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Impacts of Climate Change on Mangrove Ecosystems in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS)

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EXECUTIVE SUMMARY

What is already happening?

Caribbean mangroves have declined by approximately 24% over the last quarter-century, largely as a result of different forms of coastal development, pollution and human exploitation.

A review of the literature that considers mangroves in the context of climate change reveals it is often challenging to distinguish what is an *observed* climate related change occurring in the present versus what is a *predicated* change that may occur in the future, and some studies interchange the two.

Sea level rise (which causes saline intrusion, coastal erosion and destruction of primary habitat) is currently the most immediate and well understood climate-related threat to mangroves in Caribbean SIDS. A growing number of studies are also demonstrating greater understanding of the impacts of hurricanes, and the ability of mangroves to recover from these extreme weather events.

What could happen in the future?

Climate change is expected to impact mangroves in Caribbean SIDS through a variety of mechanisms, including, but not limited to: sea level rise; increases in atmospheric CO_2; rise in surface temperatures; changes in precipitation; and a predicted increase in the frequency and severity of extreme weather.

Mangroves in Caribbean SIDS are at a high risk of negative impacts due to climate change. In addition to facing continual sea level rise, climate models predict that over the next century the Caribbean will experience: 1) a *very likely* rise in sea surface temperature; 2) a *very likely* decrease in precipitation; and 3) a *likely* increase in hurricanes and other extreme weather.

The cumulative impacts of climate change - especially sea level rise, decreasing rainfall, an increase in extreme weather and loss of protection from waves and storms provided by nearby coral reefs - are expected to cause a significant decline of mangrove ecosystems, and the many ecosystem services and economic values that mangroves provide to people, throughout Caribbean SIDS in coming decades.

Introduction

Mangrove status, values and threats

A globally rare yet highly threatened coastal forest ecosystem, mangroves cover approximately 137,760 km^2 – 152,360km^2 of the world's surface (Kainuma et al., 2013). A total of 73 mangrove species and hybrids are dispersed across 123 countries and territories around the globe (Spalding et al., 2010).

Four mangrove species—*Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemose* and *Conocarpus erectus*—are found throughout the Wider Caribbean. An additional five species occur in smaller ranges dispersed across different countries and territories in the region (Ellison and Farnsworth, 1996).

Mangroves are trees or large shrubs that have adapted to exist in harsh environmental conditions. Their evolution has forged

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unique survival features in the face of high salinity, anaerobic and waterlogged soils, and a challenging environment for seed dispersal and propagation (Spalding et al., 2010). Moreover, mangrove ecosystems are a haven for biological diversity and research continues to show critical interdependencies with nearby marine ecosystems such as seagrass beds and coral reefs (Nagelkerken et al., 2001; Mumby et al., 2004; Dorenbosch et al., 2006; Harm et al., 2008; Nagelkerken et al., 2008).

Mangroves provide numerous ecosystem services that contribute to human wellbeing (Vegh et al., 2014; Van Bochove et al., 2014; Friess, 2016) and may be threatened by climate change. Around the globe mangroves enhance coastal fisheries, sequester carbon, provide provisions to local inhabitants, filter nutrients and sediment, support tourism and protect coastlines and coastal communities from waves and extreme weather, among other values (Mukherjee et al., 2014). In the Caribbean, particularly in small island developing states (SIDS), mangroves provide numerous commercial and subsistence goods, serve as a natural form of coastal protection and resilience, and support a range of marine and coastal tourism enterprises (Table 1) (Brown et al., 2007).

Table 1. Important mangrove values in the Caribbean

Removal of anthropogenic pollutants from inland surface water flows and development	Water quality protection and sediment load reduction for nearby seagrasses and coral reefs
Breeding, feeding and nursery habitat for fish and other terrestrial and marine species	Shoreline stabilization, wave and wind reduction, and protection from extreme weather
Nutrient export to nearby ecosystems such as coral reefs and seagrasses	Long-term sequestration and storage of atmospheric carbon
Support for artisanal fishing and collecting grounds (e.g., fish, crabs, wood etc.)	Support for coastal tourism enterprises and sustainable livelihoods for local residents

Adapted from Brown et al., 2007 and Van Bochove et al., 2014

What is Already Happening?

Anthropogenic threats and impacts to mangroves

Studies show that the loss of mangroves around the world has been severe over the last several decades, including in the Caribbean. According to the United Nations Food and Agriculture Organization (FAO), approximately 35,600km^2 (3,560 hectares) of mangroves were cleared or otherwise destroyed between 1980 and 2005 (FAO, 2007). A recent compilation of global research suggests that more than 25% of the world's original mangrove cover is gone (Spalding et al., 2010; Van Bochove et al., 2014). Mangroves found across the Caribbean have declined by approximately 24% over the last quarter-century (Polidoro et al., 2010).

Most anthropogenic (human-caused) drivers of mangrove destruction and degradation are the result of land use activities near human population centres along the coastal zone. Globally, the primary and emergent anthropogenic threats to mangroves include (Spalding et al., 2010; Van Bochove et al, 2014):

- Coastal development (e.g., roads, ports and marinas, urban growth and tourism accommodations)
- Agriculture and aquaculture
- Pollution and environmental degradation
- Local exploitation (e.g., wood for cooking or building)
- Rising seas due to climate change.

In the Caribbean, Bacon (1993) and Ellison and Farnsworth (1996) identified five categories of anthropogenic disturbance to mangroves back in the 1990s, including the emergence of climate change:

- Disturbance resulting from extractive uses of mangrove trees and mangrove fauna
- Disturbance resulting from changes in upland hydrology due to construction
- Pollution of mangroves
- Destruction of mangroves associated with reclamation for non-extractive uses
- Impacts of climate change resulting from increases in CO_2 and sea level rise.

