Overview of the research in the North Brazil Shelf

Serious research. Real people. Important decisions.

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Our work in Integrated Coastal Management (ICM) for the North Brazil Shelf (NBS)

Over the last year, Conservation International (CI) worked with government and other local partners in Guyana and Suriname to better understand mangroves along the North Brazil Shelf (NBS) and the services they provide. We recognized that this knowledge could help us better protect the mangroves that people need.

People who live along this stretch of coast (the NBS), from Guyana to French Guiana, need mangroves to thrive and survive. Part of our work involved assessing the size and spread of the services mangroves provide to local communities. Our study also describes methods that can be used to estimate the monetary value of these services and provides initial estimates of the services mangroves provide to the fisheries sector, as an example.

Mangroves provide big benefits to coastal communities in Guyana and Suriname

Who will be affected by mangrove loss?

There are four (4) major groups who will be affected the most by mangrove loss in Guyana and Suriname. These are **small-scale fishers and the workers that support their operations, indigenous communities (in Guyana), local communities living near the coast, and the global community** which benefit greatly from the carbon-storing superpower of mangroves and connected ecosystems.

These people need mangroves for their livelihoods, their social and cultural values, for good quality water, and protection from flooding and coastal erosion more than likely due to rising sea levels.

People everywhere in the world also need mangroves because its carbon storing superpower makes it important in fighting climate change.

Now is the time to plan and design with nature in mind.

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Have a question? Email us at mangroves@conservation.org

About the project

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Research Credits

Crooks, S., Beers L., Mak, M. and May, C. 2019. Setting the foundations for zero net loss of the mangroves that underpin human wellbeing in the North Brazil Shelf LME: *Regional Biophysical Review*. Report by Conservation International and Silvestrum Climate Associates.

Beers, L., Crooks, S., May, C., and Mak, M. 2019. North Brazil Shelf Mangrove Project: *Blue Carbon Feasibility Assessment*. Report by Conservation International and Silvestrum Climate Associates.

Mak, M., May, K., Beers, L., and Crooks, S. (2019). North Brazil Shelf Mangrove Project: *Nature Based Solutions*. Report by Silvestrum Climate Associates.

UCLA Anderson Strategic Management Research Field Study, Agustin Caso, Eden Dahan, Andrew de Niese, Ian Landgreen, Madelon Navarro, Yandro Valdez

Local community benefits from ecosystem services provided by mangroves on the North Brazil Shelf, Research Team at the Nicholas Institute for Environmental Policy Solutions, Duke University, Tibor Vegh, Celeste Bollini, Emily Millar, John Virdin

Published August 2019

Funded by the **Global Environment Facility** through *Setting the Foundation for Zero Net Deforestation of the Mangroves that Underpin Human Wellbeing in the North Brazil Shelf.*

Overview of the Mangrove Research in the North Brazil Shelf

When mangroves are lost anywhere, it is felt by people everywhere.

Foreward

100 years ago mangroves covered more than 181, 000 km2 of the Earth's surface in about 120 tropical and subtropical countries. This was great for the planet and great for the people that lived around them given the multiple provisioning and regulating services mangroves provide. For people mangroves provide wood, useful extracts, healthy fisheries, clean water and protection from storm winds and surges. For the planet, mangroves are more effective at locking up large amounts of carbon than just about any other ecosystem. Unfortunately, over the past 40 years over 25% of mangroves have been lost globally due to a wide range of development pressures, including the expansion of cities, agriculture and aquaculture. Plain and simple, stopping mangrove loss- and indeed, restoring many lost mangrove areas- must become a global priority to meet basic development and security goals.

The mangroves of the North Brazil Shelf- the area encompassing all coastal areas of Guyana, Suriname, French Guyana and parts of Venezuela and northern Brazil- are some of the most extensive, dynamic, carbon rich and nationally important on Earth. In the case of Guyana, Suriname and French Guiana, over 80% of people live on coasts, most of which comprise mangroves, or did so historically. Despite the geophysical similarities of these coasts and the ubiquitousness of mangroves in close association with large populations, how people use, value and the reasons for which they are lost varies greatly from country to country. What is common to these countries is the need to manage mangroves both more effectively to prevent loss and degradation and - given the very strong ecological connectivity between them - is the need to coordinate management strategies so that progress is one country is complemented by progress by their neighbors.

The Global Environment Facility funded 'Setting the Foundations for Zero Net Loss of the Mangroves that Underpin Human Wellbeing in the North Brazil Shelf' project has provided a critical step to towards establishing the knowledge base, partnerships on the ground and intergovernmental coordination required to achieve effective transboundary management of mangroves. This report presents the results of both desktop reviews and primary fieldwork across the multiple dimensions relevant to effective mangrove management. A firm grasp of the ecology, value, threats, impacts of loss, opportunities for conservation and restoration and feasibility of different approaches for financing work are all crucially important parts of that knowledge base.

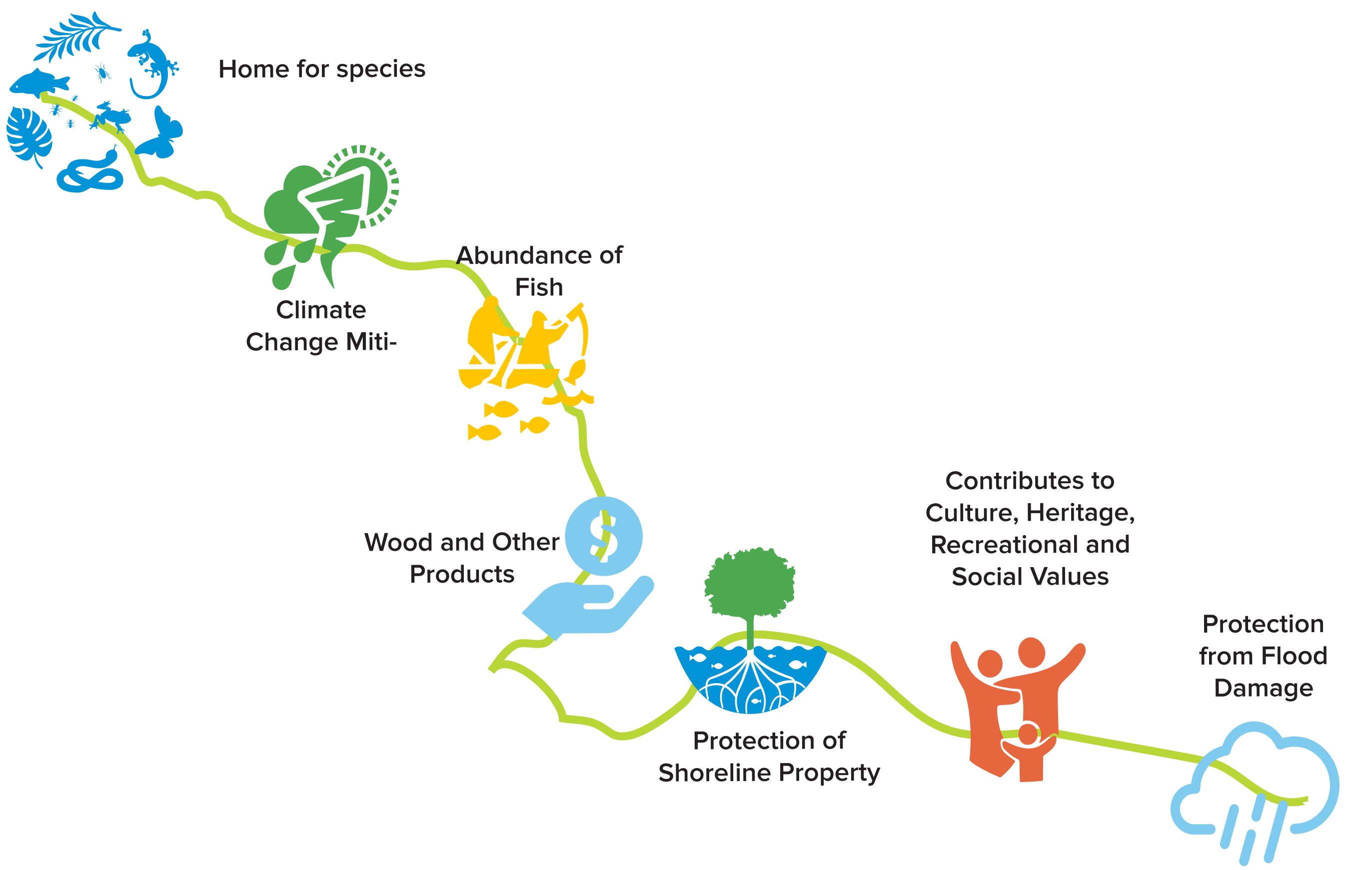
But, knowledge is only as good as the use it is put to. Moving forward, it is paramount that civil society, the private sector and governments pull together with the support of donors to stop and reverse mangrove loss and destruction in the North Brazil Shelf through development of an Integrated Coastal Zone Mangrove Management Plan. Indeed, as this report shows, a zero net loss is not good enough in many places where mangrove restoration is desperately needed to protect and provide for people. The North Brazil Shelf countries are now positioned to become global leaders in mangrove conservation and restoration. The progress and cooperation demonstrated in undertaking this project bodes well for this to happen.

Scott Henderson
Vice President
Sustainable Landscapes and Seascapes
Conservation International

What people say about mangroves and benefits...

Our research team conducted focus groups in selected communities along the coasts of Guyana and Suriname. Participants seemed very aware of the benefits mangroves provide to their communities.

Benefits provided by mangroves include protection from rising sea-levels, health impacts and recreational value. Follow the illustration to learn more.



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Regional Biophysical Review

Geographical Setting

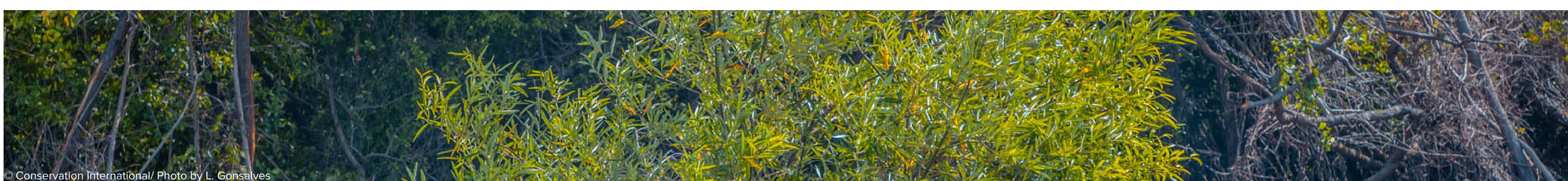
The coast between the mouth of the Amazon and the Orinoco rivers is one of the world's most spectacular muddy shorelines. Over thousands of years, muds built up here, creating an expansive coastal plain which is covered at high tide and uncovered at low tide and still linked to a highly active nearshore environment of migrating mud banks (Anthony et al. 2013). During warm interglacial stretches (a period of milder climate between glacial or cold periods), the coastal plain hosts swamp forests and, at the saline or saltwater margin, mangroves. Enormous deposits of intertidal mud and subtidal mud (below the low tide mark which is usually covered by water) migrate in movements like slow-moving waves northwest along the shore from the Amazon River to the Orinoco River. These mud deposits allow new mangroves to advance from the shore, they retreat again once a mud bank passes. Away from the coastline, the coastal plain has existed in relative stability.

The ecology of the coastal plain is a rich variety of various communities of freshwater swamp forest, upland forests on higher sandy deposits, and chenier (sandy or shelly) ridges and marsh areas. Deep peat soils are found at and just above a natural area of land formed by high and low tide movements. They appear here and there along the inner coastal plain where saturation by freshwater has encouraged organic materials to build up.

... the coastal plain is a rich variety of various communities of freshwater swamp forest, upland forests on higher sandy deposits, and chenier (sandy or shelly) ridges and marsh areas.

Towards the coast, the soils become increasingly rich in minerals. As a result, land conversion on the coastal plain for agriculture and settlement is most intense in Guyana, progressively decreasing through Suriname, French Guiana and into Brazil. Drained lands are below sea level, requiring drainage channels and protection by engineered sea defences from river and tidal flooding. Extensive areas of reclaimed farmland have been abandoned due to flooding and the effects of acidic soils. In a few locations, failure of levees caused permanent flooding.

Ongoing discussion about management of the coastal plain recognizes the importance of ecological conservation, the demand for land conversion to agriculture and settlement, and the growing frequency and scale of flooding from sea level rise. Substantial research has been, and continues to be, undertaken along the coastline of the Guianas, focused largely on understanding mangrove-mud bank interactions and dynamics. The consequences of levee construction along the shore have been identified as a driver of mudflat erosion. Mangrove planting, along with experimental brushwood fencing to encourage sedimentation and shoreline stability, is being trialled.



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Mangrove and Coastal Swamps

While this report focuses on mangrove ecosystems, the importance of the value of coastal swamp forest should be noted. Coastal swamp forests occupy an area five or more times greater that of mangroves and face intense pressure from land use changes. These ecosystems form an ecological and geomorphic continuum and together provide a wide range of ecosystem benefits and services.

Mangroves and coastal swamps are interconnected components of the coastal plain landscape. The nature and extent of these habitats are defined by how sediments, water and plants interact. The health and biodiversity of these habitats are sensitive to hydrology (the properties and movement of water in relation to land), how it is changed by people as well as changes in climate. The variety of habitat reflects the prevailing hydrology of freshwater and saline flows, soils building to maintain lands at, or just above, sea level, and rhythmic tidal flooding, as well as disturbance events of droughts and floods.

Over thousands of years organic soils built up at the inland and more stable reaches of the coastal plain. Towards the shore where natural physical disturbance is more common soils are more mineral. As long as soils are maintained wet and undisturbed, they remain sinks for long-term carbon storage – which the planet desperately needs in the battle again climate change. The presence of vegetation helps to baffle wave energy that drives erosion and bind soft sediment increasing resistance to erosion (Figure 2). Mangroves do not grow at elevations lower than mean sea level and, as such, their capacity to bind sediments is limited to the upper reaches of the tidal range. Given this, the mangrove edge is subject to periods of erosion and accretion (gradual build up of organic material) with the passage of mud waves that build and lower the shore, modifying the wave climate.

