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

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EXECUTIVE SUMMARY

The current and future available evidence (based on AR5 scenarios) suggests that small islands will be vulnerable to sea level rise (SLR) and increased sea surface temperature (SST). Extent of coastal vegetated wetlands is also expected to decrease;

The impact of increased SST on seagrass and mangroves beds in the Caribbean is uncertain, but some studies suggests that the photosynthetic mechanism of tropical seagrasses could become damaged at very high temperatures;

Shellfish and fisheries are important food and economic resources for SIDS. These may be directly and indirectly affected under climate change effects, further research is needed to fully understand and minimise these expected effects;

Some evidence suggests that increased temperatures and low winds could be favouring the appearance of *Sargassum natans* and *Sargassum fluitans* introduction in the Caribbean region;

Coral bleaching could become an annual or biannual event in the next 30 to 50 years or sooner, without an increase in thermal tolerance of corals of 0.2 to 1.0°C;

In the Caribbean, there is a 0.5 m SLR projected which is likely to cause a decrease in turtle nesting habitat by up to 35%;

Recent research has shown that the invasion of the Caribbean Sea by the successful predator the Indo-Pacific lionfish (*Pterois volitans*) has contributed to an increase in algal dominance in coral and sponge communities in the Caribbean region. Presence of the predator may reduce the resilience of reef communities to climate stressors, and vice versa;

Plans and some actions to mitigate the effects of climate change on biodiversity are already being developed in some SIDS, but this work is still in its infancy.

Introduction

The Caribbean region has been recognised to be a hot-spot for biodiversity worldwide (UNEP, 2009; Myers *et al*., 2000). This report card summarises the current evidence and expected future climate change effects on important marine habitats and species. The topics considered in this review are seagrasses and turtles, mammals, plankton and invasive species. Whilst it is acknowledged that other habitats and species are also contributing towards the overall biodiversity (e.g. coral, fish and shellfish, and mangroves) in these areas, these habitats and species have been covered as individual ('hot topic') reports. However, this review has also included a brief section where these important species and habitats have been considered because they are key contributors to the overall Caribbean biodiversity. In this short summary, we have indicated the likely expected climate change effects. The observed effects of climate change and expected future changes will act differently across species and habitats. Some SIDS are already experiencing some of these changes and in some cases there will be some site-specific effects across these areas.

This review has collated information on all countries in the Caribbean Region, however, the main emphasis is on the following Small Island Development States (SIDS): Antigua &

Barbuda; Belize; Dominica; Grenada; Guyana; Jamaica; Saint Lucia; Saint Vincent & Grenadines (Figure 1). This section on key impacts has integrated knowledge on i) what is already happening? and ii) what could happen in the future? A detailed overview is provided on seagrasses and specific species. It is expected that the effects of climate change on biodiversity will have synergistic interactions with other human activities (e.g. fishing, recreational sports, tourisms, sewage discharges) and will have repercussions for the ecology and ecosystems distributed in these areas. Climate change effects may have interactions with many other stressors as documented elsewhere (Birchenough et al., 2015; Day 2009).

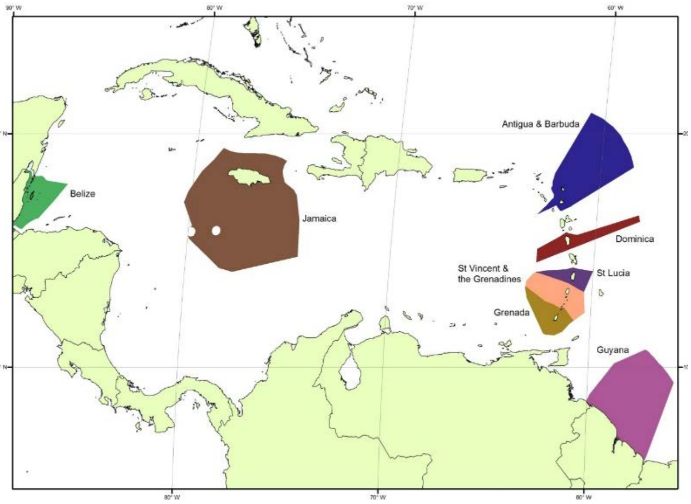

Figure 1. Overview of the maritime area of the Small Island Developing States (SIDS) in the Caribbean.

Key topics

Some of the main issues for corals, mangroves, fish and shellfish key topics are briefly included in the sections below. However, a dedicated review can be found in the full research papers concentrating on these topics see (see Wilson, 2017 mangroves; Oxenford and Monnereau, 2017 -fish and shellfish; McField, 2017 corals). The topic research papers have included sections on: key messages, what is already happening, what could happen in the future, the confidence levels based on our current understanding as well as knowledge gaps and socio-economic impacts.

What is Already Happening?

