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

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EXECUTIVE SUMMARY

Based on the current observations and climate projections for this region, and knowledge garnered mostly from other tropical regions, it is clear that the fishery sector of Caribbean SIDS is highly vulnerable to climate change.

Reductions in fish and shellfish fishery catches in Caribbean SIDS can be expected to have significant socio-economic impacts on those working in the harvest and post-harvest sectors as well as their dependants. It will also have implications at the level of national governments for: domestic productivity in the fishing sector; food security and food sovereignty (and by implication on the food import bill); export trade and foreign currency earnings.

The catch data in the region are generally of low resolution and there is a dearth of fishing effort and socio-economic data, making quantitative and qualitative assessments of the impacts of climate change to the fishery sector very difficult, and separation of impacts from other stressors and factors remains challenging, especially given their synergistic effects.

Negative impacts that are already obvious in this region include coral bleaching (damaging critical fish habitat), increasing intensity of storms together with increased sea level (damaging fish habitats, fishery access and assets), and sargassum influxes (disrupting fishing operations and communities and impacting the sustainability of the resource).

Coral bleaching will negatively affect fish production and the protection of beaches and landing sites. As a result fishers are affected be declining catches and thus less livelihood and employment opportunities while also suffering from a decrease in food security. Associated industries such as the tourism sector in which fishers often also work will be affected as well.

Enormous influxes of sargassum in recent years have affected the harvest sector and fishing communities by limiting access to fishing vessels and fishing grounds, blocking vessel movement in ports, interfering with fishing gear, damaging vessel motors, affecting the catchability of some pelagic species, and impacting the post-harvesting sector.

Changes in availability of high-value species (e.g. spiny lobster, conch, shrimp and snapper) will have particular impact on the harvest sector (both small-scale and semi-industrial) as fishers productivity and catch per unit of effort will go down and will in turn negatively affect export trade volumes and foreign currency revenue generation.

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EXECUTIVE SUMMARY Cont.

Increased intensity and frequency of storms and hurricanes will affect the safety of fishers at sea and potentially increase the number of accidents. As a result, improved safety-at sea training and associated equipment are required, as well as early warning systems which are currently not prominent in small-scale fisheries across the region.

In the short-term, the reef-associated fisheries, already severely degraded, and on which the region is heavily reliant, will be hardest hit by current and near-future climate change impacts.

Changes in the productivity and distribution of oceanic pelagic species can lead to fishers having to fish longer or travel further to maintain catch rates, or rely on moored FADs to aggregate fishes. In addition, fishers will have to use more ice to ensure similar levels of quality. These factors combined will have financial consequences and safety implications for fishers.

Smaller catches of pelagic species and associated increased ex-vessel prices will have significant impact on the harvest and the post-harvest sector, especially as it is these species that generally support the greatest value-added processing.

Increasing SST in the region is also expected to affect the safety of fish consumption for the local population and tourism industry, as it is expected to increase the level of ciguatera fish poisoning. This will affect food safety as consumers in the region depend on fisheries to a high degree for their consumption of animal protein, as well as affect cultural patterns of fish consumption.

Climate change impacts such as sea level rise, and storms and hurricanes, are expected to impact piers and landing sites and requiring the need for (more) safe harbours and calm moorings.

Decreases in the profitability of fishing will negatively affect the willingness of investors, and the attractiveness of investing in the harvest and post-harvest processing sectors.

Over the longer-term as reef resources become increasingly degraded and over-exploited and pelagic species less available, fisherfolk may have to abandon fishing and look for scarce alternative employment opportunities. This will likely require government incentives and training programmes to retool fishers. Alternatively, the sector may adapt by switching from small-scale to medium-sized boats, resulting in higher capital investment and maintenance costs as well as higher potential losses in cases of extreme-weather events.

Reducing abundance of fish and shellfish resources will also exacerbate conflict, not only intra-fisheries conflict amongst fishers competing for the same limited resource, including commercial versus recreational fishers, but also between the fisheries sector (consumptive users) and other non-consumptive users (e.g. recreational divers). The latter will be especially acute for reef fishes.

Fish resources in the region are commonly transboundary and shared amongst multiple nations. Changes to their distribution and connectivity (of particular importance for pelagic species) due to climate change could ultimately impact on their current management arrangements including multi-lateral or international agreements.

Changes in fish stock abundance as a result of climate change may also impact existing allocation arrangements between countries.