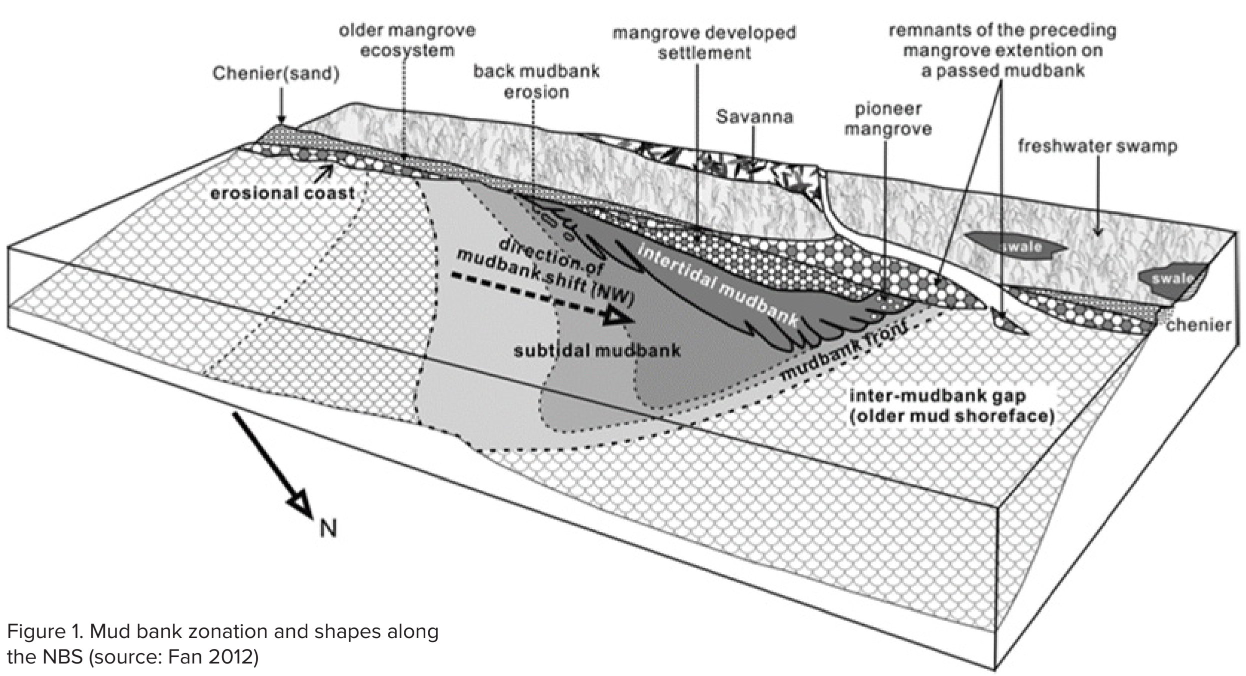

Figure 1. Mud bank zonation and shapes along the NBS (source: Fan 2012)

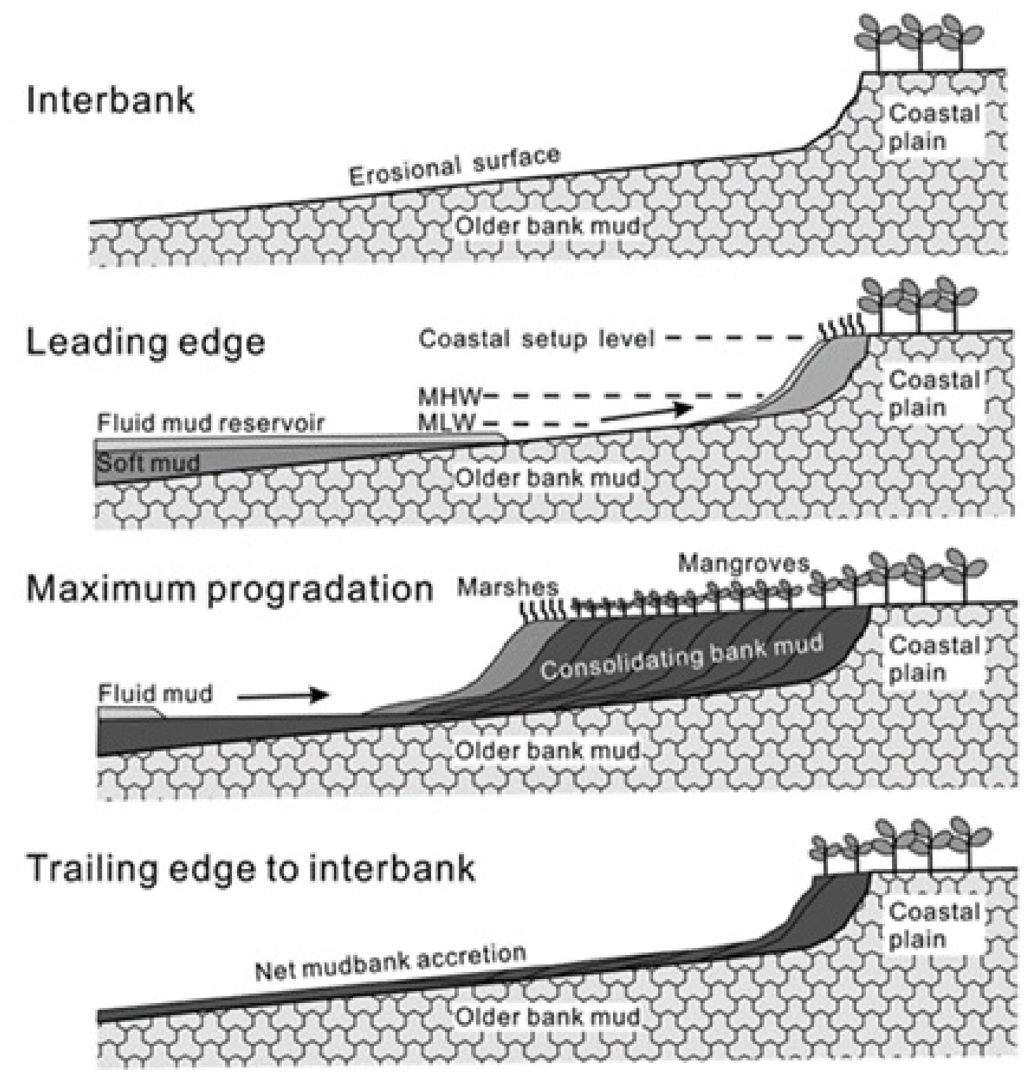

Figure 2. Example of shoreline evolution along the NBS shelf (source: Fan 2012)

Figure 3. Example of mangrove die-off due to hypersalinization in Coronie, Suriname (source: Toorman et al. 2018)

Infrastructure built within the dynamic fringe of the mangrove is subject to periodic erosion threat as passing mud wave holders lower the shore. The presence of levees further acts to worsen erosion by enhancing wave energy and hindering sedimentation on mudflats next to or adjoining each other. Setting back infrastructure can help create the space to sustain a mangrove area that responds resiliently to dynamic coastal changes with passing mud waves and act to lessen wave energy. On abandoned lands reconnected to tides, some impairment to mangrove recovery was observed as a result of high wave energy. Measures to temporarily reduce wave energy on restoring site may be required to promote and accelerate mangrove recovery.

The ecology and extent of the coastal plain are defined by hydrology and how both sediments and plants interact with water flows and quality. Even though Beard (1955) surveyed the coastal landscape of Suriname in the 1940s and 1950s, he described broadly representative conditions. Swamp forest and woodlands are found near creeks, where drainage changes, and lines of moving water create better aerated conditions. He suggested that soil conditions drove a distinction between swamp forest and un-forested lands, with swamp forests occurring where flow of freshwater maintained aeriated soil conditions and un-forested wetlands where hampered flows favoured herbaceous (herb) cover.

At the shore, the ecology is increasingly influenced by salinity and freshwater/brackish water tolerant forest species that give way to mangroves. Even amongst mangrove species, there are differences in capacity to withstand flooding and salinity. Black mangrove (Avicennia spp.) are the most salt tolerant and are found on the open shore but these trees may also die back under conditions of prolonged flooding, impaired drainage and hyper-salinization. Red (Rhizophora spp.) and white mangroves (Laguncularia racemosa) tend to be found in less saline settings.

Disruption to freshwater flows from rivers and seeping from coastal swamps can significantly impact coastal ecology. The free flow of freshwater has been obstructed by several infrastructure projects over the past 50 years including major road construction and development projects. In one case, the construction of small dams to sustain large-scale mechanized rice farms were cited by the Members of the Committee for the Rehabilitation of the Northern Coronie Polder to limit freshwater flow to the coast, causing mangrove die off and worsening coastal erosion (Figure 3).

In addition to the direct impact of water flow and quality on the ecology of the coastal plain, hydrology and sediment supply also influence soil building. The structure or fabric of soil consists of two components: organic and mineral material. Organic material is derived mainly from in-situ plant production but also material brought in by flooding waters. Under low oxygen availability occurring in wetland soils, decomposition of organic matter is substantially curtailed leading to accumulation of organic soils and peats (Krauss et al. 2014). This accumulation rate is relatively slow but continuous over centuries, with soils functioning as a carbon sink if they stay saturated and protected from erosion.

The coastal processes that shape the nearshore and shoreline edge of the Guianas have been the subject of substantial research investigations and are a global 'type-site' for understanding open coast muddy systems (Fan 2012, Toorman et al. 2018). They found that the shoreline continuously undergoes multi-decadal scale periods of accretion and erosion, overlaid on a long-term trend of sea level rise and periods of shifted trade wind conditions. These fluctuations are a result of alongshore migration of mud banks derived from the Amazon river, 45 km in width and extending offshore ten kilometres to a depth of 20 m. At the shore, the mud waves' height from trough to crest is 3 meters and they travel at a rate of 1.5 km yr-1 (Figure 4).

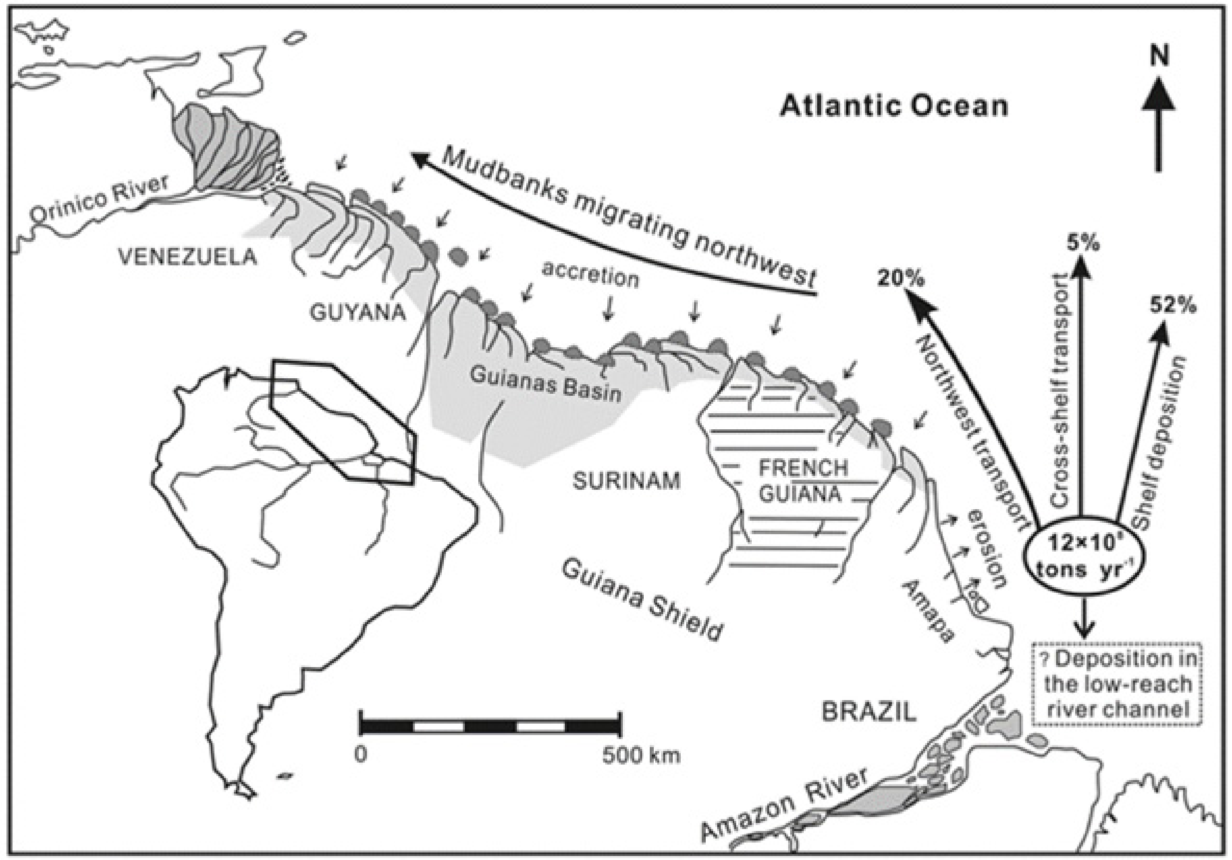

Figure 4. Distribution of migrating mud banks along NBS (source: Fan 2012)

Another potential multi-decadal cycle driving erosion and accretion are changes in winds and ocean wave climate (Eisma et al. 1991, Allison et al. 2000, Augustinus 2004). Identified from aerial photographs across Suriname, a period of net shoreline erosion (1947-1966) was followed by a period of advancement (1966-1981). Coincident with the shoreline's adjustments was a change in wind direction (from NE to ENE) with stronger winds more parallel to the shore, driving sediment transport, extension of mud banks and shoreline advancement (Augustinus 2004). The progression of mud banks is a manifestation of largescale fluid mud transport under waves and tidal currents. These observations highlight the dynamic nature of the shoreline and its sensitivity response to changing environmental conditions, which need to be considered when planning restoration and conservation activities, especially in regard to sea level rise.

Impacts of Land Use Conversion on Shoreline Stability

A detailed geomorphic assessment by Brunier et al. (2019) describes the unintended negative consequences for shoreline stability of converting mangrove and swamp forest to rice fields in French Guiana. Construction involved clearing mangrove and swamp forest, and draining, embanking and levelling land to form polders for rice. Land use conversion extended to the seaward edge of the mangroves. Replacing the mangroves with a hard structure set in motion a phase of sustained coastal erosion. It prevented the geomorphic interaction between mangroves and mud flats that allow the periodic attachment of mangroves during passage of mud wave crests (Figure 5).

Under natural conditions, mangroves stabilize sediments, baffle waves and contribute to sediment accumulation in adjacent mudflats. This function is an important precursor for the "attachment" of passing mud waves and the associated phase of mangrove advancement. In addition to losing the ability to holding on to passing sediment, replacing mangroves with hard infrastructure results in an increase in wave energy, as waves reflect off the structure, further reducing sedimentation (Winterwerp et al. 2013). This lowers the mudflat and results in conditions that prevent mangrove re-establishment.