Corals

Coral reefs are important habitats as they provide shoreline protection from extreme events such as storms and hurricanes. Their role also contributes to the provision of medicines, food, and recreational activities. Their overall estimated global value of 172 billion U.S. dollars per year (EurekAlert-AAAS, 2009). A study assessing Belize's coral reef and coastal mangroves estimated their overall value to be $395 - $559 million U.S. dollars per year, considering all of the direct benefits and wider ecosystem services (Cooper et al, 2009). Corals also host much of the biodiversity of the oceans as well as providing critical protection against erosion and wave-induced damages resulting from tropical storms and hurricanes, safeguarding properties and lives. To date, evidence suggests that climate change is impacting coral reefs through coral bleaching, disease outbreaks, ocean acidification and dedicated physical damage from frequent hurricanes. Additionally, an increase in sea temperature is clearly having an impact on the coral reef ecosystem health globally (McField, 2017 for further details).

Meta-analyses have indicated that global climate change could increase the frequency of coral bleaching threating the long-term integrity of coral reefs. These results were based on the projecting outputs from an atmosphere–ocean general circulation models (GCMs), with regards to the local conditions found across representative coral reefs. The overall work is a comprehensive global assessment of coral bleaching, based on the work conducted by the NOAA Coral Reef Watch bleaching prediction method, with a low- and high-climate sensitivity GCM. The overall results were site-specific, very dependent of the geographic variability observed over thermal adaptation. Research suggest that bleaching could become an annual or biannual event for the majority of the world's coral reefs in the next 30–50 years without an increase in thermal tolerance of 0.2–1.0°C per decade. The work conducted was based on available model and emissions scenarios, suggesting that for some coral reefs, the expected effects resulting from climate change will vary across regions (Donner et al., 2005).

Overall, the Caribbean SIDS have not yet experienced the global widespread degree of bleaching-induced mass mortality compared effects observed elsewhere (e.g. areas in the Pacific). However, some clear events have been recently observed in certain areas (e.g. Belize) (McField, 2017). Furthermore, the resulting effects on coral integrity resulting from diseases have been underestimated. Maynard et al. (2016) postulated that bleaching is the likely cause of coral mortality in the future and that further consideration needs to be included in management and monitoring of these areas. The increase in sea temperature is also contributing to the declines in coral reproductive success (Baird et al., 2009), metabolic rates (Munday et al., 2009), and shifts in geo-graphic ranges (Hughes et al., 2012). Overall, the combined effects of climate change with overfishing and pollution could exacerbate the effects on coral reefs over recent decades (Game et al., 2005). There is a need to climate proof the current conservation strategies to protect, restore and manage these important habitats.

Mangroves

Mangroves cover approximately 137,760 km^2 – 152,360km^2 of the world's surface (Kainuma et al., 2013), these habitats are highly threatened worldwide (Spalding et al., 2010). There are four mangrove species—*Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemose* and *Conocarpus erectus*—found throughout the Wider Caribbean. Studies show that the loss of mangroves worldwide has been severe over the last several decades. Mangrove habitats are important as they provide numerous ecosystem services for human wellbeing (Van Bochove et al., 2014; Friess, 2016) and climate change could be also adding an additional pressure to these species. Mangroves are important as they 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 storms among other values (Mukherjee et al., 2014). In the Caribbean, particularly in 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 (Brown et al., 2007).

Studies have demonstrated that mangroves across the Caribbean have declined by approximately 24% over the last quarter-century (Polidoro et al., 2010). The main human activities which are considered to be drivers of mangrove destruction and/or degradation are mainly resulting from land use activities along the coastal zone (Spalding et al., 2010; Van Bochove et al, 2014). Studies have listed the primary and emergent anthropogenic threats to mangroves. These are outlined below:

- Coastal development (e.g. roads, ports, 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

The 5th Assessment Report prepared by the Intergovernmental Panel on Climate Change (IPCC-AR5), contains a section on small islands. This work indentified main climate and pressures that are expected to impact mangrove ecosystems in Caribbean SIDS (Nurse et al., 2014). These 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)

Furthermore, a recent review of climate change impacts on mangrove ecosystems (Alongi, 2015; McKee 2011 and Krauss et al., 2013) conducted a comprehensive review of the SLR issue as these effects are directly related to mangroves (McIvor, 2012). This work showed that the presence of deep peat deposits, provides evidence that in some Caribbean locations in the past, landward migration of mangroves continue to shift with SLR. Additional studies have also shown some limits in which mangroves cannot keep pace with SLR, demonstrating the degration of these habitats (Alongi, 2015).