Climate change also challenges the effectiveness of many current fishery management regulations, and will increasingly exacerbate the ongoing decline of fish resources in the region, caused by overfishing and degradation of the marine environment.

Introduction

Importance of the fishing sector

The Caribbean region comprises more than 7000 islands, islets, reefs and cays (Palanisamy *et al*., 2012). The majority of the population inhabits the coastal zone, and there is a very high dependence on marine resources for livelihoods from fishing and tourism, particularly among the small island developing states (SIDS) (Monnereau *et al*. 2015). It is therefore not surprising that the fisheries sector supports the socio-economic viability of coastal communities by providing direct employment, livelihood and benefits to thousands of people in the region. The Caribbean fishery sector is important in terms of food security in the region as annual fish consumption per capita is on average some 20 kg, contributing between 2 and 15 percent of protein intake of the population in the region (FAO, 2016a). The sector also provides employment in the post-harvest sub-sector in marketing, trading and processing as well as in many ancillary services. However, the contribution of the fisheries sector to Gross Domestic Product (GDP) in the Caribbean can be considered relatively minor according to official statistics[1] particularly compared to, for example, the tourism sector. It should be noted that GDP is calculated from the ex-vessel value of fish landed, and this underestimates the true economic value of fisheries in the Caribbean by ignoring the value added throughout the fish chain (Mahon *et al*., 2007; Masters, 2012). Furthermore, these figures do not include the contribution of the recreational fishery, which is a rapidly growing subsector closely linked to tourism. At the government level the sector provides revenues through licence fees, lease of fishing rights, vessel registration fees, taxes on landings or on sales, export duties and royalties, income and company taxation from employees and owners of fishing and processing companies, as well as saving foreign exchange on the food import bill and earning foreign exchange from exports (Macfadyen & Allison, 2009). This latter point is of particular importance to countries, for example the Bahamas, Belize, Guyana and Jamaica, which export significant amounts of high-value seafood species such as lobster, conch and shrimp. It can therefore be concluded that overall, the fisheries sector is important to social and economic development in the Caribbean.

Special vulnerability of SIDS

Caribbean SIDS share similar sustainability challenges related to their specific characteristics such as small size, susceptibility to natural disasters and climate change, vulnerability to external shocks, concentration of population and infrastructure in the coastal zone, high dependence on limited resources including marine resources; fragile environments, and excessive dependence on international trade (Guillotreau *et al*., 2012; Mimura *et al*., 2007; Nurse *et al*., 2014; Polido *et al*., 2014; Monnereau *et al*., 2017). Monnereau *et al*. (2017) recently carried out an assessment of climate change vulnerability of the fisheries sector at the national level across 173 countries, based on 35 indicators across the components of exposure, sensitivity and adaptive capacity. Their data suggests that the fisheries sector in SIDS are the more vulnerable in comparison to other country groups to climate change, and that the Caribbean region is particularly vulnerable.

Chronic anthropogenic stressors

Alongside the pressures now faced by the sector in terms of climate change, the marine ecosystems in the region have seen unprecedented challenges over the past decades through, *inter alia*: fisheries overexploitation (including illegal unreported and unregulated (IUU) fishing), pollution of coastal waters (e.g. sewage and agricultural runoff), invasive species, habitat destruction, and coastal erosion (Fanning *et al*., 2011; FAO, 2016a). Some 55 percent of the commercially harvested fisheries stocks in the region are already overexploited or depleted and some 40 percent of the stocks are fully exploited (FAO, 2016a). In addition, IUU fishing is estimated at between 20 and 30 percent of total reported production levels (FAO, 2016a). For the Wider Caribbean region fish production is currently around 1.4 million tonnes, 300 thousand tonnes below the 30 year average (FAO, 2016a). In addition, more than 75% of the reefs in the Caribbean are already threatened by anthropogenic activities, with more than 30% in the high and very high threat categories (Burke *et al.*, 2011). The insular Caribbean reefs are particularly at risk: from Jamaica through to the Lesser Antilles, more than 90 % of all reefs are considered threatened, with nearly 70% classified as high or very high threat (Burke *et al*., 2011). Climate change will exacerbate these threats faced by coral reefs in the region.