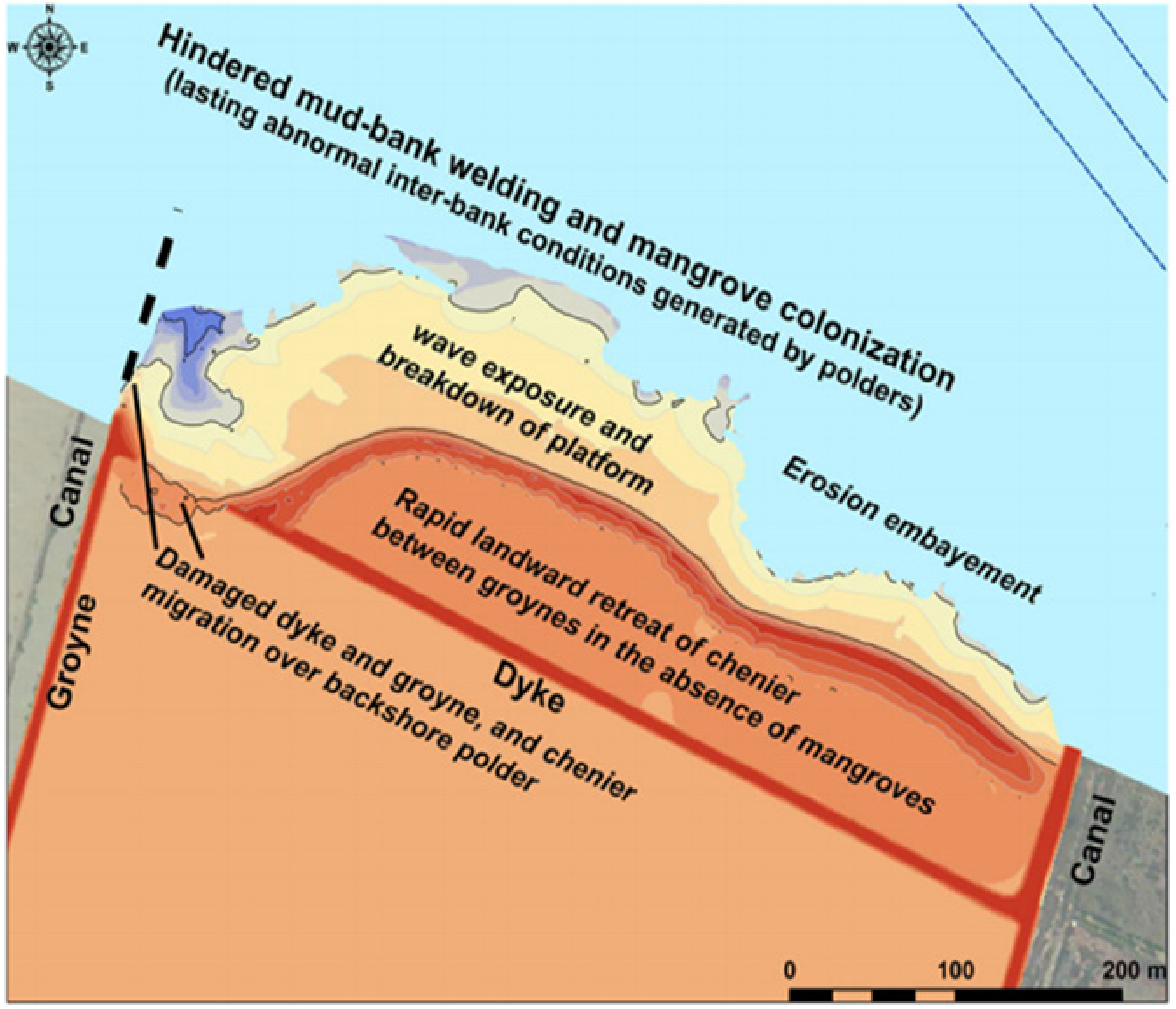

Figure 5. Erosional processes once mangroves are removed, viewed at the scale of a polder plot (source: Brunier et al. 2019).

Response of the Coastline to Sea Level Rise

In review of existing studies on the coastline of the Guianas, there is no indication to support that the existing position of the shoreline will be maintained as sea level rises. Rather, depending on the magnitude of sea level rise in coming decades and centuries the shoreline will retreat. This is consistent with studies elsewhere. There is enough sediment for mangroves to build vertically with high rates of sea level rise, but at the same time they will very likely retreat landwards. Given enough space mangroves on the coastal plain will be very resilient to sea level rise.

Success in preserving mangroves will depend on room for landward migration. Where flood coastal protection exists, the migration mangroves will be squeezed between rising waters and hard infrastructure. Mangroves built on the dynamic coastal fringe through artificial means (e.g. sediment field approaches) will be under increasing erosion pressures as sea level rises. These approaches can be used to aid mangrove recovery on abandoned lands where levees have been set back. Potential salinization of brackish and freshwater systems may occur, changing the ecology of coastal swamps. With enough planning there is potential to include mangrove restoration as part of nature-based solutions for climate adaptation, flood risk reduction, and sustenance of natural systems.

To explore the magnitude of coastal retreat and whether mangroves will migrate and can be established further inland, a simple geometric model is applied in this report. It is based upon a hypothetical 2-dimensional mangrove – mudflat shore profile (described in Appendices 1 and 2 of full report).

The model is based upon several assumptions: (1) that the slope of the mudflat is in balance with wave energy; (2) changes in water depth with sea level rise drive erosion to extend that slope; and (3) mineral sediment will be supplied to the mangrove surface with sea level rise and contribute to soil building. At this stage, the model has yet to be standardized for the NBS region and is thus configured with scenarios that are likely more conservative than necessary.

Key interpretations from applying the simple geometric model:

1) There is enough mineral sediment in circulation to maintain mangrove soil building under existing and future higher rates of sea level rise. Previous studies suggest that a time averaged concentration of sediment in the water column delivered to a coastal wetland of 300 mg l-1 is required to sustain soil building against high rates of sea level rise (Orr et al. 2003, Stralberg et al. 2011, Morris et al. 2012, Kirwan and Megonigal, 2013, Lovelock et al. 2015). Sediment availability to the mangroves of the Guianas far exceeds that threshold.

2) The relatively high tidal range along the coast is a positive attribute to support mangrove resilience to sea level rise over coming decades (Morris et al. 2012). Mature tidal wetlands build towards an elevation around mean high water spring tide elevation. At a location with a tidal range of 2 meters, mature mangroves at mean high water spring tide elevation will have approximately 1 meter of elevation capital in term of sea level rise (in absence of any soil building) before water elevations attain the level of drowning the forest (an elevation just above mean sea level). This follows the rule that in locations with higher tidal range the magnitude of elevation capital increases.

3) Applying the high sea level rise curve (RCP8.5 Max, IPCC 2014), the model calculates retreat of the mangrove edge of 46 meters by year 2050, 102 meters by year 2075, and 174 meters by year 2100. While the calculations are not yet precisely calibrated for the local region, they are informative in terms of the scale of erosion that will very likely result from sea level rise.

Mangrove Restoration: Opportunities and Constraints

Mangrove restoration is an important component of natural infrastructure approaches. As a primary principle, the best place to restore mangroves is in the location where they once existed, given that basic conditions of tidal influence, salinity, appropriate substrate and ecosystem connections are still present. Thus, this is not always possible because of a combination of land use, infrastructure and environmental constraints. Yet, abandoned lands, reconnected to the sea as needed, with constructed levees to protect neighbors from flooding as needed, offer a restoration opportunity that has the potential to restore a colonizing forest relatively quickly. From a mangrove restoration perspective, the coastline of the Guianas is blessed with a great abundance of sediment. Sediment is critical for rebuilding soils to an elevation that will support mangrove colonization. The Guianas also have a climate that supports rapid mangrove tree growth once established.

Opportunities

1. Suriname and Guyana host substantial areas of former agricultural land abandoned due to low land productivity and salinization. Depending upon hydrology and geomorphic setting, these lands may offer sites for coastal swamp forest or mangrove recovery.
2. Connecting mangrove restoration sites to abundant sediment supply from the nearshore will accelerate the restoration process.
3. Setting back mangrove restoration from the active coastal edge offers potential to restore mature mangrove forest, build space to accommodate erosion of the coastal edge with sea level rise, as well as create a buffer for dynamic edge processes.
4. Mangrove restoration planning design may include green infrastructure approaches to facilitate flood risk reduction; including maintaining scour / reducing sedimentation flood conveyance channels and attenuating wave action.
5. Mangrove restoration and coastal swamp forest may be planned and designed to provide habitat and transport corridors for fisherfolk.

6. Mangrove and coastal swamp forest restoration may be planned and designed to include areas for public access and recreation as well as site of low disturbance for biodiversity.
7. Mangrove and coastal swamp forest restoration may be planned to reduce landscape fragmentation and connectivity between habitats, as well as hydrological connectivity necessary to support a mosaic of biodiverse wetlands.
8. Mangrove and coastal forest restoration may be planned and designed to accommodate sea level rise adaptation, recognizing that the shoreline will respond dynamically to changing water levels and the need for space.
9. Construction of structures to reduce erosion of the mangrove edge will be less costly as pre-restoration activity on dry land than a restoration activity on soft muds in the intertidal shore. Mangrove restoration approaches on abandoned lands might be planned in coordination with sedimentation fields constructed on the dynamic open shore.
10. Rewetting soils can arrest development or worsening of acid sulphate soil conditions on drained wetlands containing organic soils.

Contraints

1. Space is required for mangrove restoration, particularly in areas set back from the dynamic mudflat edge.
2. A set-back buffer to accommodate sea level rise will also be required to sustain mangroves. There are challenges in quantifying the extent of the setback distance required.
3. Levees may be needed to protect neighboring properties from flooding. Construction of levees increases the cost of projects and fragments the landscape but are often necessary.
4. Wave energy and possible acid sulphate soil conditions on abandoned lands setback for mangrove restoration and to provide a flood protection buffer should be taken into consideration as part of the mangrove or coastal forest restoration planning process.

Blue Carbon Feasibility Assessment

Mangrove Ecological Structure

Mangrove forests cover about 0.1 percent of the planet's surface but store up to 10 times more carbon per hectare than forests found on dry land.

Mangrove forests cover about 0.1 percent of the planet's surface but store up to 10 times more carbon per hectare than forests found on dry land. The ecological[1] structure of mangrove forests directly impacts the rate of carbon sequestration and storage that occurs in these ecosystems. An evaluation of the potential of Guyana and Suriname's mangrove ecosystems to contribute to climate change mitigation was made based on their ability to sequester carbon.

The coastlines of Suriname and Guyana extend 386 and 459 km, respectively, and were historically lined in wide fringing mangroves. Compared to the Indo-Pacific, the mangroves of the North Brazil Shelf (NBS), and the Caribbean in general, are low in species diversity yet they still serve the same important ecosystem functions as national carbon sinks.

Mangrove systems along the NBS are comprised of three genera: Avicennia germinans (also accounts of A. schaueriana in Suriname; black mangrove, parwa, courida), Rhizophora mangle (also accounts of R. racemosa and R. harrisonii (hybrid); red mangrove, mango, red mango), and Laguncularia racemosa (white mangrove, akira). Black mangroves are the dominant species along the North Atlantic Ocean and have the potential to withstand high soil salinities, upwards of 60 PSU (Marchand et al. 2004). There are four main mangrove-stand characterizations along the NBS coast: (1) pioneer and young mangroves, (2) mature coastal/pure mangroves, (3) mature riverine/mixed mangroves, and (4) declining or dead mangroves (Figure 1; Fromard et al. 1998).

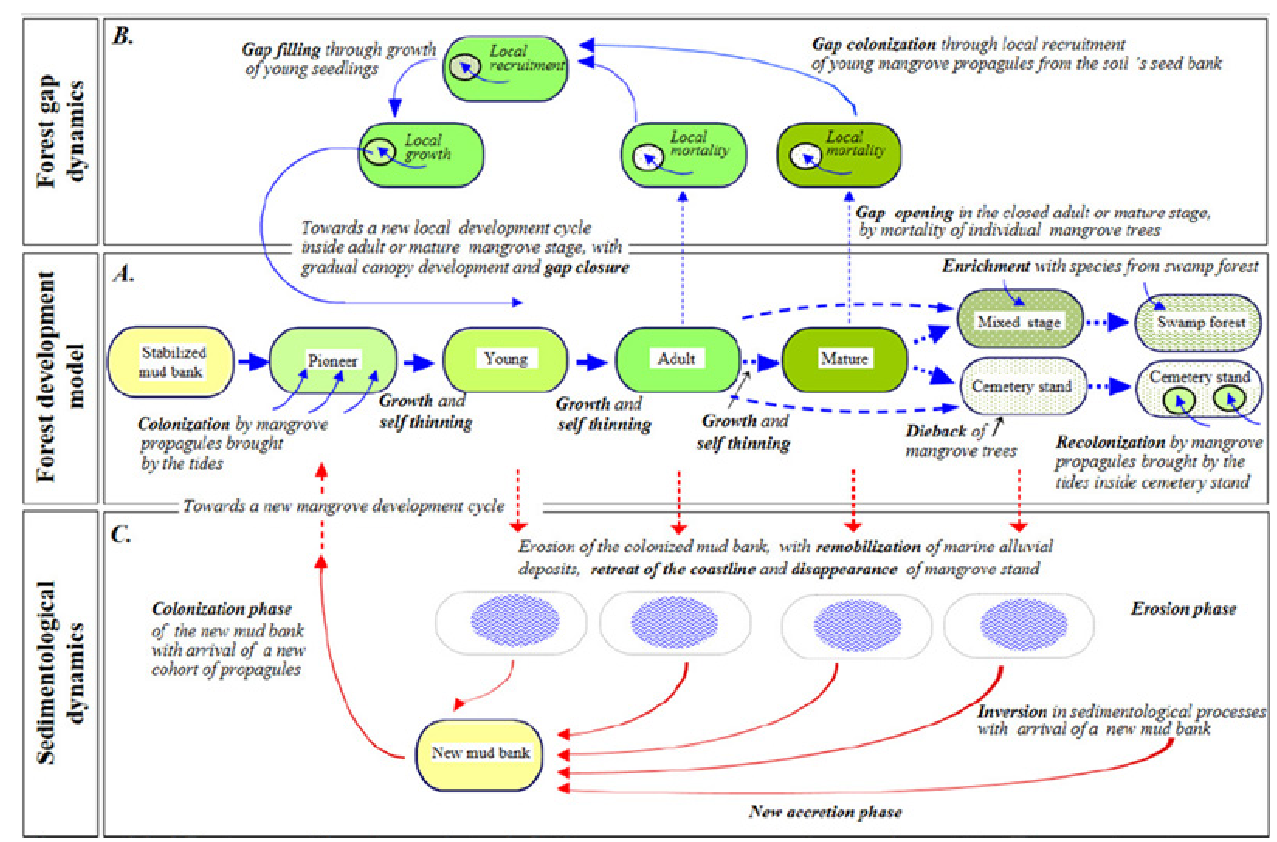

Figure 1 Mangrove dynamics along the NBS (source: Fromard et al. 2004)

1 Relating to or concerned with the relation of living organisms to one another and to their physical surroundings.

Degradation

This highly dynamic system formed by the ever-changing location of mud banks creates a coastal mosaic with the presence and absence of mangroves. This complex mangrove-mud bank dynamic has functioned in this manner for 5-6,000 years, and the mangrove distributions are inseparably tied to the location and movement of mud banks along the coast (Anthony 2015).

However, human removal and degradation of mangroves has already affected this dynamic system, and a general lack of understanding on how this system works could significantly affect its protection (Anthony 2015). In French Guiana, the conversion of mangroves to rice fields has resulted in shoreline retreat of up to 180 m per year in some areas (Anthony 2015).

Continued conversion and degradation could disrupt the unique mangrove-mud bank relationship, resulting in far fewer mangrove systems along the coastline over time (Anthony 2015). The majority of the coast of Suriname is protected through four Multiple Use Management Areas (MUMAs) and six Nature Reserves, totalling approximately 128,000 ha; only the area around Paramaribo and the eastern stretch of coast are not protected (UNDP 2016).

