The predicted elasticity (Ɛ) was calculated from the model by multiplying the regression coefficients by the site measures for each variable and summing them:

-0.926 - 0.636 **(1)** + 1.02 **(1)** + 0.0265 **(44)** - 0.00457 **(12)** = 0.569

Since the meta-regression is a log-linear model, the resulting value was then untransformed,

$$\mathbf{Ɛ} = e^{0.542} = \mathit{1.77},$$

In order to obtain the expected percentage change in fish catch, **Ɛ** is multiplied by the percentage change in mangrove area **(%M)** in Suriname,

1.77 x (-0.76%) = **-1.34% loss in finfish catch per year in Suriname**

4. Discussion

4.1 Benefits of mangrove restoration

When estimating the benefits of mangrove restoration, 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). 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 (Ferrerira *et al.*, 2016 and Willems *et al.*, 2016), it is likely the following benefit estimates are biased upwards.

4.1.1 Guyana

The estimated loss in shellfish catch due to mangrove area loss in Guyana is 1.81%. Atlantic seabob accounts for the largest share of fish catch in the country. In 2014, the seabob catch was 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 32,580 kg (1.81% of 1.8 million kg). At the market price of \$18 kg^{-1} (FRED), the Guyanese fishery would have gained \$586,440. The expected monetary gain can be divided by mangrove area change to determine the value per hectare of mangroves for the shellfish fishery:

$$\frac{\$586{,}440}{1.96\% * 20{,}000\ ha} = \$1496\ per\ ha\ per\ year$$

4.1.2 Suriname

The estimated loss in finfish catch in Suriname due to mangrove area change is 1.34%. Weakfish are the most common type of fish caught in Suriname, totaling 2.7 million kg in 2014. The market price at this time was \$5 kg^{-1} (TRIDGE). If the 0.76% loss in mangrove area had not occurred, the fishery would have gained 36,180 kg of weakfish, resulting in an expected monetary gain of \$180,900. To determine the value of one hectare of mangroves to the Surinamese weakfish fishery, the estimated monetary gain was divided by mangrove area change:

$$\frac{\$180{,}900}{0.76\% * 50{,}000\ ha} = \$476\ per\ ha\ per\ year$$

4.2 Comparison to previous mangrove-fishery linkage studies

4.2.1 Shellfish elasticities

The estimated elasticity for shellfish in Guyana was 0.924, 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 similarity between the reported elasticity median and the results of our benefit transfer increase confidence in the accuracy of this value.

4.2.1 Finfish elasticities

The estimated elasticity for finfish in Suriname is 1.77. This number is greater than one standard deviation from the mean of the reported elasticities for finfish from studies included in the meta-analysis. The mean of these values was 0.916, with a standard deviation of 0.744, and the median was 0.716. One possible explanation for such a difference in elasticity could be the high percent of the Surinamese fish stock that is rebuilding or developing. The mean and median values for the fish stock improving variable in finfish studies are 28.4 and 21.2 respectively. In Suriname, this value is 44. If the elasticity for Suriname is recalculated using the median value for fish stock improving instead of the actual value, the result is an elasticity of 0.966 which is consistent with the elasticities from the studies included in the meta-analysis. This result supports the theory that the status of the fish stock in Suriname is the driver of the large elasticity estimate.

4.3 Limitations

One of the most significant limitations of this study 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 study 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. Some of this could be 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 (UCS, 2011). 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 sister 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 (Nourland et al. 2017 and Macneil 2015). 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 sister ecosystems, but few studies in the meta-analysis sample reported information on seagrass and coral presence, so it was eventually removed.