Fish and shellfish

Fish and shellfish are important economic and food resources in the SIDS. Some of the shellfish and fish are already experiencing climate change effects. For example, measurements of across the entire Caribbean Sea have shown an overall increase in SST; with an increase in the frequency of occurrence of anomalous 'hotspots' (e.g. greater than 1°C above mean monthly maximum SST), as well as an increase in the occurrence of periods of deleterious 'heating stress' (greater than 8 degree heating weeks), and an increase in the frequency of category 4 and 5 hurricanes. It is clear that warmer SSTs are having a direct impact on Caribbean fish and shellfish metabolism since they are poikilothermic ectotherms ('cold blooded'). This impact is likely to be largely negative, given that many species are already likely to be close to their critical maximum temperature and minimum oxygen tolerances, at least during the summer months. Changing temperatures will have already impacted species' phenologies and early life history development times with the likely result of less successful recruitment (population replenishment). However, again there are no studies that have examined likely changes in, for example: metabolic rate, growth, development of early life history stages, phenologies, or mortality from anoxia in Caribbean species from any of the commercially important groups in the wild, over time-scales long enough to detect change that can be attributed to climate-induced changes in SST.

However, increasing SSTs and associated changes have had measurable negative impacts across the Caribbean on the essential habitats of fish and shellfish, especially coral reefs since the 1980s, through mass coral bleaching and mortality events, increased incidences of coral and other invertebrate diseases, and greater physical destruction. These climate change stressors have exacerbated the on-going chronic degradation of these habitats from other anthropogenic stressors including deteriorating water quality (from land-based activities along the coast and within watersheds), physical destruction (from coastal development and marine construction), and chronic over-harvesting. The evidence is clear in the changing composition of the foundational reef species, the decline in live coral cover and architectural complexity (rugosity) of reef structural framework; as well as in the loss of mangrove and seagrass habitat.

The indirect impacts of the climate-induced changes to essential habitats (including the open ocean) on the fish and shellfish resources have not been widely monitored or reported, and are indeed difficult to separate from the whole level of changes occurring within these habitats that have been largely caused by other anthropogenic stressors. However, there are several studies providing evidence on the decline in live coral cover, caused largely by temperature-induced mass coral bleaching, as well as decline in herbivorous reef fish biomass across the Caribbean.

Climate change impacts on commercially important fish and shellfish will have a wide array of social and economic implications in Caribbean SIDS including impacts on: (1) consumers and value of the food as a resource with potential repercussions for food and job security for the fisheries; (2) recreational diving (e.g. SCUBA and snorkelling) in these areas with potential reduction in revenue; and 3) the ecological functions provided by fish and shellfish, mainly on the regulation of ecosystem services (more details are provided in Oxenford and Monnereau, 2017).

Furthermore, studies to date have not shown direct evidence of reduced calcification by Caribbean fish or shellfish, although there is worldwide evidence of potential observed effects on some of these species elsewhere from laboratory and field studies that may help to inform these stocks.

Seagrasses

Seagrasses are considered to be ecologically important environments as they host and provide a range of ecosystem goods and services (Guannel et al., 2016; Waite et al., 2014; de Goot et al., 2012; Polidoro et al., 2010; Waycott et al., 2009; Cooper et al., 2009; Constanza et al., 2008). These habitats contribute significantly to the well-being of small island communities. These ecosystems are generally distributed along the coast in shallow water where sunlight penetration is adequate to allow photosynthesis. Their location leaves them highly susceptible to run-off from land-based activities and to stressors arising from water sports. Seagrasses play a significant role in stabilising the seabed and for providing habitat to juvenile fishes and importantly commercial species (e.g. conch and lobster) which are consider to be ecosystem components. Their contribution is mainly as primary producers in the food chain of the reef community, with their production of 4000 g C/m^2/yr. Seagrasses also actively contribute to: i) nitrogen fixation; ii) habitat provision (mainly for feeding, breeding and recruitment for juveniles and adults) of reef organisms (e.g. commercial species and the culturally important sea egg urchin (*Tripneustes ventricosus*)); iii) reduction in sediment movement in nearshore waters and removing sediments from the water column; iv) decreasing turbidity of the water; and vi) stabilizing and protecting the coastline during storms (Guannel et al., 2016;).

These habitats help to maintain ocean clarity, helping to support tourism and recreation (e.g. snorkelling). Some of the non-climate change effects on these habitats can be expected from siltation (arising from shore construction) as well as pollution sources, smothering and damaging the blades of the seagrasses. Some of the general evidence presented in the Caribbean area states that potential expected effects of climate change can result from sea level rise, ocean acidification, intensified storms and increased sea surface temperature. Some specific information is described below for individual SIDs.

In Anguilla, there is limited evidence on the effects of climate change on seagrasses. However, climate change remains to be a relatively new threat to these ecosystems. Therefore, there have been limited studies on distinct climate change impacts on seagrasses. Nevertheless, some of the potential threats identified may arise from SLR, changes in localised salinity, increased SST and effects from extreme weather events. Generally, as it is expected for coral reefs, similar effects may arise from SLR, which will reduce the sunlight and could also have repercussions for the integrity of seagrass beds. In Antigua & Barbuda and Saint Lucia the main identified potential impacts, are associated with an increased SST and could affect seagrass beds in this area. However, there is a limited understanding on what could be the magnitude of these effects on these habitats. Some available evidence has suggested that the photosynthetic mechanism of tropical seagrasses could become damaged at very increased temperatures (see Campbell et al., 2006).