The greatest immediate threat to mangroves comes from different forms of coastal development, pollution and human exploitation. Although global losses decreased when comparing the 1980s (≈1.04% per year) to the 2000 – 2005 time period (≈0.66% per year), mangroves are still destroyed at a rate three to five times faster than any other forest type (Spalding et al., 2010). That said, one comprehensive study of mangroves notes that climate change may prove to be the ultimate anthropogenic disturbance factor, resulting in a maximum loss of 10 – 15% of mangrove ecosystems globally (Alongi, 2008).

Mangroves in the context of a changing climate

Mangroves are well studied the world over. A vast amount of literature exists on mangrove ecology, ecosystem service values, threats and most recently, quantified economic and carbon-based values (blue carbon). Beginning around the late 1980s, as evidence grew demonstrating global warming, a growing body of research has explored, and attempted to predict, how mangroves around the world, including in the Caribbean, will respond to and persist in a changing climate.

A review of the scientific literature that considers mangroves in the context of climate change reveals that it is often challenging to distinguish what is an *observed* change occurring in the present versus what is a *predicated* change that will occur in the future, and some studies interchange the two (Nurse et al., 2014). Several studies offer predictive analyses of what may happen to mangroves as the planet warms, sea level rises, and the chemical composition of the atmosphere and oceans changes (Alongi et al., 2007; Gilman et al., 2008; Record et al., 2013; Nitto et al., 2014; Lugo et al., 2014; Alongi, 2015; Short et al., 2016).

According to the 5th Assessment Report prepared by the Intergovernmental Panel on Climate Change (IPCC-AR5), specifically the small islands chapter (Nurse et al., 2014), the key climate and ocean drivers of change that are expected to impact mangrove ecosystems in Caribbean SIDS include the following:

- Variations in air and ocean temperatures
- Ocean chemistry
- Rainfall
- Wind strength and direction
- Sea levels and wave climate (especially extremes such as hurricanes, drought and storm surges).

It is also important to note that threats and associated impacts posed by climate change to mangroves in Caribbean SIDS cannot be considered in isolation from the many other anthropogenic stressors, described above, that have already, and continue to, negatively impact coastal ecosystems throughout the region (Day, 2009). The cumulative impacts of a wide range of coastal disturbances across the Caribbean therefore present challenges in making precise attribution of specific impacts to mangroves as a results of climate change, even if this is the case (Nurse et al., 2014; National Academies, 2016).

Describing what is already happening and what may happen in the future

Some specific *observed* trends and mangrove responses relative to habitat stability in the context of sea level rise (SLR), both from the deep past and in the present, are described below. Both historical and present day evidence provides a lens into "what is already happening" to mangroves in Caribbean SIDS, while at the same time offering insight into potential future impacts and the adaptive capacity of mangrove ecosystems.

Additional *predicted* impacts associated with climate change - including mangrove responses to SLR, increased carbon dioxide (CO_2), precipitation changes, temperature increases, and storminess and extreme weather events - are, based on the forward-looking nature of most studies, described in the "what may happen in the future" section later in this document.

Of note, this paper does not suggest that climate change is not already impacting mangroves through the variety of aforementioned mechanisms, instead of simply through SLR. As scientists continue to study and improve our understanding of mangroves in the context of a warming climate, many of the topics considered as potential future impacts may be confirmed to already be occurring in the present.

Sea level rise

SLR is occurring throughout the world due to thermal expansion of ocean water and melting of the polar ice caps. It is estimated that between 1901 and 2010, global mean sea level increased overall by 0.19 ± 0.02 metres (IPCC, 2013). According to the small islands chapter of the IPCC AR5 report, SLR poses one of the greatest and most widely researched threats to coastal ecosystems like mangroves (Nurse et al., 2014).

Mangroves in tropical and sub-tropical Caribbean SIDS are particularly susceptible to SLR given that: 1) they flourish largely in the intertidal zone; 2) they commonly have limited opportunity to move landward due to terrestrial space constraints, sediment poor environments and existing human structures and land uses in the coastal zone; and 3) changes in SLR can cause sediment erosion, inundation stress and increased salinity in mangrove habitat (Ellison, 1994; Day, 2009; Ward, 2016).

Nurse et al., (2014) note that, "over much of the 20th century, global mean sea level rose at a rate between 1.3 and 1.7 millimetres yr^{-1} and since 1993, at a rate between 2.8 and 3.6 millimetres yr^{-1} and acceleration is detected in longer records since 1870." That said, rates of SLR have not been consistent across the globe; some regions have shown higher than average SLR. Palanisamy et al., 2012, "found that over the last 60 years the mean rate of SLR in the Caribbean region was similar to the global average of approximately 1.89 mm yr^{-1}" (Palanisamy et al., 2012, cited in Nurse et al., 2014).

Mangrove responses to sea level rise

A small number of seminal studies have demonstrated *observed* trends in mangrove responses to SLR by examining stratigraphic layers from the Holocene, thereby reconstructing the past existence of mangrove ecosystems in different parts of the world. Others have looked at how environmental processes contribute to vertical accretion of soils and elevation change in mangroves, and how mangroves may or may not be able to keep pace with SLR in the coming years.

In a pioneering set of studies, Ellison and Stoddart (1991) and Ellison (1993) reconstructed ancient mangroves in small islands in the Caribbean, Pacific and Indian oceans. One particular study reviewed the stratigraphic record along Hungry Bay in Bermuda, just north of the Eastern Caribbean, and determined how well mangrove ecosystems kept pace with SLR several thousand years ago. Similar reconstruction of Holocene mangroves was conducted in the Cayman Islands and Tonga, in the south Pacific. Collectively these studies infer that coastal mangroves on small islands in the Caribbean and elsewhere - faced with saltwater inundation, erosion and resulting loss of peat, and limited soil accretion in the face of changing environmental conditions - may not be able to keep pace with the rate of projected future SLR over the next century due to climate change.