4.4 Recommendations for Further Study

In order to improve estimates for the economic value of mangroves for fisheries in Guyana and Suriname, it is recommended that an "on-the-ground" study be undertaken to determine accurate values for mangrove area in both countries. These "on-the-ground" efforts could be paired with previous spatial analysis studies to produce more accurate values of mangrove area change over time as well. This could be done through a government program alone or through a cooperative effort between governments, NGOs, universities, and local communities. Surveys aimed at uncovering local uses of mangroves and the role fisheries play in local communities—particularly the size of the non-commercial fishing effort—would also be helpful in determining the true benefits mangroves provide.

5. Conclusion

This study was conducted in support of a larger collaborative project between the Nicholas Institute for Environmental Policy Solutions and Conservation International. The larger project seeks to identify the economic value of a variety of ecosystem services provided by mangroves on the North Brazil Shelf. This particular study examined the impact of mangroves on fish catch in Guyana and Suriname.

In order to examine this impact, a meta-analysis of 21 mangrove-fishery linkage studies was conducted. To be able to make comparisons between a variety of units and research methods, the dependent variable in the regression was expressed as an elasticity. The final models used in this analysis were selected because of their applicability to the study sites. The shellfish model was used in the benefit transfer for Guyana because seabob shrimp account for the largest portion of fish catch in the country, while the finfish model was used for the construction of the benefit transfer equation for Suriname because weakfish makes up the largest portion of fish catch in the country. Percentage change in mangrove area for each country was determined by averaging the estimated percentage change reported by Global Forest Watch and Hamilton *et. al*.. The elasticities from the benefit transfer were multiplied by the percentage changes in mangrove area in order to estimate the percentage change in fish catch.

In Guyana, the calculated elasticity was 0.924, and the estimated percentage loss in fish catch was 1.81%. In Suriname, the calculated elasticity was 1.77, and the estimated percentage loss in fish catch was 0.76%. The total value of the loss in seabob catch in Guyana is $586,400 whereas the loss in weakfish catch in Suriname was $180,900. While these values reflect recent observed trends within the countries, the elasticities calculated in this study can be applied to any scenario of mangrove area change to predict the effect on fish catch in Guyana and Suriname, respectively. The annual value of one hectare of mangroves adds to the Guyanese seabob fishery is $1,496, while the annual value which one hectare of mangroves adds to the Surinamese weakfish fishery is $476. It is important to acknowledge that these numbers do not represent the total value of one hectare of mangroves for the fisheries of each country, let alone the total value for ecosystem services of one hectare of mangroves.

This study provides insight into mangrove-fishery linkages within the countries of Guyana and Suriname for specific fisheries and the associated monetary gains resulting from conserving mangrove area. When trying to determine the total benefits of conserving mangrove area these values are insufficient, but a more accurate estimate of the total value could be determined by applying similar valuation methods to additional ecosystem services.

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7. Appendix

Figure 1. Mangrove distribution and vegetation biomass. Adapted from *"The importance of mangroves to people: A call to Action"* by Duke *et.al*., 2014.