Key climate change stressors and fisheries of Caribbean SIDS

Recent substantive reviews that have examined the impact of climate change globally on marine ecosystems include Hoegh-Guldberg & Bruno (2010), Cheung *et al*. (2010), Doney *et al*. (2012) and those of the Working Group II (WGII) of the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (Magrin *et al*., 2014; Nurse *et al*., 2014; Pörtner *et al*., 2014; Wong *et al*., 2014). There have been very few reviews that have considered possible climate change impacts specifically on Caribbean marine resources supporting fisheries (e.g. Lum Kong, 2002; Mahon, 2002; McConney *et al*., 2009, 2015; Nurse, 2011; and Simpson *et al*., 2009). A review of available literature published since Nurse (2011) has confirmed what he reported at the time as a scarcity of studies on the impacts of climate change on fishery species and the fisheries sector specific to the Caribbean region, perhaps with the exception of coral reef fishes (e.g. Burke *et al*., 2011; Mumby *et al*., 2014; Rogers *et al.,* 2014).

Stresses on marine and coastal ecosystems are expected to be exacerbated by direct and indirect climate change impacts such as sea level rise (SLR), sea surface temperature (STT) increases, ocean acidification (OA), and increased intensity of storms and hurricanes. The direct and indirect impacts of climate change drivers will result in changes at the level of the harvest and post-harvest sectors, as well as at the broad national level (Macfadyen & Allison, 2009). These changes can be expected to be somewhat different across the four Caribbean major fish groups: (1) reef-associated shallow shelf species; (2) deep slope species; (3) shrimp and groundfish and (4) oceanic pelagic species. These four groups are loosely categorized by the environment (broad habitat types) in which they are found, as well as gears and techniques used to harvest them, and the scale of fishery operations and the post-harvest sector (see Table 1). Climate change impacts in on these four fishery groups can be expected to differ based on their dissimilar biological and

[1] e.g. see http://www.crfm.net/ for member state profiles

ecological characteristics; the different types of fisheries exploiting them; and the different national level socio-economic and governance conditions. Impacts on the harvest sector will relate to changes in the capture yield of fish and shellfish and the changes required to associated boats, gears and fishing techniques. Post-harvest activities may be impacted anywhere along the value chain after the catch is landed, such as handling and transportation, processing, preserving, storing and distribution of fish and fishery products. At the national level, climate change can impact the level of revenues, exports, per capita fish supply, and contributions of the fisheries sector to employment and GDP. It may also require changes to current management and legislation of fisheries. This paper will address the climate change impacts on these four fishery groups in the Caribbean region.

What is Already Happening?

Scientific evidence suggests that the Caribbean region is already experiencing the effects of changes in climate (Eakin *et al*., 2010; Nurse, 2011; Nurse *et al*., 2014; Nurse & Charlery, 2016; Mimura *et al*., 2007; Oxenford *et al*., 2008; Pörtner *et al*., 2014).

Sea level rise (SLR)

In the Caribbean region the mean sea level rise (SLR), amounting to 1.8 ± 0.1 mm/yr, has been similar to the global mean (≈ 1.8 ± 0.5 mm/yr) over the last 60 years (Palanisamy *et al.,* 2012). However, the advances made in examining the potential effects have largely been at either the global level, or focused on the temperate zones and there is less downscaled level data available for the Caribbean region. However, Palanisamy et al. (2012) have shown a variation of sea level rise across the region whereby their findings indicate that the observed interannual sea level variability was higher in the Northern Caribbean than in the Southern Caribbean while the Eastern Caribbean shows a greater interannual variability during recent decades. The literature suggests that sea level rise is occurring in the region and seems likely to accelerate (Meehl et al. 2007, Cazenave and Llovel 2010). However, the processes driving coastal flooding and erosion are more related to sea surges driven by tropical storms, and hurricane activity and tidal ranges, on top of rising sea levels.

Sea-level rise in the region has already impacted the fisheries sector (in particular in combination with damages caused by storms and hurricanes) by means of beach erosion and the impacts thereof on housing and fisheries landing sites. In Barbados, for example, fishers have had to relocate in the Sixmens fishing community partly as a result on the increasing level of beach erosion.

Extreme weather events

During the past decades, unusual extreme weather events have affected the Caribbean region contributing to the vulnerability of human systems to natural disasters (Magrin *et al*., 2014). Evidence suggests that more disturbances in the Atlantic are reaching tropical cyclone intensity and that the frequency of hurricanes in the Caribbean has increased over the period 1944 – 2006 (Elsner & Jagger, 2008), showing a dramatic increase in frequency since 1995 (Pulwarty *et al*., 2010). However, there is disagreement in the literature, with other studies suggesting that there has been a decrease in the total number of hurricanes but an increase in hurricane intensity, with a higher number of category 4 and 5 hurricanes in this region (Bender *et al*., 2010; Zhao & Held, 2010; Murakami *et al*., 2012).