There currently are no marine protected areas. While there is institutional knowledge about the importance and role of mangroves in coastal processes along the NBS and capacity is in place amongst agencies, mangrove management has not received much attention from the government, which has complicated institutional arrangements, and no programs for monitoring and management are currently in place (UNDP 2016).

There are currently no coastal marine protected areas along the coast of Guyana. In 2001, the Guyana National Mangrove Management Action Plan was formed to address legislation regarding mangroves, highlighting the need within government agencies with administrative capacity to create a legal framework for mangrove management and promote sustainable management, to support and manage research in mangroves, to effectively create and implement mangrove restoration, rehabilitation and protection, and to continue public outreach and education about mangroves (Evans 1998).

... the conversion of mangroves to rice fields has resulted in shoreline retreat of up to 180 m per year in some areas.

There has been mixed public perception regarding the roles of mangroves as sea defence although outreach campaigns have proven effective in increasing community knowledge about mangroves (Allan et al. 2002, Da Silva 2015a). This is due in large part to the Guyana Mangrove Restoration Project, which was initiated in 2010.

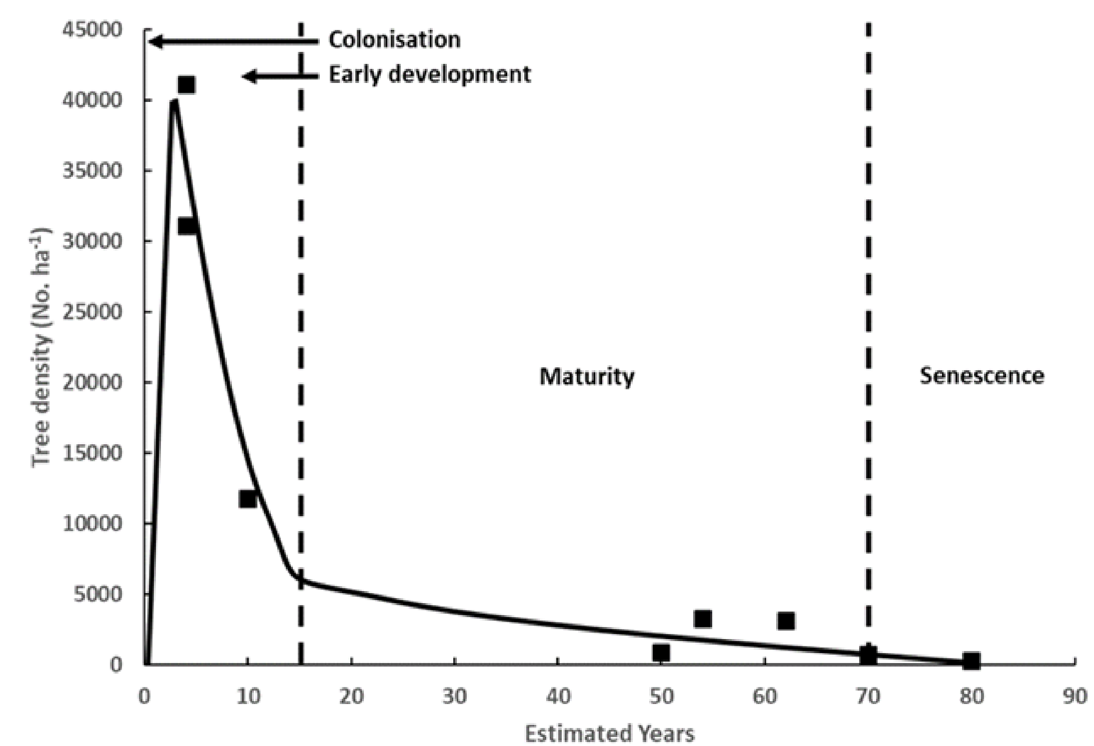

Figure 2: Changes in tree density during mangrove stand development (Fromard et al. 1998)

Blue Carbon -Sequestration and Release

Over the past 15 years, the crucial role of coastal ecosystems, specifically mangroves, tidal marshes, and seagrass beds, in sequestering significant amounts of carbon, termed 'blue carbon' due its coastal influence, has been clearly demonstrated (Donato et al. 2011, McLeod et al. 2011, Sifleet et al. 2011, Fourqurean et al. 2012, Pendleton et al. 2012, Windham-Myers et al. 2018). This is largely due to the extremely slow decomposition and mineralization rates of organic matter produced by wetland plants that occur under conditions created with inundated, anoxic soils.

As soon as these soils are exposed to oxygen through diking and draining of wetlands, mineralization occurs quickly, and the stored carbon is released rapidly to the atmosphere. This impact is particularly notable in mangroves that have been converted to shrimp ponds or cattle pastures. Kauffman et al. (2017) reported that 54% of soil carbon pools can be lost with conversion to shrimp ponds and that total ecosystem C stocks can decline by 554 ± 230 Mg C ha-1, a staggering number considering the short duration of land use from these activities.

Mangrove Stock Quantification

Mangrove ecosystem carbon stocks are comprised of above- and belowground tree, dead tree, downed wood, and soil components.

Mangrove biomass and carbon stock data are derived from measurements in French Guiana, which is the nearest country to Guyana and Suriname along the NBS where a rich history of mangrove research has occurred (Marchand 2017, Walcker et al. 2018). Mangroves of various stand ages were surveyed by Walcker et al. (2018) and estimates of above and belowground biomass were made using region-specific allometric equations. No data were collected regarding standing dead and downed wood carbon stocks. Tree biomass was converted to tree carbon using conversion factors of 0.48 and 0.39 for above- and belowground biomass, respectively (Kauffman and Donato 2012). Based on area estimates for mangrove stands of different age classes in French Guiana, it was assumed that 25% of mangrove forests are pioneer (<10 years old), 26% of forests are young (10 to 20 years old), and 48% of forests are mature / senescent (>20 years old). The stand distribution could be different from

Table 1. Total mangrove carbon stock estimates for Guyana and Suriname from Hamilton and Friess (2018).

Country	Year	Area (ha)	Total C (Mg C)	Min. Total C (Mg C)	Max. Total C (Mg C)
Guyana	2012	18,770	9,905,985	9,773,820	10,038,149
Suriname	2012	51,201	26,827,971	26,385,436	27,270,505

French Guiana but incorporating variability in stand age in the dynamic NBS system will allow for a more accurate assessment than assuming a uniform stand age.

Soil carbon to one meter in depth was quantified in mangroves of various stand ages in French Guiana by Walcker et al. (2018) in a portion of stands where tree measurements were made, and additional soil data were incorporated from Marchand (2017). Marchand (2017) also examined the soils under mangrove stands of differing ages in French Guiana and determined that the depth of mangrove-influenced soil (the pedogenetic layer) increased with stand age and that the oldest senescent stands had mangrove-influenced soil that was nearly 50 cm deep. Below that, organic carbon content in the mud bank sediment was never greater than 1% and was comparable to that from shoreface sediment (Marchand 2017). Marchand (2017) also quantified soil carbon accumulation rates based on stands of different ages (Table 4). Soil carbon data specific to Guyana and Suriname were not located; therefore, the data from French Guiana were used in this analysis.

Mangrove area estimates came from several sources, all of which were determined using remote sensing techniques on a global basis. One of the most widely used datasets of global mangrove coverage is from Giri et al. (2011) who classified mangrove distributions for the year 2000 using Landsat imagery (resolution of 30 m). The World Atlas of Mangroves data also represents mangrove distributions from 2000 (Spalding et al. 2010). The Global Mangrove Watch distributions were estimated with an accuracy of 94% from classification of ALOS PALSAR and Landsat sensor data, and were informed by the Giri et al. (2011) and Spalding et al. (2010) distributions (Bunting et al. 2018). They

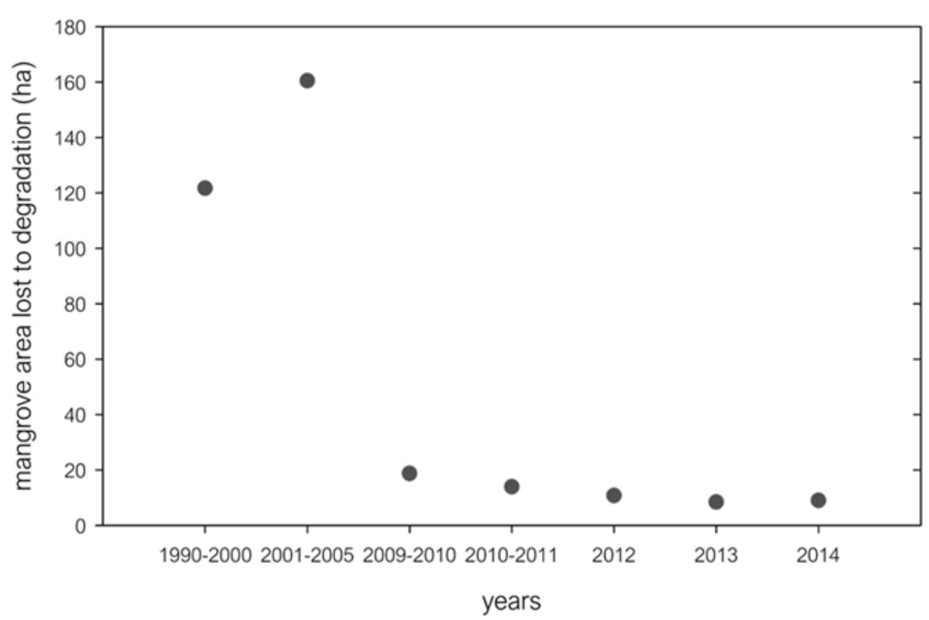

Figure 4: Mangrove deforestation in Guyana.

calculated global mangrove distributions for 1996, 2007-2010, 2015, and 2016 (Global Mangrove Watch, unpublished data, used with permission). Hamilton and Casey (2016) used two initial datasets to estimate mangrove distributions from 2000 through 2012 that incorporated the area within a Landsat pixel that is covered by mangroves instead of just presence/absence. They also projected mangrove areas for 2013 and 2014. In this report, only the area estimates based on the Giri et al. (2011) dataset were used since the other dataset using the Terrestrial Forest of the World appears to overestimate mangrove coverage.

For each of the estimated mangrove areas and years described above, country-level carbon stocks were calculated for mangrove trees, including above- and belowground stocks, and soil to one meter to assess variability over time and methodology. Using the percentage of stand age area presented in these studies, tree carbon stocks were scaled accordingly for Guyana and Suriname.

Additionally, total mangrove carbon stock data from Hamilton and Friess (2018) were incorporated. Hamilton and Friess (2018) calculated total mangrove and soil carbon stocks globally by using five different models and the 2012 mangrove coverage estimated in Hamilton and Casey (2016). The average total carbon stock as well as minimum and maximum values were presented for Guyana and Suriname; however, the data were not presented by individual carbon pools (e.g. above- and belowground tree and soil C stocks) or by each of the five models.

Because of the progradational and erosional mangrove dynamics along the NBS, teasing apart natural from man-made loss can be difficult from the available global mangrove datasets. Country or region-specific data and insight are needed. In Guyana, mangrove degradation data were assembled by the Guyana Forest Commission during seven time periods between 1990 and 2014 (Guyana Forest Commission, data used with permission). Deforestation spatial data for Suriname were provided by the National Land Monitoring System of Suriname between 2000 and 2017 over six time periods (GONINI 2019). Mangrove deforestation was calculated by taking the deforestation spatial data for each time period and intersecting that with the most relevant mangrove coverage data for that time using ArcGIS Pro 2.3.2 (Spalding et al. 2010, Giri et al. 2011, Bunting et al. 2018). The total area of mangroves deforested across the country was then collated.

Much of the mangrove deforestation that has occurred in Guyana and Suriname happened in conjunction with the development and growth of Georgetown and Paramaribo, respectively, largely before coverage estimates were known. As stated earlier, most of the coast of Suriname is protected in some form; therefore, mangrove deforestation in theory should be minimal if protection measures are enforced. Future development plans, and subsequent deforestation, in Suriname suggest that the majority will occur in freshwater marsh forests: 1,500 ha converted to sugar cane as part of a bio-fuels initiative and rice paddy formation is expected to increase another 30,000 ha (FAO 2015).

The unique mangrove system created by the mud banks along the NBS results in soil and tree carbon that is generally only stabilized for 30 to 50 years (Fromard et al. 2004). Within this time, however, significant amounts of carbon can be sequestered within the trees and soil. As described earlier, the data used for creating the stock estimates in Suriname and Guyana were collected in French Guiana. For the most accurate assessment of carbon stocks, local data should be collected, specifically tree characteristics (density, height, diameter at breast height (DBH), canopy width, etc.) in stands of various ages, soil salinity with depth, soil cores to quantify carbon stocks, and ideally measurements of CH4 and N2O, both from the soil and from the trees themselves.

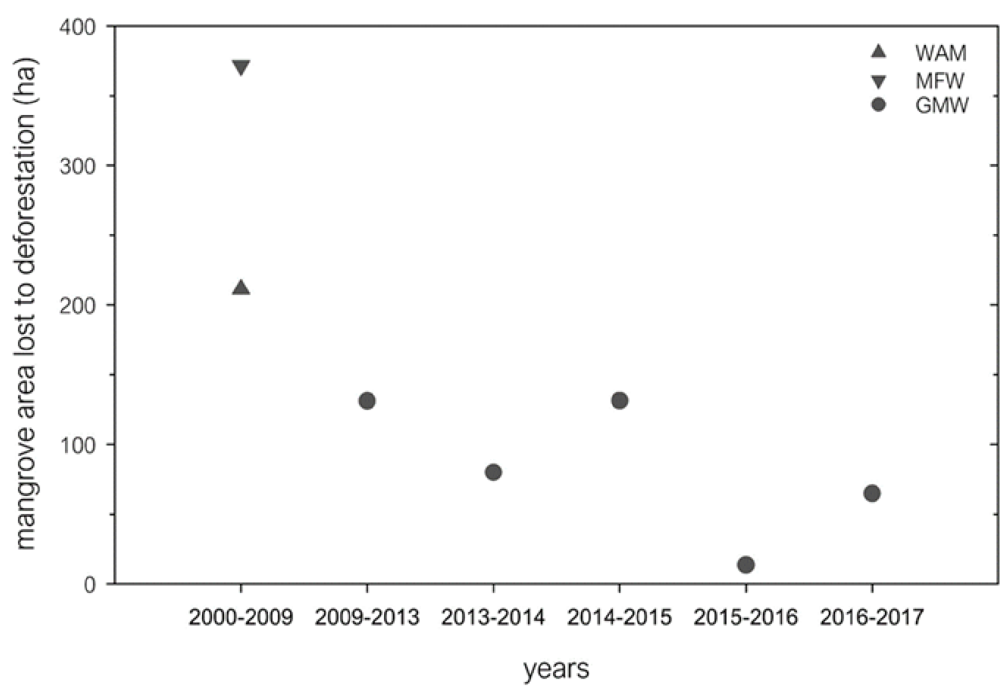

Figure 5: Mangrove deforestation in Suriname. Years represent the time period that deforestation occurred, the symbols represent the dataset used (WAM = World Atlas of Mangroves; MFW = Mangrove Forests of the World; GMW = Global Mangrove Watch).