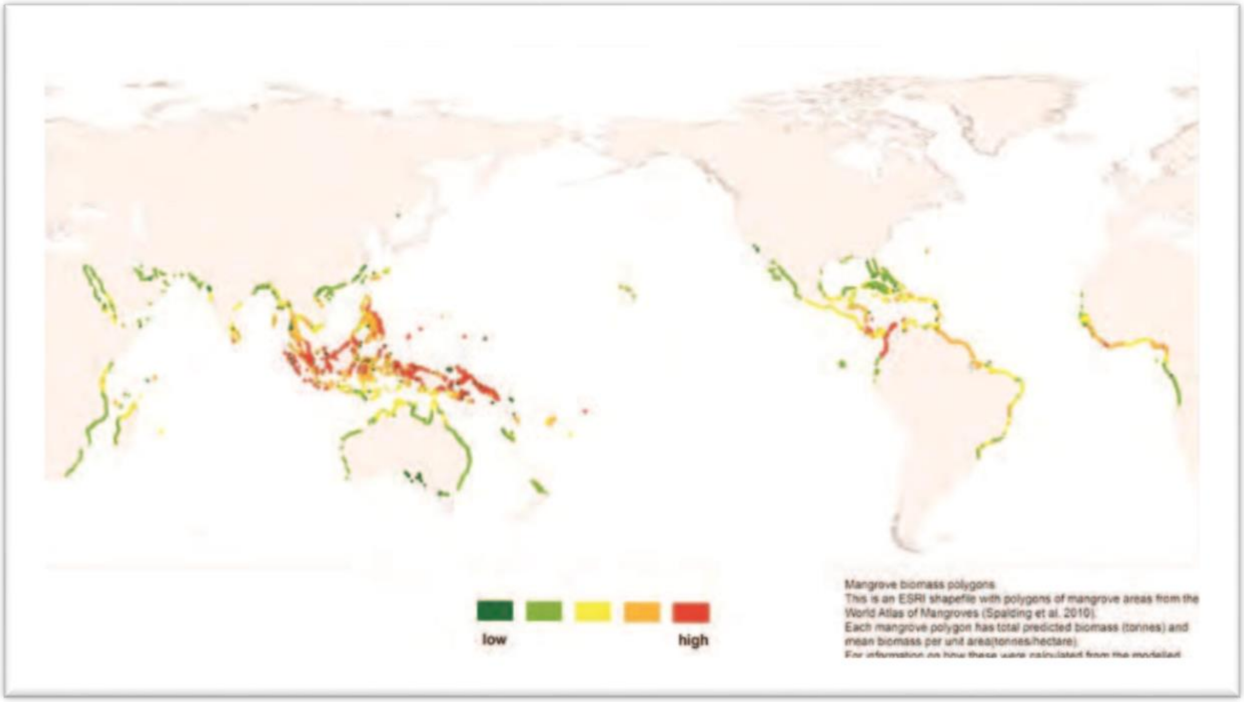


Table 2. Percent in Mangrove Area Change per Regions in Guyana and Suriname using Global Forest Watch source.

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	0.625%
Banasika	0.275%
Essequibo	0.09%
Wakenaam	1.06%
Demerara	0.09%
Suriname	
Regions	
Galbi	0.050%
Margareta	0.41%
Kwatta	0.55%
Welgelegen	0.02%
Johanna	0.019%
Westelyke	0.08%

Table 3. List of studies used in the meta-analysis.

Study	Title	Country	Catch Type
Abdul e*t 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	Philipines	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)	Valuning 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

Table 5. List of variables used in the meta-regression.

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

Figure 2. Guyana: Trend in mangrove area, 1980-2000 (FAO)