In the Bahamas, seagrass beds are well-known for their significant role as seabed stabilizers and in habitat provision to juvenile fishes and commercial species (mainly conch and lobster) (Caribsave report-The Bahamas, 2011). The Bahamas has recognised the importance of these habitats and adopted strict control and regulation on Environmental Impact Assessments. These considerations are applicable with regards to several tourism expansions and take account how these developments will be likely to affect several habitats (including mangroves, seagrass beds and coral reefs). In Barbados and the Dominican Republic, four species of seagrasses have been identified, these are: *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), *Halodule wrightii* (shoal grass) and *Halophila* spp. (Caribsave report- Barbados, 2011; Caribsave report- The Dominican Republic, 2011). The majority of the seagrass beds in the Dominican Republic lie within protected areas, although some of these coastal ecosystems are still subjected several threats. These are mainly sedimentation from river outflows, agro-chemical pollution, and pressures from coastal developments. Furthermore, the effects resulting from overfishing and destructive fishing practices are also damaging these seagrass habitats. Seagrasses are very sensitive to changes in the surrounding water so they are considered to be important “indicator species” of the general health of coastal ecosystems. In Belize, seagrass beds (such as *T. testudinum* and *S. filiforme*) are distributed throughout the entire length of Belize (Caribsave- Belize, 2011). These beds support large populations of manatees, which are an important eco-tourism attraction in the tourism centres of San Pedro, Caye Caulker and Placencia.

In Grenada seagrass beds are found along the east central and southern coasts in the Telescope area and within the barrier type reef extending from Grenville Bay to Prickly Bay in the south. Most of the reefs and seagrasses continue to be negatively impacted by tourism activities and over-fishing. In Jamaica, there is limited evidence on climate change impacts on seagrass beds, although recent evidence suggests that the proximity of seagrass beds to coral reefs exposes them to similar climatic change impacts. As with corals, SLR may reduce the available sunlight to seagrass beds and hence reduce their productivity. While there is no consensus amongst the models as to whether the frequencies and intensities of rainfall on the heaviest rainfall days will increase or decrease in the region (Simpson, *et al.*, 2010), increased rainfall could mean localised decreased salinity and thus decreased productivity of seagrass habitats. At Nevis, some effects on seagrasses were observed in the 1990s. It is generally conceded that seagrasses around Nevis, especially around Charlestown, were "slowly disappearing" (Robinson, 1991). There is clear evidence that some factors have contributed to the degradation of coral reefs and seagrasses; a result of anchor damage and sedimentation, shipping-related pollution and land-based run-off. These effects have caused physical damage to seagrasses and reduced the quality of coastal water (Eckert & Honebrink, 1992). Saint Vincent and the Grenadines (SVG) possess a wide range of seagrasses beds, these are found along the shoreline in shallow water where sunlight penetration is adequate to allow photosynthesis. There has been very little mapping and monitoring of these ecosystems on the main island of St Vincent. Some maps are available on the Marsis website (see http://www.grenadinesmarsis.com/Files_and_Maps.html) for the Grenadines and these seagrass beds tend to be relatively small and isolated. Overall, most of the information available has helped to document seagrass distribution and effects from a wide range of human activities. However, the current knowledge on climate change effects on these habitats is limited and mostly speculative from other habitats (e.g. corals and mangroves).

Overall, the effects of climate change on seagrasses remain largely uncertain. Potential threats may arise from SLR, changes in localised salinity, increased SST and intensity of extreme weather events. As with corals, SLR may reduce the sunlight available to seagrass beds and hence reduce their productivity (Nurse et al., 2014). While there is no consensus amongst the models as to whether the frequencies and intensities of rainfall on the heaviest rainfall days will increase or decrease in the region, increased rainfall could mean a localised decrease in salinity and resulting decrease in productivity of seagrass habitats. On the other hand, CO_2 enrichment of the ocean may have a positive effect on photosynthesis and growth. The photosynthetic activity of dense seagrass stands have been shown to increase local pH potentially balancing a decreased pH from projected ocean acidification (Bjork & Beer, 2009). An increase of CO_2 levels may also increase the production and biomass of epiphytic algae on seagrass leaves, which may adversely impact seagrasses by causing shading; thus changes may occur in the competition between seagrass species and between seagrasses and algae (Beer and Koch 1996). Seagrasses are sensitive to thermal discharges and can only accept temperatures up to 2-3°C above summer temperatures (Anderson, 2000). However, the impact of increased SST on seagrass beds in the Caribbean is uncertain, since studies have suggested that the photosynthetic mechanism of tropical seagrasses becomes damaged at temperatures as high as 40-45°C indicating that they may be able to tolerate temperature increases above some climate change model projections (Campbell, et al. 2006).