For example, Ellison (1993) revealed that, in Bermuda, mangroves which existed during the Holocene were able to move landward and persist with SLR of 8 – 9 centimetres per 100 years. That said, mangroves could not persist if SLR exceeded 12 centimetres per 100 years. In a follow-up study, Ellison noted that mangroves in low-relief islands that lack major rivers, like Caribbean SIDS, were especially vulnerable to SLR based on the presence of sediment poor environments and limited topography that would therefore prevent landward migration in the face of increasing SLR (Ellison, 1993). Other modern day studies, however, have cited research from Key West, Florida, which demonstrates that mangroves have been able to keep up with a more rapid rate of SLR in recent decades, thereby offering a contrasting view of mangrove resilience to rapidly changing environmental conditions (Alongi, 2008).

Another study in the Pacific observed landward migration of island mangroves in Fiji over the course of four decades, and surmised that SLR is causing the migration (Gilman at al., 2005). This study—as well as studies conducted by Ellison and Stoddart (1991, 1993) and others cited in Alongi (2008)—demonstrate observed trends from the near and distant past that inform how mangroves in Caribbean SIDS may or may not be able to adjust to SLR in the coming decades. As such, they are both *observational* and *predictive* in nature.

In the Caribbean, McKee et al., (2007; 2011) considered the linkages between habitat stability of mangroves in Belize and Florida with the maintenance of soil elevation as it relates to SLR. These studies examined how biological processes contribute to vertical accretion of soils and elevation change in mangroves. These studies demonstrated that the production of roots and formation of benthic mats play a central role in accretion and elevation change in Caribbean mangroves, and are therefore important considerations in determining how to sustain these types of coastal ecosystems in the face of projected future SLR. Again, these findings present another *observed* trend—evidence of "what is happening now" in the field—which provides further insight into how some mangroves are adapting to SLR in the Caribbean, and may continue to adapt in the future.

A more recent review of climate change impacts on mangrove ecosystems (Alongi, 2015)—in citing studies by McKee (2011), Krauss et al., (2013) and a comprehensive review of the SLR issue as it relates to mangroves (McIvor, 2011)—suggests that deep peat deposits provide strong evidence that, in some Caribbean and other locations in the past, landward migration of mangroves did indeed keep pace with SLR. At the same time, these and other studies also show that there is a threshold in which mangroves cannot keep pace with SLR and will, if this threshold is crossed, not survive (Alongi, 2015).

What Could Happen?

A substantial body of scientific literature over the last three decades considers mangroves in the context of climate change. Generally, most studies focus on existential climate change threats and predicted future impacts; development of vulnerability assessment and monitoring methodologies; or management considerations linked to adaptation, mitigation and building resilience in coastal environments.

In recent years, a growing number of studies have described the multitude of ecosystems services and economic values which mangroves provide, including methods for assessing such values. These studies have provided insight into which values may be lost due to climate change, and what the resulting negative impacts will be on society, especially in nations like Caribbean SIDS which are disproportionately dependent on healthy, functioning coastal ecosystems (see socio-economic impacts section below).

A review of peer reviewed and other published literature, which explores the nexus of mangroves and climate change, as noted above, reveals it is often challenging to distinguish what is an *observed* change in mangroves linked to climate change in the present versus what is a *predicated* change that may occur in the future (Nurse et al., 2014). Specific climate change threats to mangroves, with associated impacts predicted to occur in the future, including in Caribbean SIDS, are described below and generally fall under the following topics:

- Sea level rise
- Increase in atmospheric carbon dioxide
- Rise in surface temperature
- Changes in precipitation
- Storminess and extreme weather events
- Impacts to nearby ecosystems
- Ocean acidification

Sea level rise

For reasons highlighted above, SLR poses perhaps the greatest climate change associated threat to mangroves in Caribbean SIDS. Several studies look to the Holocene, while others explore the potential for future habitat stability in the face of SLR, to demonstrate observable impacts and other evidence that informs scientific thinking on how mangroves may or may not be able to cope with present and future rates of SLR (Ellison and Stoddart, 1991; Ellison, 1993; Gilman at al., 2005; McKee et al., 2011; Krauss et al., 2013; Cohen et al., 2016).

The IPCC AR5 report predicts average annual SLR between 1.8 – 2.4 millimetres globally (Change et al., 2013). Under this scenario, one study predicts that mangroves in low islands like Caribbean SIDS will decline as there is little to no geographic space for inward terrestrial migration (Alongi, 2015). A relatively new device, known as the Rod Surface Elevation Table (RSET), allows for high-precision measurement of sediment elevation in mangroves (Cahoon et al., 2002). One comprehensive study evaluated mangrove surface elevation dynamics around the world using the RSET method and concluded that fringing mangroves in small islands, like Caribbean SIDS, may be more vulnerable to SLR than basin mangroves found in mainland areas (Sasmito et al., 2016). This study also suggested that more mangrove surface elevation monitoring is needed around the world in order to better understand how mangroves may or may not be able to keep pace with predicted SLR.

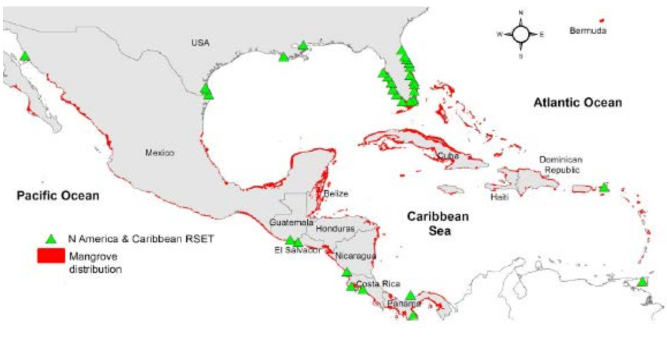


Figure 1: Distribution of mangroves and locations of mangrove RSETs in North America and the Caribbean. Data derived from Giri et al. (2011a). Source: Ward et al., 2016.