Recent storms and hurricanes have caused substantial damage to the fisheries sector in the region. In 2008 Hurricane Gustavo caused a 14 million USD loss to the marine fisheries sector in Jamaica, related mainly to the loss of fishing gear, particularly fish traps that were left at sea during the passage of the storm (Planning Institute of Jamaica, 2008). In 2010 Hurricane Earl caused a total of 122,000 USD in damage to the fishing sector in Antigua and Barbuda due largely to loss and damage of boats and gear. In 2015 Hurricane Erika caused over 2 million USD in damage to the fisheries sector in Dominica, with 95% of the damages being to engines and boats (COD, 2015). A recent study on poverty among fishing communities in CARICOM showed that 37% of households surveyed claimed to have been adversely affected by an environmental hazard, with Montserrat, Jamaica, Guyana, St. Vincent and the Grenadines, Belize, and Grenada being the countries most affected (CRFM, 2012). Hurricanes and floods were listed as the most common major environmental hazards which fisher households in CARICOM countries have to face (CRFM, 2012).

Sea surface temperature (SST)

The Caribbean Sea has warmed by approximately 1.5°C over the last century (Palanisamy *et al*., 2012) and is expected to rise further by an average of 1.4ºC by 2081–2100 compared to 1986–2005 levels (Nurse *et al*., 2014). Extreme high sea surface temperatures (SSTs) have been increasingly documented firstly in the western Caribbean, and since 2005 across the entire Caribbean, resulting in repeated mass bleaching events (1993, 1998, 2005 and 2010) on the Mesoamerican barrier reef system of Belize, Honduras, and Guatemala (Eakin *et al*., 2010). In 2005 SSTs exceeded any values in the 150-year record for the Caribbean Sea, and thermal stress was the highest ever recorded, resulting in a mass coral bleaching event that affected 80% of all Caribbean reef corals, after which up to 40% died (Wilkinson & Souter, 2008; Eakin *et al*., 2010). In 2010 the entire Caribbean was again affected by a mass coral bleaching event (Eakin *et al*., 2010; Jackson *et al*., 2014).

Coral bleaching can have severe effects on reef health and productivity, especially on reefs already degraded by other anthropogenic stressors. Increasing SST together with other anthropogenic activities causing eutrophication (increased nutrient load) can also enhance the blooming of pelagic (floating) algae which can harm tourism-based economies, smother aquaculture operations or disrupt traditional small-scale fisheries (Smetacek & Zingone, 2013). Such events are becoming more common, with the Caribbean experiencing unprecedented influxes of pelagic sargassum since 2011 (Franks *et al*., 2012; Smetacek & Zingone, 2013). These extraordinary sargassum blooms, entering the Caribbean Sea through the Lesser Antilles as large floating mats, have resulted in mass coastal strandings of sargassum seaweed throughout the region (especially severe in 2011 and 2014-2015), with seaweed drifts accumulating up to several metres high along beaches, which have in turn impacted fisheries and fishing communities by limiting access to fishing vessels and fishing grounds, blocking vessel movement in ports, interfering with fishing gear, damaging vessel motors, affecting the catchability of some pelagic species, and impacting the post-harvesting sector (Ramlogan *et al*., in press).

Ocean Acidification (OA)

The elevated levels of carbon dioxide (CO_2) in the atmosphere have resulted in an increased uptake of CO_2 at the ocean's surface, manifesting as higher partial pressure of CO_2 (pCO_2) in the ocean and leading to a decline in seawater pH and a change in the relative concentrations of carbonate, bicarbonate and hydrogen ions and decreasing carbonate/aragonite saturation state. The outcome of these chemical processes in seawater is referred to generally as 'ocean acidification' (OA) (Doney, 2010). Since the 1800s, the surface ocean pH has decreased by 0.1 units and it is predicted to decline another 0.2–0.5 units by the end of this century (Cummings *et al*., 2011). In the Caribbean basin, a recorded decrease in the pH of seawater has followed the global trend and has been accompanied by a sustained decrease in the aragonite saturation state over the period 1988 – 2012, although there have been seasonal and spatial variations in the region (Mumby *et al*., 2014). There has no evidence yet of impacts of the declining pH levels in the Caribbean region.