Nature-based Solutions

Historical Sea Level Rise

... countries along the coastal plain of the Guianas will have to urgently adopt nature-based solutions to secure human well-being.

As global sea level rise continues to affect the North Brazil Shelf (NBS), countries along the coastal plain of the Guianas will have to urgently adopt nature-based solutions to secure human well-being. Natural ecosystems provide a host of benefits to local communities and national economies, and if managed correctly, they can also provide coastal flood protection from damaging surge and wave hazards. Understanding how sea levels have risen, and how they are projected to rise over time, is critical when planning and implementing coastal defence structures that can be adapted and strengthened over time.

Prior studies using tide station observations near Georgetown, Guyana reported a wide range of historical sea level rise rates over time, ranging from 10.2 mm/yr from 1951 to 1979 (Ruh Ali 2016), 5.1 mm/yr from 1960 to 1981 (Dalrymple and Pulwarty 2006), 4.7 mm/yr from 1960 to 2010 (Ruh Ali 2016), and 3.8 m/yr from 1992 to 2017. Across the NBS region, historical sea level rise appears to be consistent, with no apparent trend across the coastline (Table 1).

These historic rates of sea level rise in the NBS region exceed global averages of 3.3 mm/yr. As sea levels rise, coastal defence structures are more likely to be overtopped, resulting in inland flooding. Although many mangrove stands have kept pace with historical sea level rise, increasing rates of sea level rise may impact the ability of the mangroves to stay in place. Ensuring we enjoy the benefits of mangroves means that we will have to deliberately invest in protecting them.

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Table 1. Historical Relative Sea Level Rise (in mm/yr) for the NBS Region

Country	Administrative Region	Historical Sea Level Rise (mm/yr)
Guyana	Barima_Waini	3.5
Guyana	Demerara-Mahaica (Georgetown)	3.8
Guyana	Mahica Berbice	3.9
Suriname	Nickerie	3.7
Suriname	Coronie/Saramacca	3.6
Suriname	Paramaribo	3.8
Suriname	Commewijne/Marowijne	3.8

Overview of Green-Grey Coastal Defence Solutions

In sheltered locations with low wave energy and gentle foreshore slopes, "green" or nature-based coastal defense strategies are preferred because they provide a variety of co-benefits, including enhancing or increasing biodiversity and promoting human well-being. Green solutions can be coupled with habitat restoration to meet multiple species and community goals. In locations with high wave energy and steeper foreshore slopes, more traditional "gray" or engineered coastal defense strategies are more common. Gray strategies can provide a higher level of flood protection than green strategies, but gray strategies often have ecosystem impacts, including habitat loss and disconnecting communities from the shoreline. Green and gray strategies can be integrated to develop solutions that provide coastal hazard reduction (during high water and wave events), while also enhancing habitat health. These hybrid "green-gray" nature-based solutions can also help preserve the connection between upland and coastal ecosystems and maintain community access to the shoreline. Adapting the existing natural environment with green or green-grey hybrid solutions to reduce coastal hazards and stabilize shorelines is expected to provide the lowest cost and most flexible option for providing flood protection for inland communities. We identified some possible environmental scenarios in the NBS and appropriate green-grey strategies.

Mixed Urban Development (Residential/Commercial) – Adjacent to Shoreline

Areas with mixed urban development, including densely populated residential and commercial/ industrial areas will require innovative strategies to reduce coastal hazards from high wave energy and storm surge. With rising sea levels, widespread overland flooding will occur more often as high-water levels overtop large stretches of the shoreline. Many of the more developed areas in Guyana and Suriname are near the shoreline, below mean sea level, and protected by some form of grey infrastructure (e.g., seawall or berm). In these areas, the presence of mangrove forests is often minimal or non-existent. Grey infrastructure often results in deeper coastal waters along the shoreline (e.g., through wave reflection and accelerated erosion of adjacent shoreline areas, see Section 6.2) creating conditions that are not suitable for mangrove establishment and that could cause the grey strategies to fail (Winterwerp et al. 2013). In some cases, the grey infrastructure has previously failed or is poorly maintained, resulting in increased flood risk.

Coupling the existing grey infrastructure with green strategies that can help establish mangroves could also increase the lifespan of the grey infrastructure, reduce maintenance needs, and increase the level of coastal protection provided to inland communities. These green strategies could include sediment trapping units or brushwood dams that trap sediment and increase the elevation of the foreshore to allow mangroves to establish. In high wave energy environments, supplemental grey strategies (e.g., offshore breakwaters) may be required. Layering green and grey strategies provides multiple lines of flood defence, reduces the likelihood for flood defence failure, and increases the ability to adapt the system over time to sea level rise.

Although there is potentially enough sediment in the NBS region for mangroves to build vertically as sea levels rise, mangrove forests are also projected to retreat wherever inland development does not constrain landward migration (Crooks et al. 2019). In areas where inland development is a constraint, mangrove forests will eventually be lost. In the long-term, the coupling of green and grey strategies will become more important, and more substantial grey strategies may be required (e.g., more significant offshore breakwaters or shoreline revetments to reduce wave hazards). A cost-benefit analysis that considers short-term and long-term flood protection needs, multi-tiered green-grey strategies, and managed retreat, should be completed.

In both mud bank and interbank shoreline stretches, a living levee design may be suitable – this type of green-grey strategy provides a gentler slope than a traditional levee design and incorporates habitat

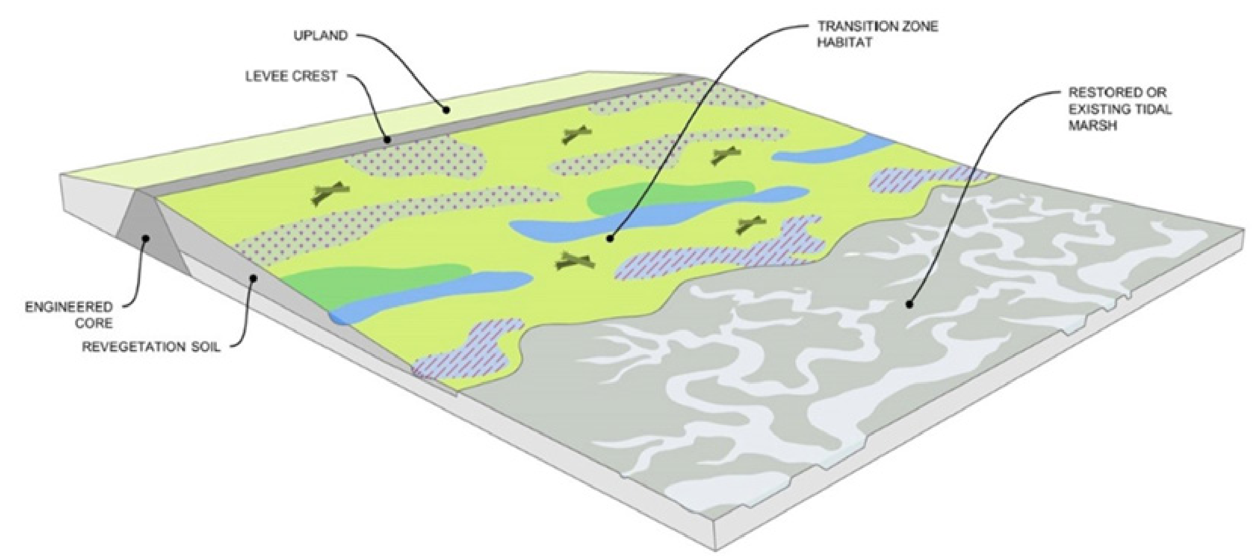

Figure 1. Living Levee example (source H.T. Harvey & Associates (Accessed at https://www.greenfoothills.org/living-levees/-2019).

transition zones between upland and tidal flat areas. An example of a living levee that incorporates multi-tiered green-grey strategies is presented in Figure 16. This strategy provides habitat restoration and flood protection, and it can be adapted to higher elevations over time in response to sea level rise and increased storm activity. This measure requires artificially extending the natural shoreline seaward in areas of coastal squeeze, so considerations of indirect impacts (e.g., sediment starvation) to adjacent shoreline areas are necessary. In developed areas behind mud banks, a living levee design would complement the gentler foreshore slope. At interbank locations with higher wave energy, the design would likely require sediment placement and more construction materials, translating to higher construction costs.

Mixed Urban Development (Residential/Commercial) – Setback from Shoreline

In areas where mixed urban development is setback from the current shoreline edge (e.g., Paramaribo, Suriname), alternative approaches may be able to leverage existing natural buffers provided by mangrove forests. Green strategies can be implemented to stabilize (and possibly extend) the natural buffer between the development and shoreline. The required development setback distance can be defined by the wave heights and/or storm surge elevation that requires attenuation.

Interbank areas may have less existing natural buffer (e.g., mangrove forest width) available; however green measures such as sediment trapping units and brushwood dams can support shoreline accretion to allow new mangrove populations to establish. Along shoreline stretches with particularly high wave energy, offshore breakwaters or artificial chenier ridges can be used to reduce wave energy on the outboard size of the mangrove fringe. If coastal protection from large storms is desired, more substantial green-grey solution may be required, depending on the setback distance between the developed areas and the shoreline. A greater need for integrated green-grey solutions will be more apparent in the longer-term when considering sea level rise.

An integrated green-grey strategy for setback development was evaluated for Paramaribo, Suriname (World Bank Group 2017). Several kilometres of mangroves were established between the shoreline edge and the developed areas, providing an opportunity to use natural infrastructure for storm risk reduction in combination with a grey measure (e.g., embankment or engineered levee). In the World Bank (2017) study, installing a flood barrier behind the existing mangroves provided the greatest cost-benefit for both the natural and built environment. A minimum mangrove buffer width of 1.5 km was found to provide the adequate setback needed to support this type of solution. In this region a buffer of less than 1.5km would be susceptible to wave-induced erosion (World Bank, 2017). Potential erosion seaward of the existing mangrove forest should be evaluated and monitored, and a supplemental solution that promotes sediment trapping and establishing may be required as sea levels rise.

Finally, if enough space is available landward of developed areas, managed retreat should be considered. This will provide additional space for the mangrove forest to migrate inland as sea levels rise and will reduce the need for other costly adaptation strategies to attenuate wave hazards and storm surge.

Sparse Residential

In areas with sparse residential (i.e., rural) communities near the shoreline, managed retreat should be considered. Residential communities behind mud banks and established mangrove populations may benefit from minor green shoreline interventions to promote continued shoreline accretion. However, over time more substantial solutions may be needed to protect against rising sea levels and associated high water level and storm surge events. Relocating these communities to upland areas further inland would provide overall cost savings in the longer term. At a minimum, rural communities should understand their flood risk and should construct their homes and infrastructure to withstand intermittent flooding. Building codes and defined flood risk zones can be effective at communicated varying degrees of flood risk. Relocating rural communities will have other long-term benefits, such as potential increasing their access to reliable water supplies. In Guyana, groundwater from coastal aquifers provide 90 percent of domestic water (United States Army Corps of Engineers 1998). Saltwater intrusion has already been a concern in the eastern lowlands (United States Army Corps of Engineers 1998), and as the sea level rises, saltwater intrusion is likely to increase. This will impact potable water supplies, particularly in rural settlements that rely on well water.

No Development

In undeveloped areas, no actions are likely needed. However, sea level rise without intervention will result in indirect impacts to these regions, including loss of carbon stock and landward migration of mangrove forests and fringe habitats.

Overview of Green-Grey Coastal Defence Solutions

Agriculture and Aquaculture

In the coastal aquifer system, there is currently brackish to saline groundwater in the north-western corner of Guyana (United States Army Corps of Engineers 1998). Although agricultural water supplies are drawn from surface water rather than groundwater (United States Army Corps of Engineers 1998), salinity intrusion into the groundwater will impact agricultural lands. As sea levels rise, the shallow groundwater surface will also rise, and saline groundwater will push farther inland. Over time, this will turn agricultural areas into coastal swamps and create conditions that will adversely affect agricultural productivity.

While nature-based strategies can increase coastal protection from rising sea levels, no shoreline infrastructure can protect from rising groundwater levels. In wide coastal floodplains where the ground has a relatively shallow landward slope, a managed retreat scenario can support the continued use of agricultural and aquaculture practices in the region. The rates of groundwater rise, and salinity intrusion are currently unknown, but should be monitored over time.

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Hardened Sea Defense Structures

Areas in Guyana where approximately 250 km of the shoreline has been hardened with engineered sea defence structures (Anthony and Gratiot 2012) present interesting examples of what occurs when grey solutions for coastal defence are used alone in the NBS Region. These structures eliminated historical mangrove populations and are preventing mangrove establishment on the incoming mud banks by isolating mangrove propagules from disseminating seaward (Anthony and Gratiot 2012). Additionally, engineered sea defence structures such as seawalls do not provide wave dissipation. Instead, these structures can create erosion issues that result in undermining of the structure and eventual structural collapse (Figure 5). Waves reflect off the hardened structure, promoting nearshore turbulence and erosion of the structure's foundation and the seabed in front of the structure. Increased nearshore turbulence can also inhibit sediment aggregation, increasing the risk of mud bank liquefaction and ultimately perturbing the dynamics of the mud bank and interbank system. This can lead to more persistent erosion of the interbank shoreline.

Figure 5. Failure of hardened sea defence structure in Guyana (source: Winterwerp et al. 2013 (left); USACE 2019 (right))

Economic Significance of Mangrove Ecosystems for Flood Risk and Coastal Erosion Reduction

Implementing grey solutions closer to the shoreline results in greater capital cost compared to green solutions. Increasing the shoreline setback available for these solutions results in cost reduction for both. Green measures may incur higher annual maintenance costs when adjacent to the shoreline, but with increasing setback distance, annual costs between green and grey solutions will converge to similar rates (Figure 2).

Integrated solutions that leverage the flood protection potential of existing mangrove forests will have a lower overall cost. Grey solutions that incorporate existing mangrove forests into the design will achieve the greater cost reduction (due to the higher initial cost of grey infrastructure). Additional justifications for pursuing an integrated (green-grey) approach can be found in the beneficial functions served by green solutions which create synergies with the functions served by grey solutions.