Turtles-nesting beaches

A vulnerability analysis of CARICOM nations to SLR and associated storm surge indicated that large areas of the coastlines in the Caribbean are highly susceptible to erosion. The beaches have clearly experienced accelerated erosion in recent decades. Some specific calculations tend to suggest that beach nesting sites for sea turtles are at significant risk to beach erosion (Simpson, et al., 2010). Overall, the expected effects of climate change on nesting sea turtles tend to indicate that there are potential expected effects on these habitats. Building, coastal infrastructure and the removal of vegetation from beaches is leading to erosion of sand and loss of nesting sites.

Beach erosion in several countries, including Tobago, St Lucia, Grenada, Jamaica and others, is being exacerbated by illegal or unregulated sand mining. These activities further undermine the quality and quantity of turtle nesting sites.

Climate change impacts on the biodiversity of beaches may also be seen as warmer average daily temperatures affect marine turtles. Incubation temperature influences the sex of baby turtles. Therefore, it is expected that warmer temperatures may skew sex ratios in developing eggs and thereby reduce the reproductive capacity of sea turtles. Such impacts will mean a further threat to species that are already critically endangered and a loss of potential revenue for the country's expanding tourism industry with an overall disruption of the marine ecosystem balance.

The following section highlights impacts of climate change on turtle nesting sites, as well as measures to reduce impacts at a SIDs level.

A dedicated vulnerability assessment conducted in St Lucia with regards to SLR, have demonstrated that that newly adopted measures to minimise SLR effects will have direct effects on turtle nesting beaches (Murray and Tulsie, 2011). Some of these species will be also at significant risk to beach erosion associated with SLR, with 51% significantly affected by erosion from 1 m SLR and 62% by erosion associated with 2 m SLR (Simpson *et al*., 2010).

In Dominica, St. Lucia and Grenada there are documented impacts of tropical cyclones between 1979 and 1995 which show the severe erosion that these weather systems have caused to beaches. In Dominica, in most instances large amounts of sand were removed and in the cases of Scott's Head Beach, Rock-a way Beach and Toucarie Beach, have been replaced with boulders. Beach profile monitoring has revealed that although beaches in Dominica have shown signs of recovery after extreme weather events, they had not yet returned to pre-hurricane conditions by the time of reporting in 2011 (Caribsave Report-Dominica, 2011.). An example of an extreme event was during the struck of Hurricane Lenny struck Grenada in 1999 severely eroding the Grand Anse beach so that the shoreline retreated inwards by 6 m (Caribsave Report-Grenada, 2011). Subsequently, Hurricane Ivan in 2005 also reported major damage to beaches. The following year Hurricane Emily struck the island and although the damage was less severe than that experienced by Ivan, the overall impacts reversed any progress that had been initially made.

In Belize, the Belize Turtle Watch Program was launched in March 2011 by ECOMAR, in partnership with the Belize Fisheries Department, with support from World Wide Fund (WWF) and Protected Areas Conservation Trust (PACT). The aim is to increase the level of knowledge on sea turtles in Belize and to establish a baseline data set on abundance and nesting beach activity so that changes over time, specifically those caused by climate change, can be measured.

Non-native or Invasive Alien Species

There is limited information for some of the SIDS regarding the threat of Invasive Alien Species (IAS) and the risks that these species will pose to the native biodiversity. Invasive species can out-compete native species for food and space and may even prey on native species, thus disrupting ecosystems, particularly those that have already been disturbed and affected as a consequence of human activities.

Since 2011, during July and August some of the islands (e.g. Anguilla, Saint Vincent and the Grenadines, Barbados, St Lucia, Antigua) have experienced exceptionally large accumulations of Sargassum seaweed *Sargassum fluitans* (Figure 2). Since this seaweed has been washed ashore and it is not originally form these Islands, it is considered to be an introduced species. These large quantities of the seaweed are causing concerns among visitors and residents. Although these events are not confirmed as climate change related effects, the phenomenon is thought to be as a direct result of the gyre in the Atlantic off Brazil (see Sargasso sea (Doyle and Franks, 2015). These floating mats of vegetation arrive in the Caribbean region annually, but over recent years they appear to be doing so in unusually large quantities. Fishers have complained that their nets and lines become entangled in the Sargassum and this has almost shut down the entire fishing sector. There is also concern over the risk of disease and invasive species that may accompany the seaweed. The large volume and weight of seaweed washed up on some beaches is unsightly and poses a problem for the tourism industry as well as a major expense and logistical challenge for governments who opt to collect and dispose of the Sargassum. If this event is indeed related to cyclonic storms that have formed in the Atlantic since the 2011 hurricane season, then coastal and marine environmental managers should prepare for the likelihood of these events occurring with increased frequency in the near future.