What Could Happen?

Introduction

The chronic stresses on marine and coastal ecosystems in the Caribbean (including overexploitation of fishery resources from legal and IUU fishing, coastal development and water pollution *inter alia*) are expected to be further exacerbated in the near-future by direct and indirect climate change impacts such as SLR, SST increases, OA, and increased intensity of storms and hurricanes (Allison *et al*. 2009; Cheung *et al*. 2010; Hallegraeff, 2010; Mora 2013; Nurse 2011; Sumaila *et al*. 2011; Pörtner *et al*., 2014).

As the ocean becomes warmer, less oxygenated, more stratified, and more acidic (see Sumaila *et al*., 2011; Pörtner *et al*., 2014) there will be spatial shifts in distribution of marine fishery resources (permanent and seasonal migrations) (Cheung *et al*., 2010; Perry *et al*., 2005; Poloczanska *et al*., 2013), changes to species community structure (Hall-Spencer *et.al*, 2008; Brierley & Kingsford, 2009), reduced productivity of most marine organisms and ecosystems (Perry *et al*., 2005; Cheung *et al.*, 2010; Pörtner *et al*., 2014; Lam *et al*., 2016) reduced size of fish (Sheridan & Bickford, 2011; Cheung *et al.*, 2012) and reduced coral reef health (Burke *et al.,* 2011; Jackson *et al*., 2014). As a result, there will be changes in the potential catches of exploited marine species (Barange *et al*., 2014; Cheung *et al*., 2010; Muhling *et al*., 2011; Pörtner *et al*., 2014; Sumaila *et al*., 2011).

Sea level rise (SLR)

The IPCC reports indicate that by the end of the century (2090-2099) there will be major rises in sea level in the Caribbean and the Atlantic compared to 1980-1999 levels, attributable to the change in seawater density and ocean circulation patterns, which is expected to be as much as 5 cm greater than the projected world average of between 0.21 - 0.48 m (Meehl *et al*., 2007).

Threats from sea level rise and related floods especially during storms will affect coastlines and critical shallow habitats such as mangroves, seagrass beds and coral reefs (Orth *et al*., 2006; McKee *et al*., 2007; Hoegh-Guldberg & Bruno, 2010; Ward *et al*., 2016). Mangroves are affected by sea level rise as they are particularly sensitive to changes in inundation duration and frequency as well as changes in salinity levels that can lead to shifts in species composition and ultimately to a reduction in productivity and ecosystem services (Ward *et al*., 2016). Mangroves are expected to respond to rising sea level by retreating shoreward, however, the topography of the shoreline together with the level of shoreline development will play a major role in determining whether the habitat will retreat or be lost due to sea level rise (Mahon, 2002). Elevated sea levels can also impact the health of coral reefs. Deeper reefs can be expected to 'drown' due to elevated sea levels (Van Woesik *et al*., 2015), meaning that they will no longer receive sufficient light due to their greater depth below the surface. This will also have a similar effect on seagrass beds. Changes in sea level can also impact the amount of wave energy that reefs experience and their effectiveness at attenuating wave action, thereby increasing the risk of shoreline erosion from both regular wave events (e.g., trade wind driven waves) and storm events (e.g. hurricanes). The negative impacts of sea level rise on critical nearshore benthic habitats that provide nurseries, shelter, living space and food for adults of commercially important species, and provide supporting ecosystem services to one another and to people (especially coastal fishing communities) by protecting coastlines from erosion, can be expected to have a ripple effect on the fisheries sector.

Loss of critical habitats will result in decreased fish production and reduced sustainable fishery yields, particularly of reef-associated fisheries whose target species rely on healthy reefs, mangrove and seagrass habitats, but also on shrimp fisheries and deep slope fisheries because of damage to critical nursery habitats for these species (mangrove estuaries and coral reefs respectively). Increased sea level, flooding and coastal erosion will impact fish landing beaches, sheltered mooring sites and fishing infrastructure such as jetties, slipways, harbours and coastal markets, and could result in significant disruption, destruction or even relocation of landing sites, market infrastructure and coastal homes.