Increase in atmospheric carbon dioxide (CO_2)

CO_2 directly affects growth and productivity in plants. Higher concentrations of CO_2 in the atmosphere may enhance productivity and water efficiency among mangroves, though laboratory research suggests that different species may respond in different ways (Ellison, 1994; Field, 1995; Ellison and Farnsworth, 1996). One study demonstrated measurable benefits of elevated CO_2 on a common Caribbean species, *Rhizophora mangle*, in terms of growth and reproduction (Ellison and Farnsworth, 1996).

Although elevated CO_2 in the atmosphere is problematic in that it contributes to SLR, some research suggests that higher levels of CO_2 may strengthen the ability of mangroves—through enhanced biological processes such as root production and soil accretion—to move to higher ground as SLR inundates primary habitat in the intertidal zone (Cherry et al., 2009). This kind of research may inform modelling that helps predict how mangroves may or may not be able to keep pace with SLR in the future.

Understanding the effect of higher concentrations of CO_2 on mangroves, including in Caribbean SIDS, is a topic that needs further research before clear conclusions about long-term impacts can be drawn (Gilman et al., 2008; Alongi, 2008). A recent review of available data suggests that mangrove responses to elevated atmospheric CO_2 will be complex, as well as species and site-specific. Some species are expected to thrive, while others will decline (Alongi, 2015).

Rise in surface temperature

Mangroves generally thrive within a temperature range of 15 – 25°C. Considered in tandem with elevated CO_2 levels, a rise in atmospheric temperature may increase mangrove productivity (Ellison, 1996). One global review of the impact of climate change on mangroves demonstrates that temperature increases may already be leading to mangrove expansion into higher latitudes around the globe (Alongi, 2015). According to Gilman et al., 2008, citing work by Field, 1995 and Ellison, 2000, "increases in surface temperature [including in the Caribbean region] are expected to affect mangroves in the following ways:

- Changing species composition;
- Changing phenological patterns (e.g., timing of flowering and fruiting);
- Increasing mangrove productivity where temperature does not exceed an upper threshold;
- Expanding mangrove ranges to higher latitudes where range is limited by temperature, but is not limited by other factors, including a supply of propagules and suitable physiographic conditions."

Although temperature increases are projected to cause greater impacts to emergent wetland plants in higher latitudes, the projected increases for the period 2016 – 2035 in the IPCC AR5 report—*likely* in the range of 0.3°C to 0.7°C (*medium confidence*)—will nonetheless stress coastal vegetation, including mangroves, throughout the tropical and sub-tropical Caribbean region. Combined with what is projected to be an increase in ocean temperatures of 0.1°C per decade, temperature driven impacts may result in cascading negative effects on coastal fringing mangroves, a common habitat type in Caribbean SIDS (Short et al., 2016).

Changes in precipitation

Lack of rainfall, as well as SLR or groundwater depletion, can lead to high salinity in mangrove environments. A decrease in rainfall may reduce the geographic area where mangroves grow. Conversely, an increase in rainfall may lead to an expansion of mangrove ecosystems, including into new, previously un-colonised zones. This is largely due to the fact that precipitation helps ensure flushing of soils and sediments, thereby minimizing the degree of salt stress faced by mangroves (Ellison, 1994). Some comprehensive reviews of potential climate change impacts on mangroves suggest that reduced rainfall may actually contribute to mangroves overtaking some salt marsh environments (Gilman, 2008; Alongi, 2015).

One study, focused on Florida and the Caribbean, considered the impacts of SLR, combined with precipitation changes, and predicted how, cumulatively, these impacts affect sediment build-up and salinity in mangrove habitats. The study hypothesized that, under a SLR scenario that also includes reduced rainfall and associated runoff, mangroves would experience high salinity and saltwater intrusion, thereby decreasing overall productivity. Conversely, higher rainfall and runoff would result in less salinity and intrusion. This would increase productivity and help maintain sediment elevation in the face of SLR (Snedaker, 1995).

Average precipitation records in the Caribbean from 1900 – 2000 demonstrate a consistent reduction of rainfall of 0.18 millimetres per year^{-1} (Nurse et al., 2014, citing Jury and Winter, 2010). Looking to the future, the IPCC AR5 report projects with medium confidence that precipitation will decrease in the Caribbean region over the coming century (IPCC, 2013). One study, citing several others, notes that predicted changes in rainfall can be expected to alter local salinity, and, ultimately, affect species composition, diversity and the interaction between mangroves and other coastal vegetation. Based on the IPCC projections of reduced rainfall over time in the Caribbean, this same study notes that reduction in mangrove cover may occur in the latitudes where many Caribbean SIDS lie (Short et al., 2016).

Storminess and extreme weather events

Mangroves in the Caribbean have long been susceptible to degradation and impaired ecosystem function caused by extreme weather events such as hurricanes and tropical storms (Walker, 1991; Lugo, 2000; Cahoon et al., 2003; Vanselow K.A. et al., 2007; Calderon-Aguilera et al., 2012). Some studies document the pace and extent of mangrove recovery in Caribbean SIDS following hurricanes—including in the Bay Islands of Honduras and offshore cays in Belize—and note mixed results depending on the extent of damage caused by wind, sediment shifts and storm surges (Cahoon et al., 2003; Piou et al., 2006; Vanselow K.A. et al., 2007).

Some question the longstanding claim that a central ecosystem service value which mangroves provide is protection from wind and storm surges caused by hurricanes and other extreme weather events, noting that past claims are commonly based on observational evidence versus empirical testing (Alongi, 2008). However, recent research demonstrates that mangroves attenuate wave energy (McIvor et al., 2012) and protect coastlines from storms, as well as from SLR, saline intrusion and erosion (Barbier, 2016). In addition, as noted above, mangroves in Caribbean SIDS serve as a nursery ground for fish and habitat for numerous species; provide commercial and subsistence goods to local populations; and support a range of marine and coastal tourism enterprises (Mumby, 2004; Brown et al., 2007; Nagelkerken et al., 2008).