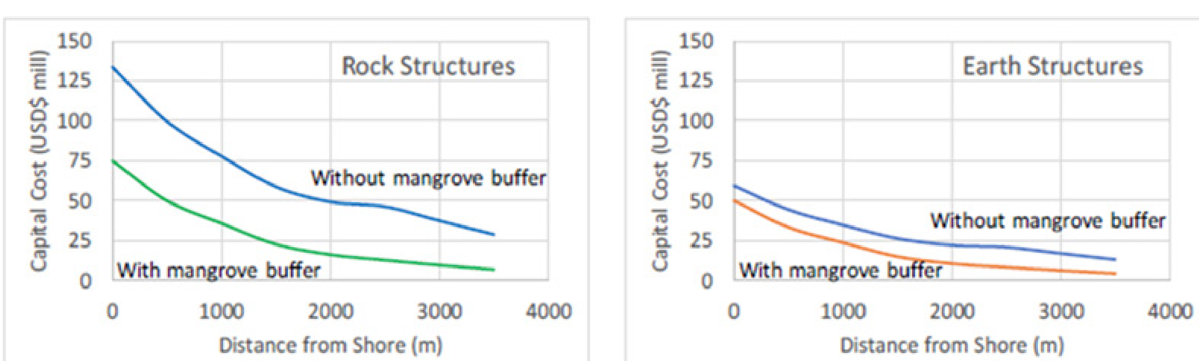


Figure 2 Cost reduction with natural infrastructure (e.g., mangrove buffer) (source: World Bank, 2017)

Storm Surge Attenuation

Coastal flooding is a concern in the low-lying coastal areas, especially where inland areas are below sea level. These low-lying areas near the shoreline, with rural settlements and agricultural lands, are already threatened by tidal flooding during spring tides. In the NBS region, most storm surges are small, with coastal water levels elevated by 0.4 m or less in Suriname (World Bank Group 2017). Georgetown (on average 2 m below sea level) and the East Coast Demerara are particularly vulnerable. In early 2005, extreme rainfall coupled with storm surge overtopped the seawall and the conservancy dam, resulting in devastating widespread flooding (Hickey and Weis 2012). Although mangroves are effective at reducing wave energy and wave heights, mangroves are less effective at reducing storm surge levels. Mangrove species composition and density play an important role in storm surge attenuation. The mangrove species Rhizophora spp. and Bruguiera spp. (with aerial roots – e.g., prop roots, knee roots, or pneumatophores) have been observed to have greater influence on the flood and ebb stages than other species without aerial roots (Figure 3).

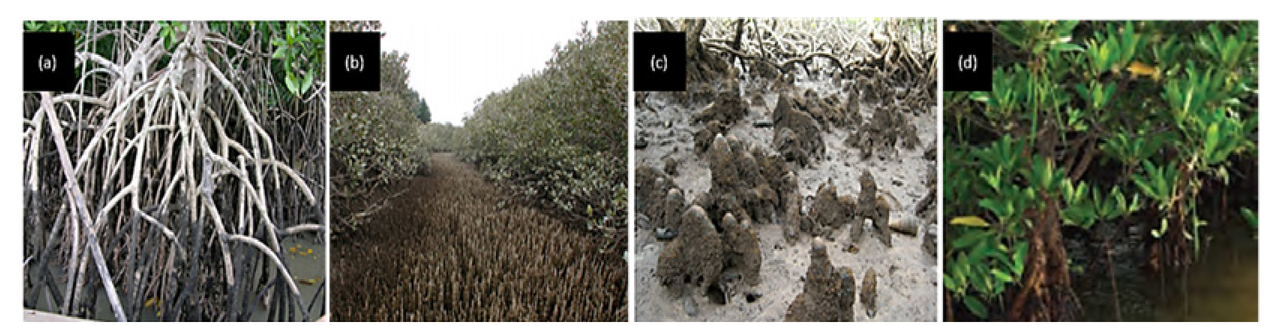


Figure 3. (a) Prop roots(Rhizophora spp.) (b) Pneumataphores (Avicennia spp.) (c) Knee roots (Bruguiera spp.) (d) Non-aerial roots (Kandelia spp.) (source: World Bank 2016)

Wave Attenuation

Wave hazards are the principal contributor to erosion along the NBS coastline. Yet, mangrove forests can effectively reduce wave energy and stabilize shorelines, with several factors contributing to the rate of wave height attenuation (Figure 4).

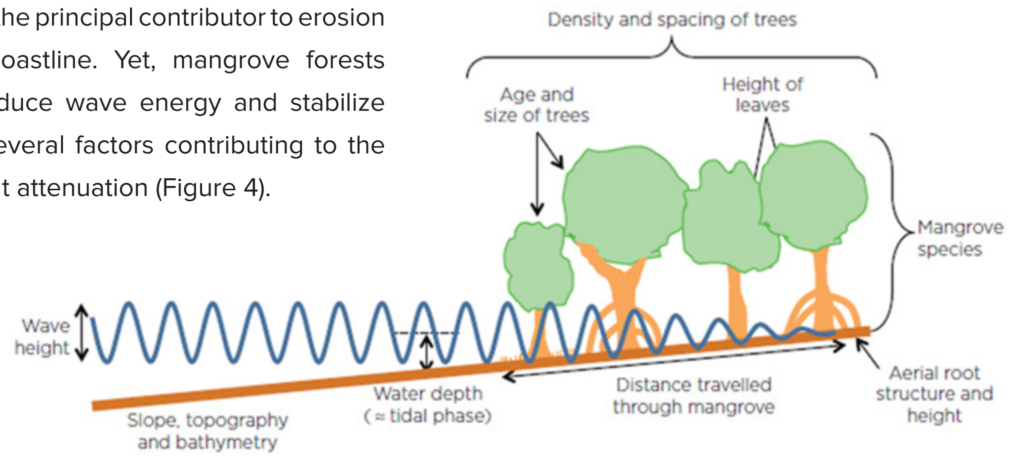


Figure 4: Key factors contributing to wave attenuation (source: World Bank 2016)

Sediment Stabilization

Mangrove roots are effective at trapping sediments and minimizing coastal erosion by creating stable banks (Thom 1967, McIvor et al. 2012, Flemming 2012). Some species (Avicennia germinans and Laguncularia racemose, both widespread in the NBS region) have denser root mats (e.g., compared to Rhizophora mangle) and are better able to stabilize the shoreline.

With several primary shoreline typologies in the NBS region, a detailed cost-benefit analysis is needed to identify the most appropriate strategies for individual vulnerable shoreline segments. The annual ecosystem services provided by mangroves has been estimated to be almost $200,000 per hectare (based on global studies (Anthony 2015)).

Governance and Policy Strategies

Although green and gray strategies are necessary for stabilizing the shoreline, re-establishing mangrove forests, and providing coastal protection for inland communities, governance and policy-related strategies will also be important for increasing the overall resilience of the NBS region. Governance strategies may include defining and enforcing building code standards, defining and enforcing land-use based flood risk zones, and developing communication and outreach strategies to inform local residents and businesses about changing flood risks over time.

Financial Mechanisms for Mangrove Conservation

... valuing mangroves based on potential cost savings by replacing manmade seawalls yields values in the range of $1.5 billion to $3.6 billion

Introduction

Mangroves provide protection and sustainable management co-benefits for various stakeholders throughout the NBS-LME and across the planet through a range of ecosystem services (e.g., carbon sequestration combating global climate change). This report examines financial strategies for the conservation and restoration of mangroves to improve coastal resilience in Guyana and Suriname through the development of symbiotic green-grey infrastructure.

However, a financial justification exclusively based on coastline protection would limit access to financing because Guyana and Suriname are developing nations. For instance, although a detailed economic valuation is beyond the scope of this report, we estimate the current value of carbon storage from mangroves in Guyana and Suriname to be in the range of $1 billion1 ($700 million in Guyana and $300 million in Suriname). Similarly, from a coastal protection standpoint, estimates of the value of mangroves just in Paramaribo, Suriname alone exceed $100 million.2 Using another approach, valuing mangroves based on potential cost savings by replacing manmade seawalls yields values in the range of $1.5 billion to $3.6 billion (approximately $100,000 to $200,000 per hectare of mangroves). Although these valuations represent rough estimates, it is clear that mangroves provide significant values to a wide variety of stakeholders. Accordingly, we recommend a similarly broad financing approach that incorporates values beyond just property protection to finance the cost of preserving mangroves, which could cost an estimated $4 million per year ($1 million in Guyana and $3 million in Suriname).

A global review of successful example projects reveals that the most successful projects employ a flexible structure to provide access to a broad array of financing sources. Accordingly, this report considers a wide range of financial strategies, including carbon-focused structures. Certain financial strategies such as green bonds and carbon-based financing mechanisms would require additional investments to develop the necessary conditions to support successful implementation. Additionally, Guyana's recent discovery of oil, estimated to yield billions of dollars annually in governmental taxes and royalties, could provide critical near-term financing consistent with the project's goals. Although implementing an oil fund structure would require building governmental and political support, it would otherwise be simpler to implement than green bonds or carbon mechanisms, which could be limited by transaction costs and technical readiness factors.

Whether pursuant to a dedicated oil extraction fund or otherwise, consolidating the mangroves project with other green projects within the NBS-LME countries may improve the project's success by taking advantage of economies of scale to leverage transaction costs associated with establishing and administering a financial mechanism to support the project. For instance, the funding mechanism for mangroves could be combined with funding mechanisms related to inland terrestrial forests, which would increase the overall funding and spread the implementation costs over a wider project base.

Because the value of mangroves may not be immediately apparent to many stakeholders, international and local marketing and education campaigns could accelerate the conditions necessary to generate critical stakeholder engagement and support. Partnerships with international corporations, who are increasingly seeking environmentally responsible projects, provide an opportunity to access technical expertise and financial resources without significant transaction costs.

Mangroves Services and Value Flows

Hypotheses

"Mangrove ecosystems are some of the most productive and biologically diverse on the planet: They serve as habitats for sharks, manatees, crabs and other species; provide food and jobs for millions; and protect some of the most vulnerable coastal communities from storms and rising sea levels. Mangroves also contain the densest stores of organic carbon on the planet— ending mangrove deforestation [at the global level] is like taking more than 1 million cars off the road... by protecting one hectare of mangrove we can: reduce storm impacts by 50%; increase tourism value by 25x per year ($1,079); store up to 1,100 tons of carbon."(Conservation International Annual Report, 2017). Within the wide array of services provided by mangroves, (ECLAC, 2018) the Project focuses on flood and erosion protection. At the global level, mangroves currently protect 3.5 million people from storm impacts, which is expected to double to 7.2 million people due to climate change impacts (Conservation International Annual Report, 2017). Although no comprehensive valuation study has been undertaken in the NBS-LME, in other geographies, valuation studies have estimated the flood protection benefits of mangroves. For instance, the flood protection value of mangroves in Cuba is an estimated $154 million each year (ECLAC, 2018). Manmade coastal flood barriers cost an estimated $2,20022 to $5,00023 per linear meter to construct and maintain. 24 While a precise economic valuation is beyond the scope of this report, the cost of constructing and maintaining seawalls in Guyana and Suriname is in the range of $1.5 billion to $3.6 billion (Table 1).

While mangroves likely could not be used in lieu of all seawalls, in instances where mangroves could replace seawalls, and assuming an average mangrove depth of 235 meters, the value of mangroves per hectare would be in the range of $100,000 to $200,000 per hectare.

Using a framework similar to that of Vietnam's Mangrove Payment for Ecosystem Services Systems, it would cost about $35 USD a hectare / year. The key ingredient to success is the inclusion of the local communities, including the people that own the land surrounding mangroves. In the IUCN report, "Protecting Mangroves: What does it cost?", the government paid a local family about $35/hectare/

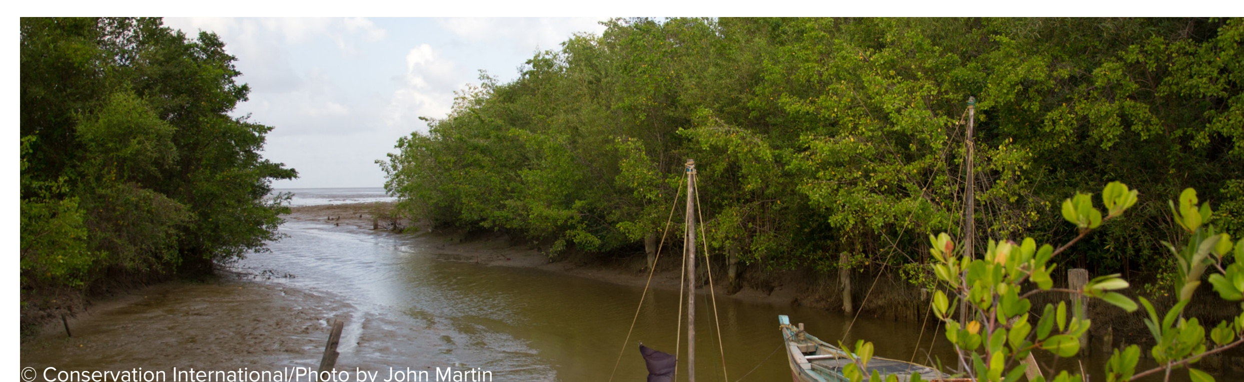
	Seawall Length (KM) (Estimated for Suriname)	Cost to Construct and Maintain Seawall Per Linear KM	Total Cost of Seawall
	Guyana		
Low	360	$ 2,200,000	$ 792,000,000
High	360	$ 5,000,000	$ 1,800,000,000
	Suriname		
Low	303	$ 2,200,000	$ 666,039,216
High	303	$ 5,000,000	$ 1,513,725,490
	Total		
Low	720	$ 2,200,000	$ 1,584,000,000
High	720	$ 5,000,000	$ 3,600,000,000

Table 1: Cost of constructing and maintaining seawalls in Guyana and Suriname.

year for preserving 56 hectares of mangroves. This paid the family about $160 a month. The underlining benefit to this method is that the family passes on the importance of committing to the contract to stop illegal tree cutting, in addition to realizing additional values such as fishing and shell collection. The payments and accountability are established through the assignment of the individuals in the families as forest rangers of the regional forest stations. Using this methodology and cost structure. The cost per year of the preservation of mangroves in Guyana would be $1,051,785 (30,051 ha), and Suriname would be $2,680,685 (79,591 ha).

The cost of restoring mangroves, according to the World Bank Data as of 2010 was about $52,000 / ha in developing areas. According to Teas 1977, Lewis 1981, Brockmeyer et al. 1997, Lewis 1999, the cost ranges from $225 from simple planting (very low success rate) - $216,000 / ha. For the purpose of our analysis, we will use the highest portion of the range due to the possibility of needing to purchase the land which results in a higher restoration cost.

While mangroves provide valuable services, they are also under immense threat. Mangroves are being lost at a rate of 1%-2% per year,25 which means that at current conversion rates, nearly 100% of global mangroves could be lost in the next 50-100 years.26 Primary deforestation threats in the NBS-LME include real estate development, fisheries, cattle ranches, farms (including rice paddies) and salt extraction (WWF Guianas, 2016).



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Mangroves Services and Value Flows - Hypotheses

The research focused on testing four hypotheses, each targeted to determine an appropriate sustainable financial mechanism to preserve and restore the mangroves in Guyana and Suriname. Preliminary research and hypothesis testing provided additional direction and scope refinement for the project. For instance, in assessing the readiness of Suriname and Guyana to adopt sophisticated financial mechanisms, preliminary findings suggest external resources may be needed for successful implementation of long-term solutions.