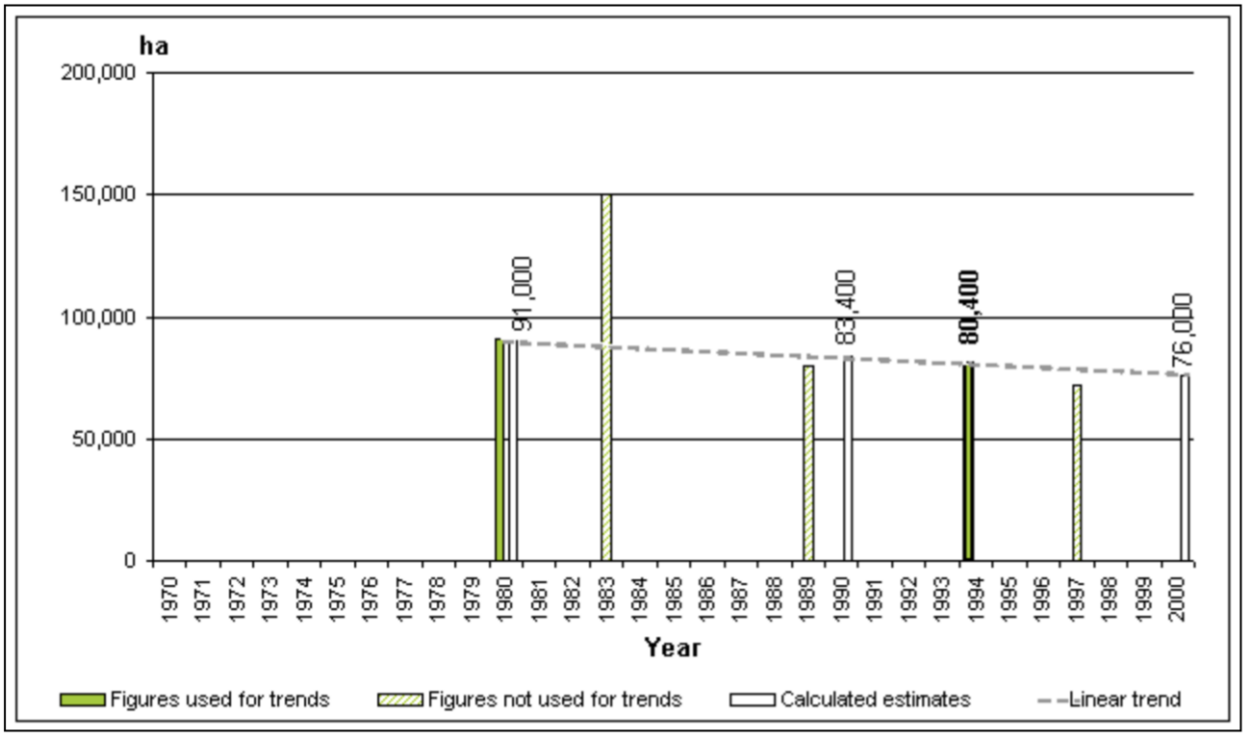


Figure 3. Suriname: Trend in mangrove area, 1980-2000 (FAO)