In Saint Lucia and Nevis the invasive Indo-Pacific lionfish (*Pterois volitans*), has been sighted (recorded since November 2010) in neighbouring territories as close as Guadeloupe and Venezuela (Figure 3). The lionfish has been observed in the Western Atlantic, Caribbean and in the Gulf of Mexico (Atkins et al., 2012; Green et al., 2012; Atkins et al., 2012). The lionfish have no apparent natural predators in the Caribbean and this has allowed the species to spread very rapidly throughout the region from both northern and southern ends of the Caribbean Basin. The fish feeds not only on reef fish such as parrotfish, which are important to maintaining reef health, but also on the juveniles of commercially important species. The St Lucia's Fisheries Division and Coastal Zone Management Unit are greatly concerned about the threat this could pose for the country's fishing industry. Some regional research on lionfish is increasing and should be monitored closely for management recommendations. (see http://www.gcfi.org/Lionfish/Lionfish.html for further additional information). Although there is no evidence that the lionfish invasion is climate-related, the concern is that when combined with pre-existing stress factors the natural resilience of Caribbean reef communities will decrease (Green et al., 2012; Albins and Hixon, 2013), making them more susceptible to climate change.

An overall threat to Jamaica's reefs and fisheries is the voracious predator lionfish. As of 2010 almost every reef of Jamaica has uncounted numbers of this invasive species which could wipe out the already depleted fishing industry (Neufville, 2010).

Overall, there is limited information on invasive species in some of the islands and the information available is still in its infancy. There is a need to document sightings and distribution of these species. Furthermore, it is also important to assess the ecological trade-off that the invasive species will have over the native fauna to gain an understanding on the overall repercussions for biodiversity effects in these areas.

Image 2. Large accumulations of *Sargassum fluitans*, known as 'the sargassum seaweed' in the Caribbean. (image ©H.Oxenford extracted from Doyle and Franks, 2015).

Image 3. The invasive Indo-Pacific lionfish *Pterois volitans*. (©Peter Randall, Cefas)

There is clear concern on the risks to small islands from climate change effects, which could be originating well beyond the borders of specific countries and/or islands. These transboundary processes could have a negative impact on small islands with strong evidence that this may be the case. For island communities, the risks associated with existing and future invasive species and human health challenges are projected to grow under climate change effects (Nurse et al., 2014). The effects of climate change may act as a multiplier of existing health conditions. Other broader effects may affect the health of the country's fisheries, tourism sector, as these activities are directly interlinked with the overall health of its marine environment, whose vulnerability is likely to be exacerbated by the anticipated effects of climate change" (see more details on a vulnerability report by Murray and Tulsie, 2011).

Marine mammals

Marine mammals are spotted in most of the islands (e.g. The Bahamas, Saint Lucia, Belize, Dominica, Granada, Jamaica and Saint Vincent and the Grenadines). The majority of species are dolphins (e.g. the common bottlenose, Atlantic spotted and the spinner). There are also 4 species of migratory whales: minke, sperm, beaked shortfin and humpback, which are often sighted. Sperm whales appear to be sighted in greater numbers from the months of October to January and humpback whales are seen migrating only between January and April. Dolphins and whales contribute to recreational tourism in the area, bringing a number of tourists over the years and creating jobs and business opportunities in the area. For example, the whale watching industry in Saint Lucia grew rapidly over a 10-year period from 65 whale watchers in 1998 to over 16,600 in 2008. Whale watching tours are now offered by different operators on the islands with a total of US $1,577,010 in direct and indirect expenditure in 2008 (O'Connor *et al.*, 2009). The number of stay over, as well as cruise ship tourists to the region continues to increase annually, offering a good prospect for expansion of the market for these tours.

Climate change impacts on the chemical and physical characteristics of marine waters will have negative consequences for prey items. Therefore, whale feeding patterns and distribution may be altered. The whale distribution changes (e.g. following food over different areas) may have repercussion for watch tour operators. Information on the biology of many cetaceans is limited and this makes it difficult to predict the consequences that climate change may have on them. Nevertheless, it is likely that changes in global temperature, sea levels, sea-ice extent, ocean acidification and salinity, rainfall patterns and extreme weather events will decrease the range of many marine mammals (Elliot and Simmonds, 2007). Current evidence suggests that the migration patterns, distribution and/or abundance of cetaceans are likely to alter in response to continued changes in sea surface temperature with global climate change (Lambert *et al.,* 2010).

In SVG there are twelve species of cetaceans which include humpback whales, sperm whales, pilot whales, bottlenose dolphins and spinner dolphins. Bequia is the second largest island in the Grenadines and is one of the few locations where whale hunting is still permitted by the International Whaling Commission due to aboriginal subsistence hunting (Mills, 2001). In Saint Lucia, the short-finned pilot whale is also distributed and harvested (Murray *pers.comm.).*

The decrease in the population of sperm whales documented by Gero and Whithead (2016) in the Eastern Caribbean of -4.5% per year in unit size started in about 2010, with numbers being fairly stable until then. There are several natural and anthropogenic threats, but no well-substantiated cause for the decline. It is possible that changes in ocean curents and temperatures associated with climate change may have been associated with this decline. The available migratory evidence suggests that marine mammals will be likely affected by climate change during some stage in their life-cycles. However, there is not distinct evidence that will imply at what specific stage or how these effects may be further influenced by other environmental stressors. There is a clear expectation that climate change effects may increase abundance or distribution range. Additionally, climate change could also contribute to higher risks of extinction for some of the most vulnerable species. One of the most critical effects resulting from climate change have been associated with oceanographic changes, which could have severe repercussions for food availability (mainly fish and plankton) for marine mammals.