A growing body of research suggests that extreme weather events may increase in scale and frequency in the Atlantic and Caribbean regions as global temperatures continue to rise (Bender et al., 2010; IPCC, 2013; Ward, 2016). Moreover, the science on this issue has advanced to the point that researchers are increasingly able to make quantitative statements about how climate change has influenced specific weather events (National Academies of Sciences, Engineering and Medicine, 2016). As extreme weather events increase in scope, intensity and occurrence due to climate change, the many ecosystem services and economic values that mangroves provide in Caribbean SIDS will be threated and may decrease in value over time as the overall health of mangroves in the coastal zone declines (Lewsey et al., 2003; Barbier, 2016).

Table 2. Additional mangrove/climate resources for select Caribbean small island developing states.

Country	*Studies*
Antigua and Barbuda	FAO Global Forest Resources Assessment: Country Report – Antigua and Barbuda Lindsay and Horwith. 1997. A Vegetation Classification of Antigua Barbuda Redonda: Implications for Conservation. Island Resources Foundation, Eastern Caribbean Program – Biodiversity Publication #2.
Belize	FAO Global Forest Resources Assessment: Country Report – Belize The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for Belize State of the Belize Coastal Zone 2003-2013. Belize Coastal Zone Management Institute and Authority
Dominica	FAO Global Forest Resources Assessment: Country Report – Dominica The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for Dominica
Grenada	FAO Global Forest Resources Assessment: Country Report – Grenada The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for Grenada Moore, G.E.; Gilmer, B.F., and Schill, S.R. 2015. Distribution of mangrove habitats of Grenada and the Grenadines. *Journal of Coastal Research*, *31*(1), 155–162. Greg Moore. 2014. Assessment of the Mangrove Ecosystem of Tyrrel Bay, Carriacou (Grenada) West Indies. Prepared for The Nature Conservancy – Eastern Caribbean Program. Greg Moore. 2014. Response of a Storm-Damaged Mangrove System to Restoration Planting, Carriacou (Grenada) West Indies. Prepared for The Nature Conservancy – Eastern Caribbean Program.
Guyana	FAO Global Forest Resources Assessment: Country Report – Guyana Pastakia. 1991. A Preliminary Study of Mangroves in Guyana. Consultancy report for the European Community. Da Silva. 2015. Mutual Benefits from Mangrove Reserves in Guyana: Coastal Protection and Avifaunal Habitats. *International Journal of Science, Environment and Technology*, Vol. 4, No 4, 2015, 924 – 933. Anthony and Gratiot. 2012. Coastal engineering and large-scale mangrove destruction in Guyana, South America: Averting an environmental catastrophe in the making. *Ecological Engineering* 47. 268– 273.
Jamaica	FAO Global Forest Resources Assessment: Country Report – Jamaica The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for Jamaica
Saint Lucia	FAO Global Forest Resources Assessment: Country Report – St. Lucia The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for St. Lucia
St. Vincent and the Grenadines	FAO Global Forest Resources Assessment: Country Report – St. Vincent and the Grenadines The CARIBSAVE Climate Change Risk Atlas (CCCRA) – Climate Change Risk Profile for St. Vincent and the Grenadines Moore, G.E.; Gilmer, B.F., and Schill, S.R., 2015. Distribution of mangrove habitats of Grenada and the Grenadines. Journal of Coastal Research, 31(1), 155–162.

Impacts to nearby ecosystems

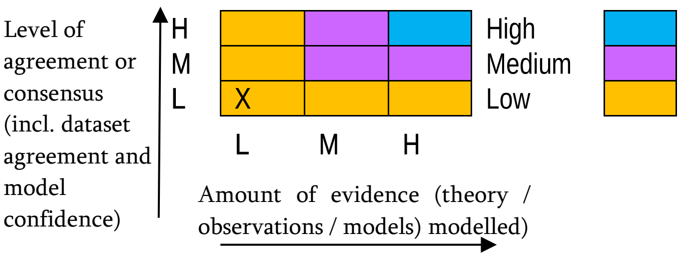
Due to critical interdependencies, climate change impacts to nearby ecosystems may lead to loss of protective services for mangroves. For example, predicted impacts to coral reefs - including coral bleaching and degradation of reef structure as a result of ocean acidification - may limit the protection these ecosystems provide from waves and storm surge, and thereby further exacerbate the degradation and decline of coastal mangroves in Caribbean SIDS (Nurse et al., 2014).

Ocean acidification

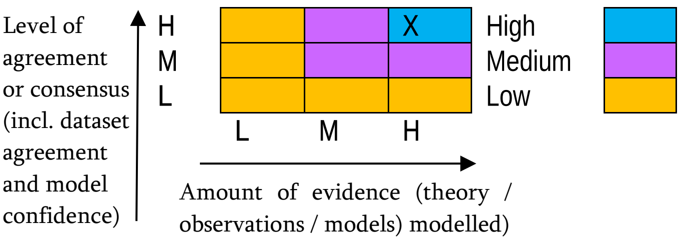
As the world's oceans absorb CO_2, the process of hydrolysis increases the potential of hydrogen (pH) of seawater. One recent study considered whether or not mangroves are drivers of ocean acidification or a buffer against it. This study determined that the export of dissolved inorganic compounds and alkalinity from six pristine mangroves creeks in Australia created a measurable increase, locally, in the coastal ocean pH, suggesting that mangroves may partially counteract ocean acidification in tropical waters (Sippo et al., 2016).

Confidence Assessment

What is already happening?



What could happen in the future?



What is already happening?

- Limited observed trends, whether from the past or in the present, in which impacts to mangroves around the world and in Caribbean SIDS can be directly attributed to climate change
- Most studies framed as predictive analyses of what could happen in the future
- Significant knowledge gaps cited in many studies

What could happen in the future?