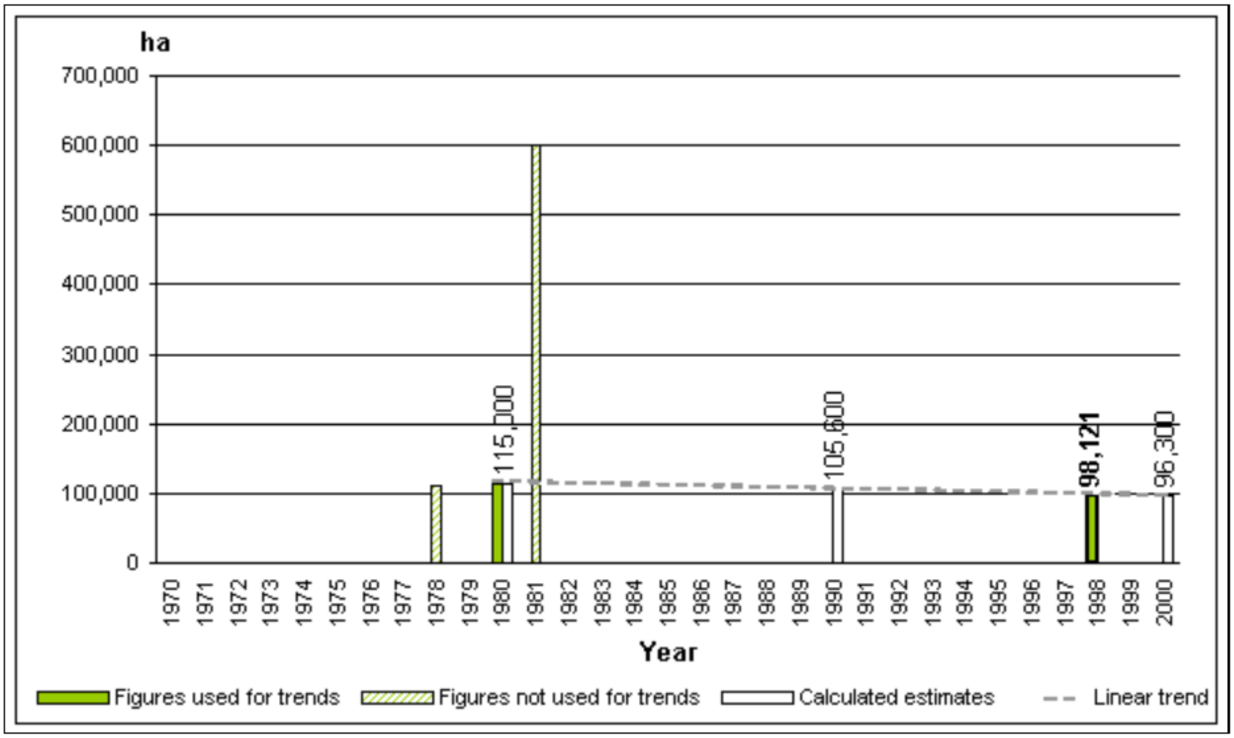


Figure 4. Mangrove area trend, 2000-2014 (Hamilton et al. 2017)