Sea surface temperature (SST)

There is spatial differentiation in the projected changes with temperature increases expected to be least in the northern and northwestern Caribbean where values vary between 0.5 and 1.0 °C above the mean temperatures for the period 2000–2009 (observed data), while in the remainder of the Caribbean region, the projected SST increase, relative to 2000–2009 varies by between 1 °C and approximately 1.5 °C (Nurse & Charlery, 2016). In the decade of the 2090s, the warming trend is expected to continue with the temperature increase expected to be between 1.5 °C to >2 °C throughout the year, with the same type of spatial variation expected across the region, whereby the northern and northwestern Caribbean are least affected (Nurse & Charlery, 2016).

Rising SSTs are causing fundamental changes to marine ecosystems (e.g. Doney *et al*., 2012; Llopiz *et al*., 2014). Among the multitude of expected impacts are: poleward shifts in plankton and fished species; changes in timing of phytoplankton blooms; changing zooplankton composition; changes in fish distribution; coral reef degradation through mass coral bleaching and mortality; increased incidence of marine diseases; changes in physiology and behaviour; altered timing and duration of spawning and migrations; disruption to food webs; and changes to population genetic structure and productivity. All of these changes have the potential to change production of fish and thus in the potential catches of exploited marine species (Cheung *et al*., 2010; Muhling *et al*., 2011; Sumaila *et al*., 2011; Pörtner *et al*., 2014; Barange *et al*., 2014). Increasing SST together with other anthropogenic activities causing eutrophication can also enhance the blooming of pelagic (floating) algae which can harm tourism-based economies, smother aquaculture operations or disrupt traditional small-scale fisheries (Smetacek & Zingone, 2013).

If extreme sea surface temperatures were to continue, the projections using Special Report on Emissions Scenarios (SRES) indicate that it is possible that the Mesoamerican barrier reef system will collapse by mid-century (between 2050 and 2070) (Vergara, 2009). Changes in reef productivity will also have impacts on trophic linkages among coastal habitats and will affect both the nearshore and the oceanic pelagic food chain such that impacts will not be limited only to reef fishes. For example, the nearshore schooling pelagic species thrive on zooplankton and small fishes mostly produced by coral reefs, whilst many of the large oceanic species such as dolphinfish consume a surprising amount of reef fish as pelagic larvae and juveniles (Oxenford & Hunte, 1999; and references therein). Many deepwater species migrate toward the surface at night to feed, returning during the day and thereby forming a trophic link between surface waters and the benthopelagic fishes. The deepwater snappers and groups of the deep slope fisheries may also be affected by the impacts of increased SST on the timing and location of spawning aggregations (Erisman & Asch, 2015).

Long-term changes in SST can also cause changes in fish distribution (Chueng *et al*., 2010; Pinnegar *et al*., 2013; Lam *et al*., 2016). The effects of climate change are expected to be most pronounced in the tropics because many tropical marine species have narrow thermal tolerances and live at or near their upper thermal limits (Hoey *et al*., 2016). Commercially important fish stocks are therefore expected to gradually move polewards (Cheung *et al*., 2010). As such, fish stocks within the semi-enclosed Caribbean Sea could shift towards the northern Caribbean, but would eventually be constrained by land barriers. The less mobile species (e.g. reef-associated shallow shelf species) would likely become more scarce or even regionally extinct, whilst the highly migratory oceanic pelagic fishes (e.g. yellowfin tuna, skipjack tuna, swordfish, billfishes); and regional large pelagics (e.g. wahoo, dolphinfish, blackfin tuna and mackerel species) will likely move poleward in the Atlantic. If they move at predicted global median rates of between 28 – 36 km per decade (Cheung *et al*., 2012), they would quickly become beyond the reach of small-scale fishers in this region; even the most mobile semi-industrial fleets, and could move beyond the relatively limited EEZs of most Caribbean states within a matter of years. Furthermore, a global analysis predicting changes in maximum body weight averaged over fish assemblages showed that fish size in the Caribbean region is expected to decrease significantly by 5-19% from the year 2000 to 2050 as a result of oxygen-limited growth of individual fish as well as a change in species composition to smaller-sized species (Cheung *et al*., 2012). Their model also demonstrated considerable variation within the region, showing the greatest size decreases (by as much as -49%) in the northern Caribbean Sea.