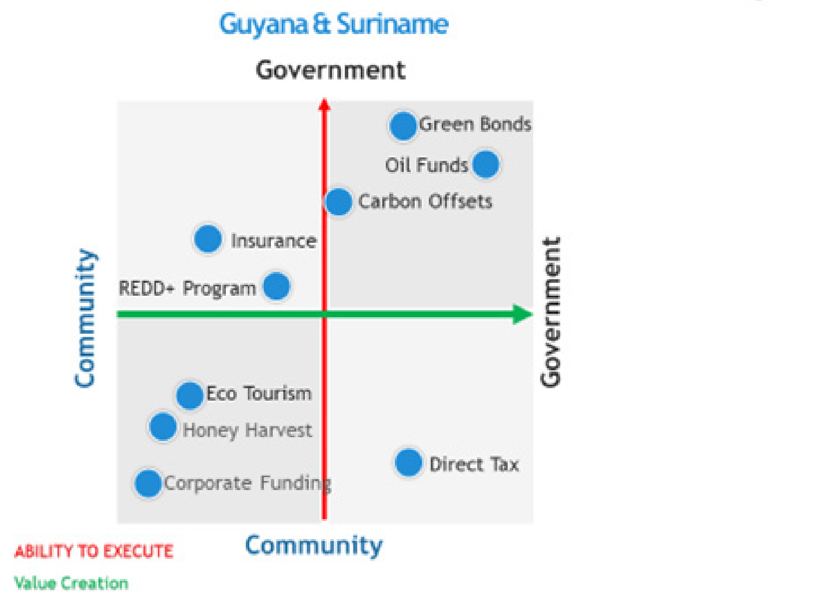
a. Funding Sources - Sources of revenue from the private sector will allocate the highest percentage of funding for the conservation of mangroves.

i. *Confirm / Rejected:* Accepted

ii. *Relevant Facts:* Taxes are an unpopular solution and might not be a viable option, but an alternative is generating public funds from owned natural resources, examples of this could be an oil-extraction tax (discussed in more detail below) and gold mining funds.

iii. *Analysis:* Third-party mechanisms would satisfy the hypothesis to evade public sourcing stress. Primary research findings indicate that private sources from multinational, regional and local corporations could be a proven source of funding.

Stakeholders and Value Creation Mechanism Diagram



b. Value Awareness - The local population and leadership realize the contribution of mangroves to their economic well-being and are willing to contribute to their conservation and management by voluntary contributions, tax, or other mechanisms.

i. *Confirm / Rejected:* Confirmed in Guyana, but rejected in Suriname

ii. *Relevant Facts:* In-country visits have proven that Guyana and Suriname are at different stages in addressing mangrove conservation.

iii. *Analysis:* Based on our first stage in-country visit, primary research suggests a lack of government involvement, lack of policy, lack of funding and lack of protection mechanisms in both Suriname and Guyana. However, Guyana's government is more proactive in conserving mangroves which is well reflected in the Forest Act and the Sea Defense Act where mangroves are identified as protected species. Since the 2005 flood in Guyana, the local coastal communities are more sensitized and are more likely to support mangrove planting projects or participate in restoration workshops. In Suriname, the government is less transparent and often unwilling to partner with local NGOs or external organizations on restoration projects. The local population is aware of the importance of mangroves but would trade mangroves for development or more immediate payouts. Overall, both the government and local communities in Suriname would opt for short-term returns instead of long-term conservation benefits.

c. Enforcement - Guyana and Suriname have a process in place with an effective framework to administer and allocate external funding in accordance with third party funding requirements.

i. *Confirm / Rejected:* Rejected

ii. Relevant Facts: There is no legal and policy framework for mangrove management. Lack of capacity, financial resources, transparency and accountability are the main problems in implementing mangrove related laws.

iii. *Analysis:* There is a need for a governing body responsible for oversight. The authority for mangrove governance is fragmented across forestry, land, marine and fisheries agencies. The success and impact of financial mechanism will depend on an effective and sustainable management of mangroves. The government should consider developing a mangrove management plan where a specific agency will be primarily responsible for the administration and enforcement, with the ability to seek the assistance and cooperation of other governmental agencies. Alternatively, an integrated and community-based management plan could be developed for a shared decision-making power, management responsibility and accountability of mangroves. In some countries in Southeast Asia and Latin America, programs involving communities partnering with nongovernmental organizations (NGOs), research organizations, and those that provide other incentives appear to generate better mangrove conservation and restoration outcomes. Throughout the readiness phase of the REDD+ framework, Suriname has set up the stage for enforcing NIMOS by creating a National Forest Monitoring System and by engaging on a multi-stakeholder process with indigenous and tribal peoples, the University of Suriname and the Government of Suriname. More enforcement mechanisms will be needed in order to address the importance of mangroves in REDD+. For Guyana, during the readiness stage, the enforcement of the National Toshoa's Council (NTC) and the National Steering Committee of Community Forestry Organizations (NSCCFO) have been addressed, but no specific information on how they will employ and regulate funding received from the Carbon Fund.

d. Restoration and Conservation - The cost of restoration is more than the cost of preservation of mangroves.

i. *Confirm / Rejected:* Accepted
ii. *Relevant Facts:* Through both primary and secondary research, we have found that the restoration of the mangroves is a labor intensive, time consuming and costly activity.
iii. *Analysis:* Our research indicates that other countries have implemented penalties for individuals that damage landscape and natural resources. This method would help reduce deforestation rates and recover funding.

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Financial Mechanisms

The group of stakeholders in-country impacted directly by the preservation and restoration of mangroves are government entities, and the local communities of Guyana and Suriname.

Green Bonds

In theory green bonds enjoy a "greenium" in which green bond investors are willing to give up financial returns in exchange for investing in green projects compared to "vanilla" bonds, but the greenium theory does not yet seem to be reflected in market prices and some studies even suggest that issuers actually increase their borrowing costs by issuing green bonds.

Thus, evaluating whether green bond issuance is viable for a mangroves project in Guyana and Suriname inherently requires balancing the pre- and post-issuance transaction costs against the benefits of gaining access to international green bond markets. Moreover, green bonds can serve as marketing tools for public and private issuers to highlight their commitment to green principles and can act as an example for potential private sector issuers. For instance, Guyana could issue a green bond to generate international awareness of its green efforts.

The green bond market is still evolving, as the first green bond was not issued until 2007,[53] and since then, cumulative green bond issuance has only just recently exceeded $500 billion worldwide.

Financial Mechanisms

Oil-Extraction Fund

A financial mechanism to protect mangroves could be funded by establishing a dedicated funding source from revenues derived from substantial offshore oil reserves in Guyana and Suriname. "The Guyana-Suriname Basin has an estimated resource potential of more than 13 billion barrels of oil, according to the U.S. Geological Survey and is considered one of the world's top unexplored basins."[62] In Guyana alone, the recent discovery of oil is estimated to yield annually $6 billion in governmental taxes and royalties, which could provide critical financing consistent with the Project's goals.

A key to establishing the oil-extraction fund mechanism is "selling" it to governmental stakeholders who control the oil revenues. There is substantial competition for the funds, so officials will need to be convinced that funding the mangroves is for the public good and they may also need to be convinced that it advances political interests. While the discussion will be broader than a mangroves-focused project, that dialogue presents an opportunity to lay the foundations for establishing an oil-extraction fund to benefit mangroves ecosystems. Because mangroves are extremely efficient in carbon sequestration, the oil fund can be packaged as a carbon-extraction tax, which requires sequestration of carbon in exchange for the right to extract carbon.

Carbon-Based Mechanism

Globally, there are 39 countries and 23 sub-national (states) who are actively pricing carbon through emission trading systems or in the form of tax[66]. While Guyana and Suriname have both signed the Paris Agreement showing real intent to reduce global warming temperatures to below 1.5 degrees Celsius and attract the subsequent funding that entails, both countries currently do not have comprehensive emission trading systems (ETS) in place.

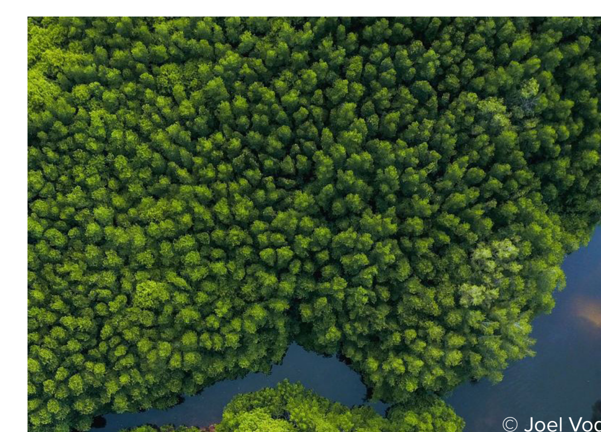
There are three main options for carbon pricing that are used around the world in which the proceeds are typically used to fund conservation efforts. The most straightforward of which is the carbon tax mechanism, followed by the Carbon Emission Mechanism and the Carbon Offset Mechanism. The latter two represent opportunities for Guyana and Suriname to obtain international and private sector funding, if they follow the specific international guidelines detailed in this report. Step one of launching a CAT program in Guyana and Suriname would be deciding the scope of the cap[67] – i.e. deciding which greenhouse gases and which emitting industries the regulation will be targeted for reduction. With the windfall of capital that is expected to come into Guyana in 2020 due to new-found oil exploration offshore (5 billion barrels of oil and counting) , industries will be jumping at the opportunity to come to Guyana to take advantage of the emerging economy. If a regulatory ETS system like a CAT is in place, it will signal that conservation is a priority in Guyana (and Suriname) and provide continuous annual capital as their economies expand.

A carbon offset financial mechanism in Guyana and Suriname would entail securing mangrove areas of the country (that would otherwise have been destroyed) for at least 30 years, verifying the carbon stock sequestered and stored, and selling these metric tons of carbon credits to companies looking to "offset" their carbon footprint in the global voluntary carbon market. The development of this mechanism could be an important source of long-term financing for Guyana and Suriname through monetizing the most important ecological value of the mangroves - carbon storage (5x more than regular trees) . With wetlands like marshes and mangroves undergoing massive deforestation at a rate of 35% since 1970-2015; three times faster than terrestrial forests, the time is now to bring awareness to the mangroves as one of the largest carbon sinks on earth.

Critical to setting up a carbon offset conservation project is following strict protocols for verification of the carbon stock. Setting up carbon offset projects could also potentially attract additional international funding under the Paris Agreement, which allows for developed nations to provide bilateral funding agreements with developing nations who have signed the pact (both Suriname and Guyana are included) to aid them in their efforts to prevent climate change and global warming. Launching carbon conservation projects that involve mangroves ("blue carbon") could play a major role.

REDD+ Framework Funding Mechanism

REDD+ is a framework that triggers Results Based Payments (RBPs), an effective financial mechanism that aids developing countries in exchange for the reduction of emissions. Although the framework has shown success for the reduction of emissions and deforestation around the globe, the main challenge is still adapting the framework despite the political stakeholders in each nation. First, there are still a large number of players interested in the deforestation, degradation, and consumption of natural resources. A second challenge is the coordination of the framework among all the entities within the government, specifically to address any persistent tradeoffs between agencies and government branches as well as the proper use of the monetary grants. And lastly, addressing transparency and setting up correctly the measurement and reporting activities in an organized way.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Exploratory Funding Sources

The primary research conducted in Suriname and Guyana led the team to entertain additional funding sources including:

- **Eco-Tourism**. According to "ITB Berlin and GREEN Destinations", Guyana was named the #1 country to visit for Ecotourism.103 This statistic was referenced by the government agencies visited and CI. In addition, CI discussed a successful example of a local community implementing an eco-tourism attraction was the remote indigenous Rewa Village in the Rupununi District. They created an Eco Fishing and Adventure Tours economy that has brought a measure of financial sustainability to the community.
- **Honey Harvest**. Women in a seaside village in Guyana, backed by government and European Union funding, are combining commercial activities like beekeeping and sustainable food processing with spreading the word on the importance of protecting their coastal mangroves. The women of Victoria, a coastal village, are taking part in the Guyana Mangrove Restoration Project, which currently generates only modest employment and income, but has the potential, they believe, to produce good economic returns.
- **Corporate Funding**. Wayne Nieuenkirk, a distribution warehouse manager working at Banks DIH, the largest company in Guyana, stated that there is an interest in funding mangrove restoration efforts. Their company is involved in the bottling and distribution of food and beverage products. They are aware of their carbon footprint and are interested in working with Conservation International to raise awareness and provide funding. In addition, Wayne stated there is likely a high interest for other large companies based in Guyana to do the same.

The Optimal Financial Mechanism

The optimal financial mechanism is a hybrid model consisting of: the ongoing REDD+, Community and Corporate Contributions, Oil Extraction Tax, Carbon Offsets, and a Green Bond program. This diverse set of funding sources would enable the sustainability of peak project funding needs such as restoration sites, and the continuous maintenance of the mangroves. The timeline in Figure 1 illustrates a theoretical implementation period based on government participation in providing the required regulatory environment to meet the reporting and international standards to access these mechanisms. The peak funding points on the graph represent one-time contributions for site restorations and/or investment needed for data analysis and reporting exercises.

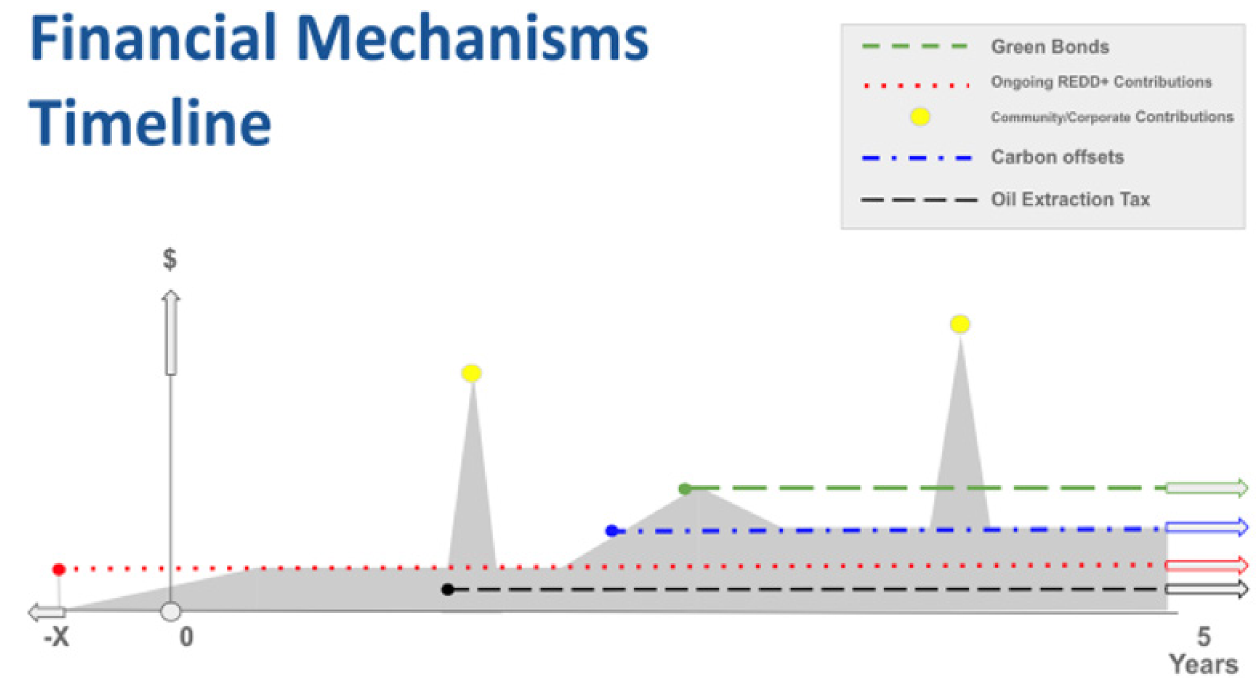


Figure 1: Illustrations of a theoretical implementation period based on government participation in providing the required regulatory environment to meet the reporting and international standards to access these mechanisms.