- Most studies framed as predictive analyses of what could happen in the future
- Relatively strong understanding of the effects of climate change associated impacts on emergent wetland ecosystems like mangroves, for example:
- SLR – saline intrusion, erosion and destruction of primary mangrove habitat
- CO2 – Predicted long-term CO2 increases with mixed effects on Caribbean mangroves
- Precipitation – Predicted decreases in long-term rainfall patterns for the Caribbean
- Temperature rise – Predicted temperature increases with mixed effects on Caribbean mangroves
- Storminess/extreme weather – Erosion, inundation and destruction of coastal ecosystems
- Impacts to nearby ecosystems – decline of protective services offered by coral reefs
- Ocean acidification – Mangroves may serve as a partial buffer against tropical ocean acidification

Knowledge Gaps

It is unclear whether or not consensus exists on the knowledge gaps listed below. Each is listed based on the frequency that the subject was discussed, whether directly or indirectly, in peer reviewed and other published literature, as well as from recommendations by reviewers of this paper.

1. Studies/models are needed that examine a range of factors (e.g., SLR, CO_2, temperature, nearshore depth etc.) and their interactions on mangrove response. In addition, given that mangrove response is highlight dependent on site specific variations, studies/models are needed that assess a wide range of situations/scenarios.
2. Additional research and application of available tools (e.g., RSET method) is needed to further describe how biological processes contribute to vertical accretion and elevation change, and thus the ability of Caribbean mangroves to keep pace with SLR.
3. Locally led efforts are needed that apply the most recent, sophisticated mangrove vulnerability assessment methodologies in Caribbean SIDS.

Socio-economic Impacts

There are a limited number of studies which ascribe specific monetary values to mangroves, including some cited below. Moreover, some of these studies look at a combined value of all tropical coastal ecosystems such as mangroves, seagrasses and coral reefs, versus considering mangroves alone. Given the many well-established ecosystem services and economic values that mangroves possess for people and nature, these studies offer a starting point to infer socio-economic impacts that will be incurred in Caribbean SIDS from the further loss and degradation of mangrove ecosystems due to climate change.

Van Bochove et al., (2014) estimate that the continued loss of mangroves around the world, including in the Caribbean, threatens countless species that depend on these ecosystems and may negatively impact up to 100 million people living in the coastal zone.

Wells et al. (2006) estimate the annual economic value of mangroves, by the cost of products and services they provide, at USD $2000,000 - $900,000 ha-1.

Lewis (1989) estimates the cost of restoring destroyed or degraded mangroves at USD $225 - $216,000 ha-1.

A World Resources Institute study estimates that mangroves contribute USD $74 – $209 million annually to the Belize economy (Cooper et al., 2008).

Conservation International estimates that the incremental benefits of the coral reefs and mangroves in Jamaica's Portland Bight Protected Area are $52.6 million in present value terms for an optimistic tourism scenario, and $40.8 million in a pessimistic tourism case, calculated over a 25-year period and at a 10% discount rate (CI, 2008).

Current trends show that the process of economic valuation is continually advancing, which gives researchers - at a local, national, regional or even global scale - tools and methodologies for assessing quantitative and qualitative value of mangroves (Vo, 2012; Mukherjee, 2014; Waite et al., 2014; Barbier 2016). This is particularly important given the role that coastal ecosystems play in sustainable economic development and poverty alleviation in Caribbean SIDS. In addition, some studies are beginning apply "payment for ecosystem service" methodologies and "blue carbon" values as a means to better understand the natural and socioeconomic values of mangrove ecosystems, and inform public policy and resource management (McLeod et al., 2011; Mitra, 2013; Locatelli et al., 2014; Friess, 2016; Sappal et al., 2016).

Finally, comprehensive methodologies have been developed to assess the vulnerability of mangroves to climate change, which can be applied in Caribbean SIDS and thereby help local stakeholders and policy makers better understand the socioeconomic costs associated with climate change impacts on mangroves (Faraco, 2010; Ellison, 2014; Osland et al., 2015).

Groups and individuals working at the nexus of climate change and mangroves:

- Caribbean Natural Resources Institute (CANARI)
- University of the West Indies
- United Nations Environment Programme – World Conservation Monitoring Centre
- World Resources Institute
- Caribbean Community Climate Change Centre
- Marine Climate Change Impacts Report Card
- Global Forest Watch
- World Resources Institute Mangrove Blog
- Planetsave
- Mangroves for the Future

Dr. Joanna Ellison, University of Tasmania (pers. comm.) Dr Ellison suggested that graduate students in the Caribbean could come and study in Tasmania and learn how to apply mangrove vulnerability assessments in the Caribbean.

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References

Alongi, D.M. (2008). Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science*, 76(1), 1-13.

Alongi, D.M. (2015). The impact of climate change on mangrove forests. *Current Climate Change Reports*, *1*(1), 30-39.

Bacon, P. R. (1993). Wetland restoration and rehabilitation in the Insular Caribbean. *Waterfowl and wetland conservation in the 1990s—a global perspective. IWRB, St. Petersburg, Florida*: 206-209.

Bender, Morris A., Thomas R. Knutson, Robert E. Tuleya, Joseph J. Sirutis, Gabriel A. Vecchi, Stephen T. Garner, and Isaac M. Held. (2010). Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. Science 327, no. 5964: 454-458.

Brown, Nicole, Tighe Geoghegan, and Yves Renard. (2007). A situation analysis for the wider Caribbean. Gland, Switzerland: IUCN: 52.

Waite et al., (2014). Coastal capital: ecosystem valuation for decision making in the Caribbean. World Resources Institute.

Cahoon, D.R., Lunch, J.C., Perez, B.C., Segura, B., Holland, R.D., Stelly, C, and Hensel, P. (2002). High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. Journal of Sedimentary Research, 72(5), 734-739.

Cahoon, D.R., Hnesel, P., Rybczyk, J., McKee, K.L., Profitt, C.E., and Perez, B.C. (2003). Mass tree mortality lead to mangrove peat collapse at the Bay Islands, Honduras after Hurricane Mitch. Journal of ecology, 91(6), 1093-1105.