Increasing SSTs and disturbance events such as hurricanes are also considered to be a significant factor in the increased occurrence of the benthic dwelling, tropical diatoms responsible for producing the potent neurotoxin (ciguatoxin) that bioaccumulates up the fish food chain and causes ciguatera fish poisoning (CFP) in humans consuming ciguatoxic reef fish (Chateau-Degat *et al*., 2005; Tester *et al*., 2010). CFP, which occurs in tropical regions around the globe, is among the most common non-bacterial foodborne illness associated with the consumption of marine products worldwide (Nurse *et al*., 2014) and affects an estimated 200,000 - 500,000 people a year (Goater *et al*., 2011). Consumption of tainted fish can lead to gastrointestinal distress followed by severe neurological and cardiovascular symptoms that can persist for months or even years and, in rare cases, result in death (Tester *et al*., 2010; Goater *et al*., 2011).

Ocean acidification

Since the 1800s, the surface ocean pH has decreased by 0.1 units and it is predicted to decline another 0.2–0.5 units by the end of this century (Cummings *et al*., 2011). In the Caribbean basin, a recorded decrease in the pH of seawater has followed the global trend and has been accompanied by a sustained decrease in the aragonite saturation state over the period 1988 – 2012, although there have been seasonal and spatial variations in the region (Mumby *et al*., 2014). Countries in the higher latitudes are predicted to be particularly affected due to colder waters having naturally low carbonate saturation levels (Cummings *et al*., 2011). Nevertheless it is expected that as oceans continue to acidify the negative impacts on coral reef accretion rates and other tropical calcifiers (e.g. shellfish) could become important (Brierley & Kingsford, 2009; Doney *et al*., 2009; Semesi *et al*., 2009).

Data on the potentially harmful effects of ocean acidification specifically for the Caribbean region are lacking, but evidence from other regions suggests that ocean acidification can have a range of other direct, far-reaching physiological impacts on marine water-breathing organisms including: a reduction in metabolic rate; impairment of neurotransmission and behavioural responses; changes to gene expression and protein synthesis *inter alia* (see Wittmann & Portner, 2013 for meta-analysis). The ultimate impacts of these changes is a new and complex area of study and it is therefore very difficult to make predictions, especially given the significantly different responses across different life history stages and different taxa (see Llopiz *et al*., 2014; Ries *et al*., 2009; Wittmann & Portner, 2013). The general consensus to date is that corals, echinoderms (e.g. urchins and sea cucumbers) and molluscs will suffer the greatest impacts; whilst the crustaceans (e.g. shrimps and lobsters) will not be significantly impacted until well after the year 2100 (Wittmann & Portner, 2013). They suggested that fish will likely be the least affected as adults, but higher mortality in the pelagic larval phases may be sufficiently serious to affect overall recruitment success and the sustainability of fish populations (see Llopiz *et al*., 2014).

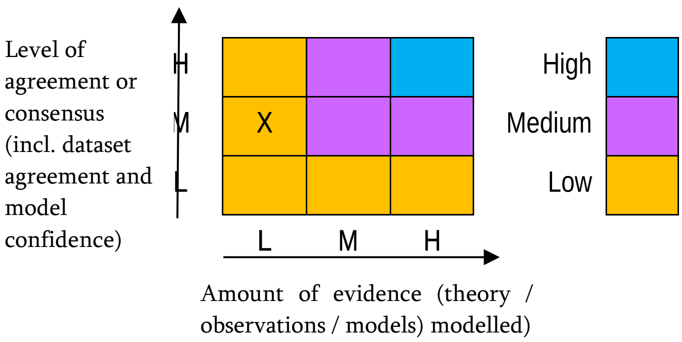
Extreme weather events

Projections so far indicate that further enhanced hurricane intensity is likely in this region with continued global warming and increasing SSTs (Elsner *et al*., 2008; Bender *et al*., 2010;), but it is recognised that the current understanding of tropical cyclone generation and frequency is still limited. Hurricanes are known to exact a significant toll on critical marine communities in the Caribbean including mangroves (McCoy *et al*., 1996; Sherman *et al*., 2001; Parenti, 2015), coral reefs (Gardner *et al*., 2005; Heron *et al*., 2008; Lugo *et al*., 2000), and seagrass beds (Fourqurean & Rutten, 2004). Hurricanes can cause extensive physical damage to coral reefs, reducing areas to rubble and reducing live coral cover by 17%, on average, in the year following a hurricane in the Caribbean region (Gardner *et al*., 2005). Shallow corals reefs are most affected as this is where the wave action is greatest (Mahon, 2002). The resultant loss of reef architecture will probably have the greatest impact on reef fish size and abundance. Rogers *et al*. (2014) have recently demonstrated a 3-fold decline in commercial fish biomass on reefs in the Bahamas when transitioning from a high- to a low-complexity reef. Increased hurricane severity will increase the damage inflicted on reefs and other critical habitats in the region and will thus lengthen the time needed for natural recovery, especially for reefs that are now in poor health from a multitude of other anthropogenic stressors (see Burke *et al*., 2011). The fisheries sector will be further impacted by the impacts of sea level rise combined with increased intensity of storms and hurricanes on the fisheries facilities and infrastructure (e.g. the disruption, destruction and relocation of landing sites due to coastal erosion and flood damage).