Plankton

The available evidence for most of the islands (e.g. Anguilla Belize, Grenada, Dominica, Saint Lucia, The Dominican Republic, Nevis and SVG), and the overall Caribbean area, is based on the available evidence via the Intergovernmental Panel on Climate Change- IPCC (A4 and A5 assessments- Nurse et al., 2014 and IPCC, 2007). Overall, there is an indication that shifts in plankton abundance will be likely to be affected by rising water temperatures, changes in ice cover, salinity, acidification, oxygen levels and circulation, as well as other species (e.g. algae and fish abundance). Recent studies conducted in the southern Caribbean areas, showed decreasing levels of plankton production, from the result of a reduction in ocean upwelling, whereby nutrients crucial for plankton production are brought from the sea floor to the surface. The decrease in upwelling has, in turn, been driven by changes in wind patterns and wind strength, themselves driven by global climate change, which may have repercussions for the sardine fisheries. Most of the available information on plankton and the likely consequences resulting from climate change effects are based on wider information from regional assessments (Nurse et al., 2014). Whilst, this information is accurate, there are no clear future plankton predictions or expected effects observed in Caribbean islands. However, the perception is that climate change will modify oceanographic conditions and therefore plankton distribution may be affected in the future, with potential repercussions for higher trophic levels.

Responding to impacts – what is already happening?

Most Caribbean islands have a great economic dependence on tourism. Coastal resources including beaches, coral reefs, seagrass beds, and mangroves offer important protection to tourism infrastructure as well having aesthetic value, visited every year by many tourists. Some of the areas have experienced severe tropical storms, hurricanes and storm surge damage to these natural resources in the past. There are some efforts to adopt structural protection (e.g. defences and seawalls) in some of the areas, but these developments have sometimes been to the expense of further degradation of many valuable natural areas. Caribbean societies and economies, the comprehensive integration of poverty, gender and livelihood issues into climate change impact and vulnerability assessment and planning processes is much needed to support the development of community-specific adaptation strategies. These activities could help to achieve the sustainable and effective responses to climate change required from wider Caribbean societies.

Local knowledge is key to identify where the main resources are distributed in the area. Furthermore, the current lack of awareness of where further changes will be expected in the Caribbean region are of concern. Particularly when there are clear gaps in the seasonal variability and specific areas where these species may be distributed and are likely to move (e.g. depending on their maximum range) as the effects of climate change may start to become more pronounced. It is necessary that management, protection and awareness measures are clearly implemented to safeguard the biodiversity of these areas. Clearly, there is already ongoing local actions taking place, with some countries having collectively (e.g. OECS Member States) developed draft (model and harmonised scenarios) laws since 2006 to manage and safeguard these resources. Some further support from the local authorities, ensuring that the promulgation of these local laws can be actively enforced will be advantageous. There are already some initiatives in place with regards to Climate Change Adaptation and Disaster Risk Management in Fisheries and Aquaculture in the CARICOM Region under the Strategy and Action Plan". This strategy and action plan integrates important policy documents. The regional policy context is primarily based on the 'Regional Framework for Achieving Development Resilient to Climate Change' (considering a Regional Framework), including CARICOM's strategy on climate change. The CARICOM Heads of Government endorsed the Regional Framework at their July 2009 meeting in Guyana and issued the Liliendaal Declaration, outlining the key climate change aims and interests of CARICOM Member States. The Liliendaal Declaration is the Implementation Plan (IP) for the Regional Framework. The CCCCC Regional Framework is based on five strategy elements and twenty goals. Overall, these goals do cover aspects of fisheries and aquaculture under an ecosystem approach. The IP is developed under the heading of coastal and marine issues. Further initiatives are looking at improving the outlook for Caribbean Coral Reefs: A Regional Plan of Action 2013-2018 (e.g. "Coral reef action plan"). The plan covers components of Strategic Elements 1: Mainstream CC Adaptation Strategies to sustainable Development / Agendas of CARICOM Member States and Strategic Elements 2: Promote the Implementation of Specific Adaptation Measures to Address Key Vulnerabilities in the Region of the Regional Framework's Implementation Plan as well as other on-going coral reef related initiatives within the Caribbean region. The key actions can assist coral reef managers, activities in the coastal zone area, and fisheries managers and local communities to improve the resilience of coral reef ecosystems.