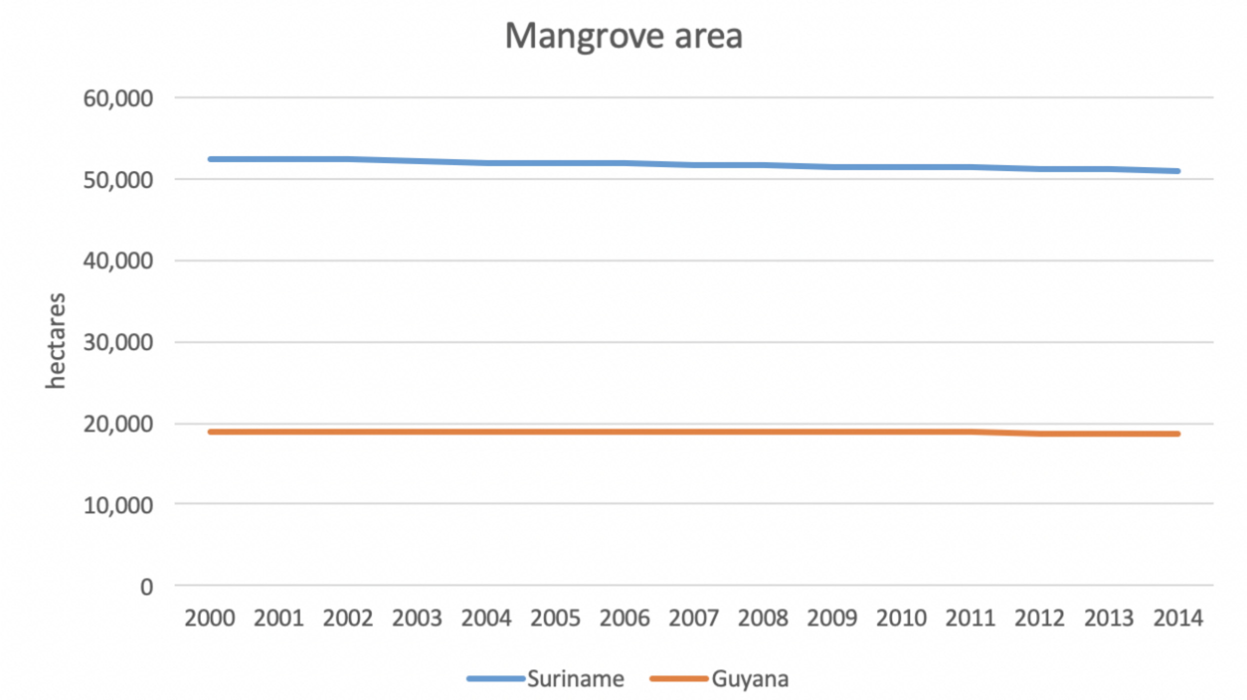
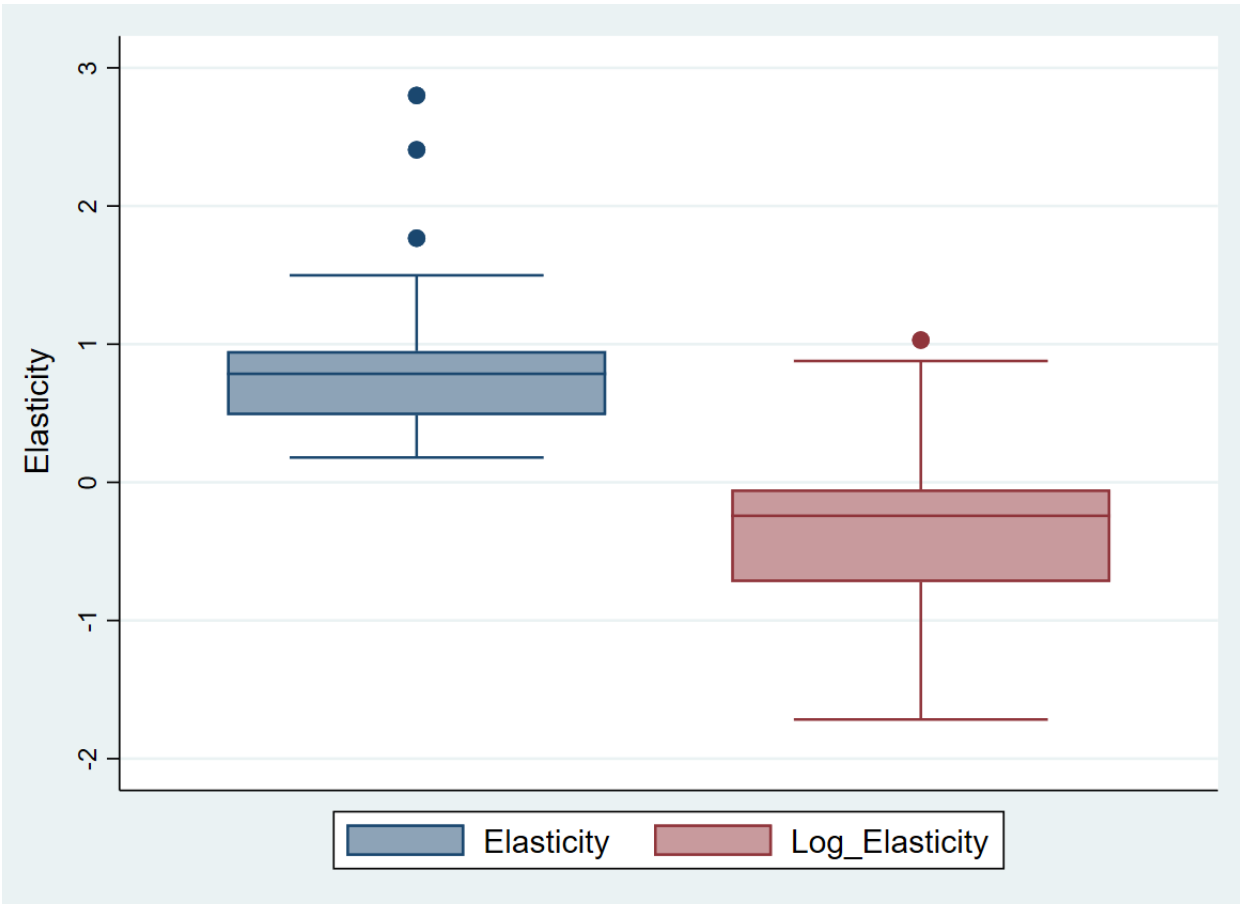


Figure 5. Untransformed and transformed elasticity



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