Calderon-Aguilera, L.E., Rivera-Monroy, V.H., Porter-Bolland, L., Martinez-Yrizar, A., Ladah, L.B., Martinez-Ramos, M., and Perez-Salicrup, D.R. (2012). An assessment of natural and human disturbance effects on Mexican ecosystems: current trends and research gaps. Biodiversity and Conservation, 21(3), 589-617.

Cambers, G., Claro, R., Juman, R. and Scott, S. (2008). Climate change impacts on coastal and marine biodiversity in the Insular Caribbean (CCBIC), a project implemented by the Caribbean Natural Resources Institute (CANARI) and supported by the John D and Catherine T MacArthur Foundation.

Change, I.C. (2013). The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.

Cherry, J.A., McKee, K.L. and Grace, J.B. (2009). Elevated CO2 enhances biological contributions to elevation change in coastal wetlands by offsetting stressors associated with sea-level rise. Journal of Ecology, 97(1), 67-77.

Clough, B.F., Andrews, T.J., and Cowan, I.R. (1982). Physiological processes in mangroves. Mangrove ecosystems in Australia: Structure, function and management, 193-210.

Cohen, M.C., Lara, R.J., Cuevas, E. E.M., and Sterberg, L.D.S. (2016). Effects of sea level rise and climatic changes on mangroves from southwestern littoral of Puerto Rico during the middle and late Holocene. Catena, 143, 187-200.

Conservation International. (2008). Economic Values of Coral Reefs, Mangroves and Seagrasses.

Cooper, E., Burke, L., and Bood, N. (2008). Belize's Coastal Capital: The Economic Contribution of Belize's Coral Reefs and Mangroves. World Resources Institute.

Day, Owen. (2009). The impacts of climate change on biodiversity in the Caribbean Islands: what we know, what we need to know and building capacity for effective adaptation. Caribbean Natural Resources Institute, 386.

Di Nitto, D., Neukermans, G. Koedam, N., Defever, H. Pattyn, F., Kairo, J.G., and Dahdouh-Guebas, F. (2014). Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise. Biogeosciences, 11(3), 857.

Dorenbosch, M., Verberk, W. C. E. P., Nagelkerken, I., & Van der Velde, G. (2007). Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs. Marine Ecology Progress Series, 334, 103-116.

Ellison, J.C. (1993). Mangrove retreat with rising sea-level, Bermuda. Estuarine, Coastal and Shelf Science., 37(1), 75-87.

Ellison, J.C. (1994). Climate change and sea level rise impacts on mangrove ecosystems. Impacts of climate change on ecosystems and species. A marine conservation and development report, IUCN.

Ellison, J.C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. Wetlands Ecology and Management, 23(2), 115-137.

Ellison, J.C. and Stoddart, D.R. (1991). Mangrove ecosystem collapse during predicted sea-level rise: Holocene analogues and implications. Journal of Coastal Research, 151-165.

Ellison, Aaron M., and Elizabeth J. Farnsworth. (1996). Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. Biotropica: 549-565.

FAO. (2007). The world's mangroves: 1980 – 2005. FAO Forestry Paper 153.

Faraco, L.F., Andriguetto-Filho, J.M., and Lana, P.C., (2010). A methodology for assessing the vulnerability of mangroves and fisherfolk to climate change. Pan-American Journal of Aquatic Sciences, 5(2), 205-223.

Friess et al., (2016). Mangrove payments for ecosystem services (PES): A viable funding mechanism for disaster risk reduction? In F.G. Renaud et al., (eds.), Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice. Advances in Natural and Technological Hazards Research 42.

Friess, D.A. (2016). Ecosystem services and disservices from Mangrove Forests: Insights from historical colonial observations. Forests, 7(9), 183.

Gilman, E., Ellison, J., and Colemen, R. (2007). Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. Environmental monitoring and assessment, 124(1), 105-130.

Gilman, E.L., Ellison, J., Duke, N.C., and Field, C. (2008). Threats to mangroves from climate change and adaptation options: a review. Aquatic botany, 89(2), 237-250.

Harm, J., E. Kearns, and M. R. Speight. (2008). Differences in coral-reef fish assemblages between mangrove-rich and mangrove-poor islands of Honduras. 11th International Coral Reef Symposium, Fort Lauderdale, Florida, USA vol. Vol. 1.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jury, M.R., and Winter, A. (2010). Warming of an elevated layer over the Caribbean. Climatic Change, 99(1), 247-259.

Kainuma, Mami, et al. (2013). Current Status of Mangroves Worldwide. Middle East 624: 0-4.

Krauss, K.W., McKee, K.L., Lovelock, C.E., Cahoon, D.R., Saintilan, N., Reef, R., and Chen, L. (2014). How mangrove forests adjust to rising sea level. New Phytologist, 202(1), 19-34.

Lewis. (1989). Creation and restoration of coastal plain wetlands in Florida. Wetland creation and restoration: the status of the science, 1, 73.

Locatelli, T., Binet, T., Kairo, J.G., King, L. Madden, S., Patenaude, G., and Huxham, M. (2014). Turning the tide: how blue carbon and payments for ecosystem services (PES) might help save mangrove forests. Ambio, 43(8), 981-995.

Lugo, A.E. (2000). Effects and outcomes of Caribbean hurricanes in a climate change scenario. Science of the Total Environment, 262(3), 243-251.

Lugo et al. (2014). Issues and challenges of mangrove conservation in the Anthropocene. Madera y Bosques, 20, 11-38.

McIvor, A.L., Iris Moller, Tom Spencer, and Mark Spalding. (2012). Reduction of wind and swell waves by mangroves. The Nature Conservancy and Wetlands International.

McIvor, A.L., Spencer, T. Moller, I., and Spalding, M. (2013). The response of mangrove soil surface elevation to sea level rise. The Nature Conservancy and Wetlands International.

McKee, K.L., Cahoon, D.R., and Feller, I.C. (2007). Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. Global Ecology and Biogeography, 16(5), 545-556.