Further ongoing work to understand the impacts of climate change across sectors is the CARIBSAVE Climate Change Risk Atlas (CCRA) project (several references where used in this review). The CCRA project synthesise the current evidence-based, cover several habitats, species and a series of sectors, which are under threat or may be vulnerable. The report also included a section on how these different sectors could adjust their practices and adapt to climate change to enable the sustainable development of these areas whilst still protecting the overall biodiversity and equally supporting the economic development of the Caribbean SIDS. Dedicated effort to document and illustrate the challenges associated with climate change on species and habitats, with likely consequences for biodiversity has been also addressed by governments of Antigua and Barbuda (CARIBSAVE, 2011a). Grenada is also actively committed to adapting to climate change, they have also produced the Strategic Program for Climate Resilience which includes practices and actions for adaptation and mitigation of climate change impacts to this island (CARIBSAVE, 2011d). The Belize Climate Change Adaptation Policy aims to encourage all government agencies to incorporate climate change aspects in their activities and overall policies. One of the most important aspects is to create public awareness and education to support biodiversity conservation (CARIBSAVE, 2011b).

An example of a climate change initiative in Saint Lucia is the Pilot Project on "Climate Resilience". In the health sector, there are a number of ongoing climate related initiatives. One example is the need to "Facilitate the design and/or upgrading and implementation of national programmes for pest and disease control", which deals with the areas of vector and water borne disease monitoring as well as pest and disease monitoring including invasive species. Another specific project has been designed to address issues relating to water quality through the project entitled "Enhancing the Water Quality Surveillance Programme of the Department of Environmental Health". This will be affected through training, as well as the procurement of equipment for water testing. One final multifaceted project entitled "Mitigating the Mental Health Impacts of Climate Change and Climate Variability in Saint Lucia" aims to identify the key mental health impacts related to climate change events on the island and assess their implications, as well as to identify ways to help individuals and communities mitigate and adapt to this social problem (MFEAND, 2011).

Further development of understanding to support adaptation

This review has demonstrated that the majority of the current and future expects climate change effects are based on broad information available in the Caribbean Region. However, for some species and habitats covered in this review there is already some available evidence, but this is still limited. It is important to highlight that climate change effects are still perceived as a new emerging threat in some of these areas. One of the clear challenges is to disentangle the direct effects resulting from climate change with other human pressures (e.g. overfishing, waste treatment, habitat degradations, pH changes, etc.). Some of the SIDS have made a start and attempted to develop effective management practices, to protect these valuable species and ecosystems. Some tangible actions are needed to document how the extent and distribution of biodiversity is being explored or developed in these areas. In the sections below, there are some recommendations that may be useful to set as priorities to ensure the biodiversity of these islands is preserved and where necessary restored:

- Adoption of mapping strategies to ensure there is a baseline of the distribution and extent of these resources (e.g. seagrasses, sea mammals, invasive species). This type of information can help to develop a robust management strategy to protect and monitor climate change effects.
- Development of an annual monitoring plan (including water quality, sedimentation rates, fauna, setting etc.) can help to undertake consistent assessments to identify cause-effect disturbances associated with climate change on these habitats and species. For example, in some areas of the Caribbean there is The Coral Reef Early Warning Systems Network (CREWS), with a suite of meteorological and air-based sensors including air temperature, wind speed and direction, barometric pressure, photosynthetically available radiation (PAR) and ultraviolet radiation (UVR). The basic suite of oceanographic sensors measure salinity, sea temperature, PAR (at 1m nominal) and UVR (at 1m nominal) (for more information visit: http://www.caribbeanclimate.bz/general/coral-reef-early-warning-system-crews.html)
- Protection and adoption of 'No take zones' as Marine Protected Areas, helping to provide protection and refugia for species that may be under threat and to preserve native socks, and where applicable to enable recovery of dedicated areas.
- Caribbean Challenge Initiative, some islands have actively engaged in this ongoing initiative, where there are dedicated actions to protect 20% of the Caribbean marine and coastal ecosystems by 2020 (http://caribbeanchallengeinitiative.org/).
- Multidisciplinary research is clearly needed for the development of more effective conservation strategies. Networks of Protected Areas (NPAs) are seen as critically important to the conservation of biodiversity, but their management is often inadequate or non-existent. Creating successful NPAs will require the input of ecologists, social scientists, and economists in order to develop effective management regimes and secure the input and support of local communities.
- Consideration of restoration strategies are a type of approach which could help to enhance areas where there has been a disturbance or decline of a particular habitat type. Adequate planning to support translocation trials could help to repopulate the damaged habitats (e.g. seagrasses or corals).
- Promotion of knowledge transfer and awareness: organise dissemination workshops to cascade the current understanding of climate change effects, and the importance of preserving habitats and species, targeted at the general public, conservation end-users, and policy makers.
- Creating awareness and investment over targeted projects to understand and disentangle climate and environmental effects (via monitoring work) in small islands. There is a clear gap in the lack of empirical data sets available to understand the present and future climate change impacts. Climate and environmental monitoring data is needed to design and implement management practices to safeguard these areas (Nurse et al.,2014).
- Investment and development of 'fit for purpose' climate change-related projections, which build on the current work conducted on temperature and sea level. The available climate-model projections of temperature and sea level have been useful, but there is clearly a need to develop projections for other variables (pH changes, wind direction, tropical storms, etc.), which are important to small islands.

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