Carbon Financing Feasibility Conservation

...mangrove restoration projects ...could be monetized through a blue carbon restoration project and generate significant income...

Restoration Blue Carbon Offset Project

There is significant potential for carbon projects in Suriname and Guyana, notably through mangrove conservation under VM0007 or Plan Vivo methodologies, although the potential net emissions reductions of a mangrove carbon project within the North Brazil Shelf (NBS) have yet to be determined. Preventing emissions by protecting intact wetlands from erosion is a recognized potential project activity under the Verified Carbon Standard (VCS).

While a conservation carbon offset program that protects a designated area from deforestation is possible for Guyana and Suriname, provided they can prove that these specific areas will be in danger of deforestation, a more likely scenario to gain verification approval through VCS would be to a reforestation blue carbon offset project. While in some countries like Brazil and Africa where there are well-documented deforestation threats, Guyana and Suriname do not have this same level of deforestation risk. Guyana and Suriname are widely considered some of the "greenest" countries on the planet (forests covering 75% of Guyana87 and 94% of Suriname's land surface area) with an annual deforestation risk of ~0.45% 88 and 0.02% respectively . As a result, it would be much tougher (not impossible) to prove the required level of "additionality" to get a conservation project approved.

As such, launching a restoration blue carbon offset project could be much easier. Particularly in a country like Suriname, where there are reportedly over 168,000 hectares land in areas that were deforested in the past and now abandoned, according to Steve Crooks of Silvestrum, mangrove restoration projects launched within this much surface area could be monetized through a blue carbon restoration project and generate significant income at a carbon price of $5-$15 per metric ton of carbon.

To launch a successful carbon offset mangrove restoration project, the process is mostly the same as for a conservation offset project, except you would use a slightly different VCS protocol – VM0033 (for wetland restoration rather than deforestation quantification)91. One would still need to select the site, ensure the protection of the site for at least 30 years, and develop your monitoring (MIR) and project design documents (PDD) to get verified. The only difference is it would be easier to prove the "additionality" of a restoration project – as planting new trees is always going to be adding carbon sequestration and storage benefit to the environment.

One final nuance to consider in setting up a restoration project is that one would still have to prove some "additionality" in a restoration project i.e.. that the trees you are planting (mangroves) would not have just grown back on their own through natural regeneration ("business as usual"). If they would have grown back on their own, then technically the project is not truly providing a benefit and it would fail verification. However, this is somewhat rare in restoration offset projects. Again, the concept of "additionality" is crucial in these offset projects proving that you are providing "additional" carbon storage and sequestration benefit through the launching of these projects.

If such measures are possible, which has yet to be determined, a first order estimate of the emissions reductions are as follows. Considering a 1 k long mangrove stand, avoided retreat of 243 m (total area 24.3 ha) would maintain a total carbon stock of 7,385 Mg C (using values in Table 2), which equates to $406,156 USD ($8.5 million GYD / $3.0 million SRD) in carbon credits at $15 USD ($3,139 GYD / $112 SRD) per metric ton CO2e assuming negligible CH4 and N2O emissions. If the scale of the prevented erosion were greater, for example avoiding mangrove retreat by 609 m, the potential value of carbon credits would increase to $1,017,897 USD ($213 million GYD / $7.6 million SRD). This assumes 1 meter of soil is impacted. Further analysis is required to determine the magnitude of erosion risk, options for reducing erosion and depth of soil that would be protected. An agency, whether a non-profit or government entity, would also need to be named as the project developer before proceeding with a carbon financing feasibility report. A project that is supported and ideally organized by the local community, such as in Kenya (example cited in report), with agency and government support, would likely have the most traction and could maximize all potential co-benefits.

The dynamic interplay between mud bank locations and mangrove presence along the NBS poses an intriguing dilemma in that the system is not fixed in space and time compared to other fringing mangrove systems worldwide. A particular mangrove stand is relatively short-lived (~60-70 years); however, the larger-scale cumulative progradation and erosion of mangroves results in a relatively consistent country-level ecosystem carbon stock, given that deforestation or other degradation would not disrupt the natural processes.

Under the methodologies, a project needs to demonstrate a certain level of permanence, meaning that a carbon project needs to persist for a certain amount of time. Especially for mangrove restoration projects conducted outside of seawalls, which are more prone to erosion, it would need to be determined whether they would pass such a permanence test. The overall best placement for a project thus needs to be considered at the onset. For example, projects on set-back sites may have a greater chance on longevity than projects in front of sea walls, yet they may also be smaller in scale and thus provide less overall area for which credits can be secured. In addition, it will need to be determined whether the historic rates of loss of mangroves along the NBS can give an indication of future rates, especially given that national land use plans highlight both risk of development on the coastal plains with sea level rise, and yet also the opportunity to increase agricultural and urban development in these areas.

There has been strong interest in restoring mangroves in Guyana, and multiple restoration efforts have been implemented under the Guyana Mangrove Restoration Project, with differing success. Some restoration sites successfully transitioned to young stands while others were washed away due to strong storm events. The cost of implementation could be quite high, ranging from $25k to $100k USD ha-1 ($5.2 to 20.8 million GYD / $186,450 to $745,800 SRD; Lewis III 2005). The best and most economical approach along the NBS, taking into consideration the size and dynamic nature of the muddy system, is to conserve mangrove patches and maintain the freshwater connections with coastal freshwater swamps so that the ability for natural regeneration can be maintained (Anthony and Gratiot 2012). Yet, regeneration of the mud bank – interbank system, which ultimately governs the stability and persistence of coastal mangrove stands, may take decades to re-establish in zones where mangroves have been eradicated (Gratiot et al. 2008).

The assessment of carbon storage and emissions presented here is limited to mangroves, despite the knowledge that coastal freshwater swamps in Suriname and Guyana have the potential to sequester soil carbon for a longer period than mangroves, likely to a greater depth as well, and are also more at risk of loss due to growing pressures from urban growth, aquaculture and agriculture. Few data are available, however, regarding how much carbon is produced and stored by NBS coastal freshwater swamps and what are the rates of loss and types of conversions. Future research into these data needs would be beneficial to provide more insight into expanded carbon project capabilities along the NBS.

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

Restoration Blue Carbon Offset 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 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.

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

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.

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.

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. 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.

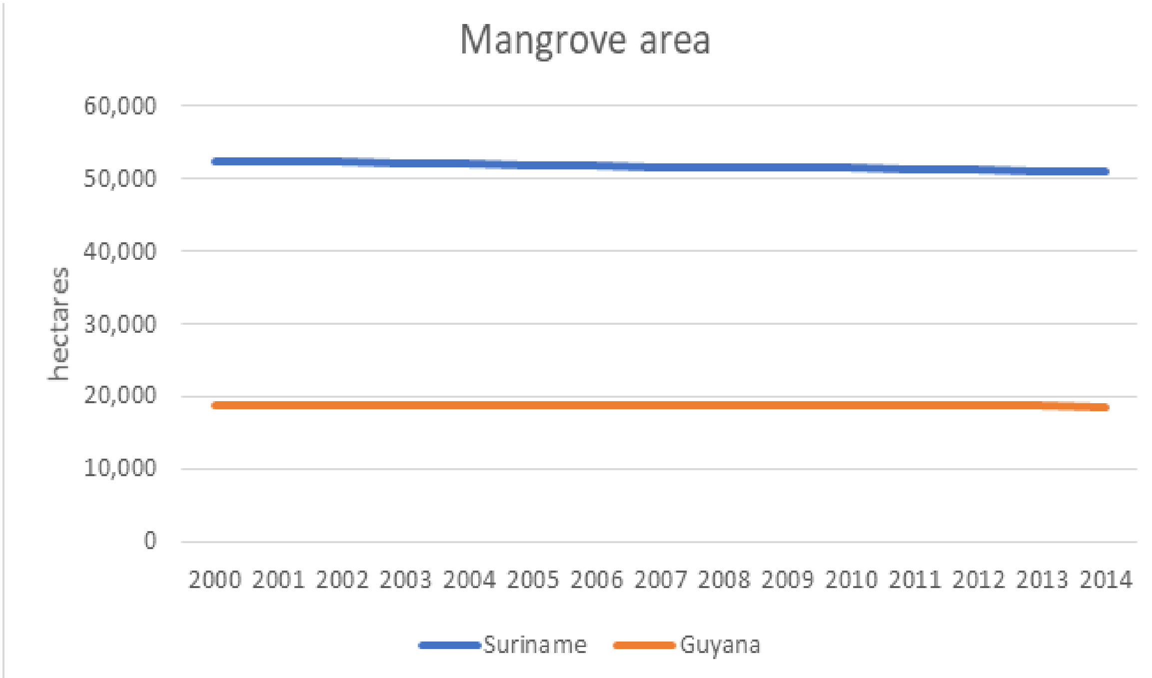
A value for percent change in mangrove area for each country was calculated as follows:

Guyana:

((-0.02% /yr) + (-3.84% /yr))/2= -1.96% /yr

Suriname:

((-0.2% /yr) + (-1.31% /yr))/2= -0.76% /yr



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

Characterizing the mangrove ecosystem services in Guyana and Suriname

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,

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.

For the coastal protection benefit of mangroves, we reviewed of the relevant scientific literature 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).

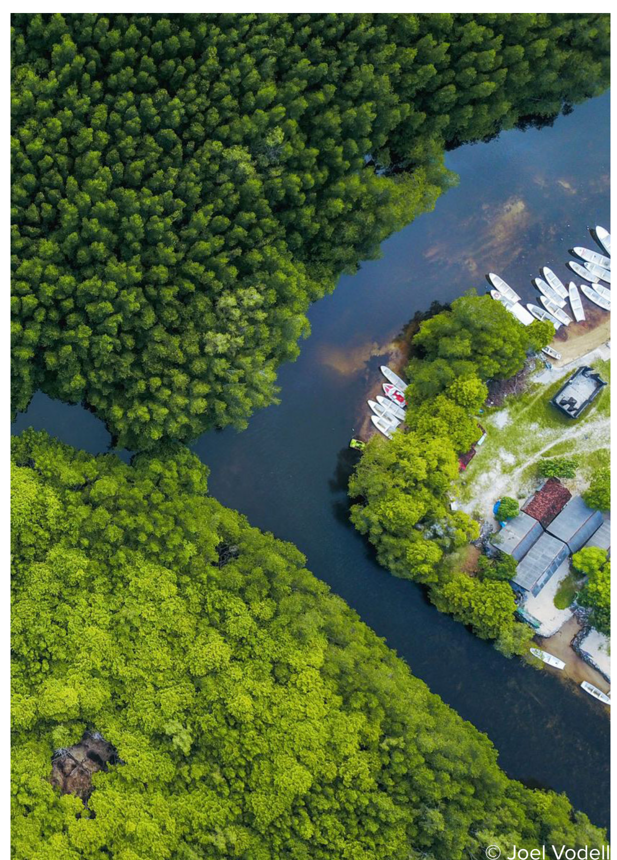
To facilitate future analyses, examples for benefit relevant indicators are provided as a first step toward economic valuation, and ecosystem services are matched to the appropriate economic valuation method from the literature. Using the ecosystem services conceptual model adopted to mangroves on the 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.

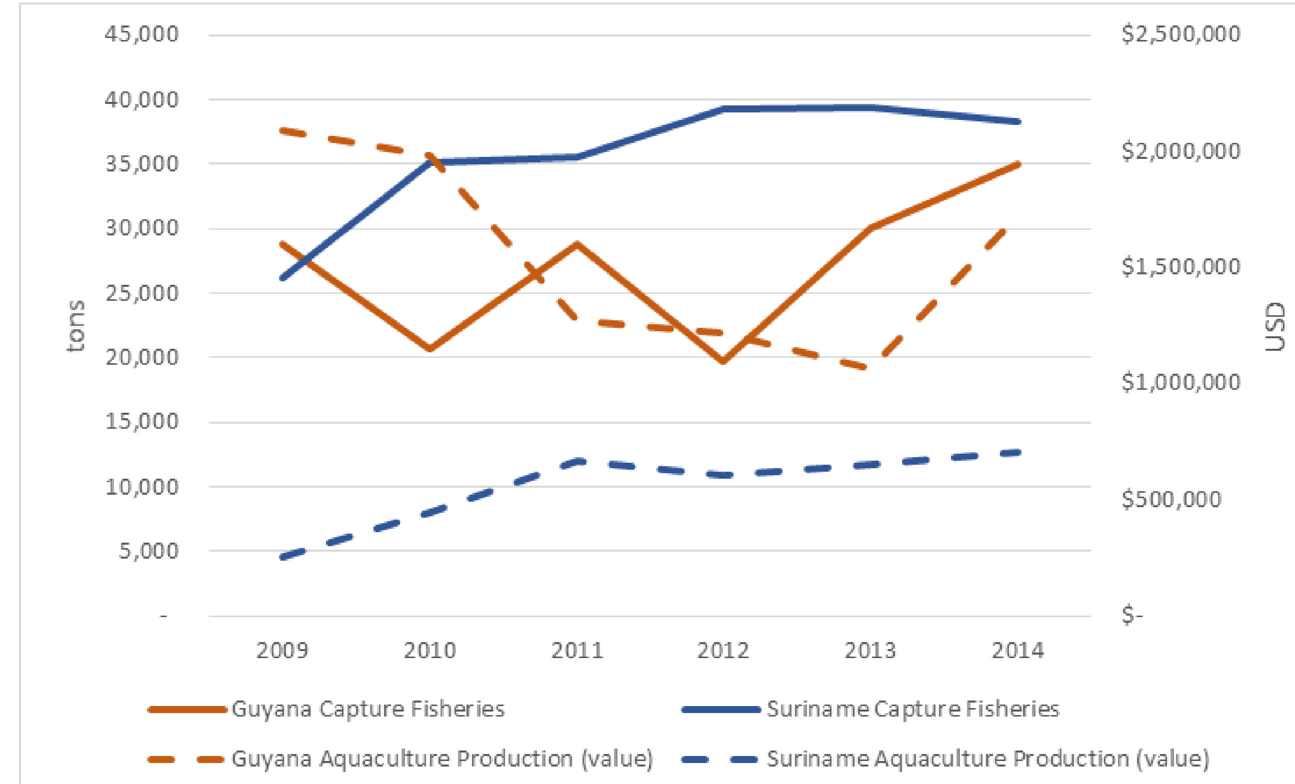
As an example for an ecosystem service provided by mangroves, capture fisheries and aquaculture are on a steady growth trajectory in both Guyana and Suriname, making them the top two countries in the CARICOM region for fisheries production. Capture fisheries' contribution to GDP was calculated at 1.8 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.





Capture fishery production volume and value of aquaculture production over time.

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