McKee, K.L., and Vervaeke, W.C. (2009). Impacts of human disturbance on soil erosion potential and habitat stability of mangrove-dominated islands in the Pelican Cays and Twin Cays Ranges, Belize. Smithsonian Contributions to the Marine Sciences, 38, 415-427.

McKee, K.L. (2011). Biophysical controls on accretion and elevation change in Caribbean mangrove ecosystems. Estuarine, Coastal and Shelf Science, 91(4), 475-483.

McLeod, E., Chmura, G.L., Bouillon, S., Salm, R., Bjork, M., Duarte, C.M., and Silliman, B.R. (2011). A blueprint for blue carbon: toward improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and Environment, 9(10), 552-560.

Mitra, A. (2013). Blue carbon: A hidden treasure in the climate change science. Journal of Marine Research and Development, 3(2).

Mukherjee N., Sutherland, Dicks, Huge, Koedam and Dahdouh-Guebas. (2014). Ecosystem Service Valuations of Mangrove Ecosystems and Future Valuation Exercises. PLOS One, Vol. 9, Issue 9.

Mumby, Peter J., et al. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427.6974: 533-536.

Nagelkerken, I., S. Kleijnen, T. Klop, R. A. C. J. Van Den Brand, E. Cocheret de La Moriniere, and G. Van der Velde. (2001). Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: a comparison of fish faunas between bays with and without mangroves/seagrass beds. Marine Ecology Progress Series 214: 225-235.

Nagelkerken, I., S. J. M. Blaber, Steven Bouillon, P. Green, M. Haywood, L. G. Kirton, J-O. Meynecke et al. (2008). The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany 89, no. 2: 155-185.

Nurse, L.A., R.F. McLean, J. Agard, L.P. Briguglio, V. Duvat-Magnan, N. Pelesikoti, E. Tompkins, and A. Webb: Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.

Osland, M.J., Enwright, N.M., Day, R.H., Gabler, C.A., Stagg, C.L. and Grace, J.B. (2016). Beyond just sea-level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. Global change biology, 22(1), 1-11.

Palanisamy, H., M. Becker, B. Meyssignac, O. Henry, and A. Cazenave, 2012: Regional sea level change and variability in the Caribbean Sea since 1950. Journal of Geodetic Science, 2(2), 125-133.

Piou, Cyril, Ilka C. Feller, Uta Berger, and Faustino Chi. (2006). Zonation patterns of Belizean offshore mangrove forests 41 years after a catastrophic hurricane. Biotropica 38, no. 3: 365-374.

Polidoro, B.A., Carpenter, K.E., Collins, L. Duke, N.C., Ellison, A.M., Ellison, J.C., ... and Livingstone, S.R. (2010). The loss of species: mangrove extinction risk and geographic areas of global concern. PloS One, 5(4), e10095.

Record, S. Charney, N.D., Zakaria, R.M, and Ellison, A.M. (2013). Projecting global mangrove species and community distributions under climate change. Ecosphere, 4(3), 1-23.

Sappal, S.M., Ranjan, P., and Ramanathan, A. (2016). Blue carbon ecosystems and their role in climate change mitigation – an overview. Journal of Climate Change, 2(2), 1-13.

Shihab et al. (1989). Small States Conference on Sea Level Rise. Conference report prepared by the Conference Secretariat, Kurumba Village, Republic of Maldives.

Short, F.T., Kosten, S., Morgan, P.A. Malone, S., and Moore, G.E. (2016). Impacts of climate change on submerged and emergent wetland plants. Aquatic Botany, 135, 3-17.

Sippo, J.Z., Maher, D.T., Tait, D.R., Holloway, C., and Santos, I.R. (2016). Are mangroves drivers or buffers of coastal acidification? Insights from alkalinity and dissolved inorganic carbon export estimates across a latitudinal transfect. Global Biogeochemical Cycles, 30(5), 753-766.

Snedaker, S.C. (1995). Mangroves and climate change in the Florida and Caribbean region: scenarios and hypothesis. In Asia-Pacific Symposium on Mangrove Ecosystems (pp. 43-49). Springer Netherlands.

Spalding, Mark. (2010). World atlas of mangroves. Routledge.

Van Bochove, J., E. Sullivan, and T. Nakamura. (2014). The importance of mangroves to people: A call to action. United Nations Environment Programme.

Vanselow, Kim Andre, Melanie Kolb, and Thams Fickert. (2007). Destruction and Regeneration of Terrestrial, Littoral and Marine Ecosystems on the Island of Guanaja/Honduras Seven Years after Hurricane Mitch (Zerstorungsausma und Regeneration terrestrisher, litoraler und mariner Okosysteme auf der Insel Guanaja/Honduras sieben Jahre nach Hurrikan Mitch. Erdkunde: 358-371.

Vo, G.T., Kunzer, C., Vo, Q.M., Moder, F. and Oppelt, N. (2012). Review of valuation methods for mangrove ecosystem services. Ecological Indicators, 23, 431-446.

Walker, L.R. (1991). Summary of the effects of Caribbean hurricanes on vegetation. Biotropica, 23(4), 442-447.

Ward, R.D., Friess, D.A., Day, R.H., and MacKenzie, R.A. (2016). Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosystem Health and Sustainability, 2(4).

Wells, S., and Ravilious, C. (2006). In the front line: shoreline protections and other ecosystem services from mangroves and coral reefs (No. 24). UNEP/Earthprint.

Online Caribbean Mangrove Resources

Caribbean Community Climate Change Centre http://www.caribbeanclimate.bz/

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) https://www.gob.mx/conabio

Marine Climate Change Impacts Report Card http://www.mccip.org.uk/annual-report-card/

Global Forest Watch http://www.globalforestwatch.org/

World Resources Institute Mangrove Blog http://www.wri.org/blog/2015/02/satellite-data-reveals-state-world%E2%80%99s-mangrove-forests

Planetsave http://planetsave.com/2015/02/18/where-without-mangroves/

Mangroves for the Future https://www.mangrovesforthefuture.org/