The magnitude of future impacts, and the ability of marine ecosystems and fisheries to adapt, depends on the rates of change of climatic stimuli and their effects, the response of the marine systems to climate change, and other factors such as: socio-economic adaptive capacity (e.g. governance); market developments; and other ecological drivers (e.g. pollution and habitat degradation).

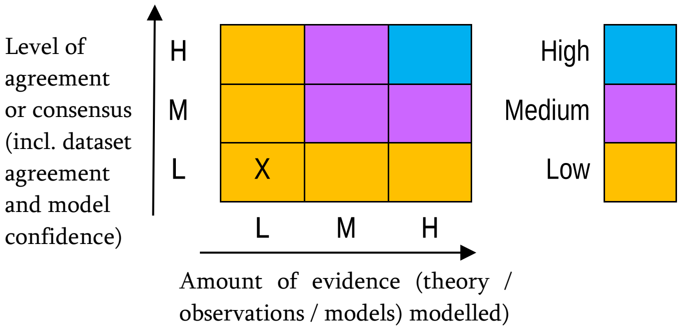
Confidence Assessment

What is already happening



Medium/high level agreement based on the very few studies published for the Caribbean region supported by impacts reported in other similar, tropical fisheries. There remain significant difficulties with separating climate change impacts from other chronic anthropogenic impacts (e.g. degradation of habitats).

What could happen in the future



Low level agreement based on the absence of any research in this area and tangible evidence in the Caribbean. Projections are complicated by an absence of knowledge regarding synergistic effects of the multiple climate change stressors combined with other anthropogenic stressors and external market forces and demographic changes.

Knowledge Gaps

Despite the significant progress made in advancing climate change science research in the Caribbean in recent years we have not seen a corresponding development in regional impact studies focused on social and economic systems. Data collection in the region has been very limited to date, which compromises the ability to adequately assess climate change impacts on resources and the fisheries they support.

There is inadequate knowledge on the current status of stocks supporting the key fisheries, and on the relative contribution of climate change and other stressors, and factors affecting harvest and post-harvest sectors.

There is a need for downscaled modelling to assess climate change impacts on key species in the region.

There is a need to assess the linkages between sargassum influxes' and key pelagic species.

There is insufficient economic data for fisheries especially for the post-harvest value chain, to understand the financial consequences of climate induced changes.

There is insufficient social data on the fisheries sector to understand the social consequences of climate induced changes.

Finally, there is insufficient knowledge on the changes needed to fisheries plans, policies and legislation at the national and regional level to address anticipated changes due to climate change.

Socio-economic Impacts

Despite some progress made in advancing climate change science research in the Caribbean in recent years there have not been many impact studies focused on social and economic system implications for the fisheries sector. There have been no quantitative studies specifically related to impacts on changes in fisheries production, fish size or fish distribution for the region or the socio-economic consequences thereof. The direct and indirect impacts of these climate change drivers will result in changes at the level of the harvest and post-harvest sectors, as well as at the broader national level. These changes can be expected to be somewhat different across the four Caribbean major fish groups: (1) reef-associated shallow shelf species; (2) deep slope species; (3) shrimp and groundfish; and (4) oceanic pelagic species. In Table 2 we highlight some of the key messages from the sections below.

Climate change impacts on the harvest sector

The harvest sector in the Caribbean region can be expected to be heavily impacted by the aforementioned changes in distribution, production, fish size as well as the direct and indirect impacts of increased intensity of extreme weather events. The fisheries sector in the Caribbean SIDS (see Table 1) is primarily small-scale and multispecies, whereby the majority of fisherfolk have privately owned, small operations and the focus is on harvesting, utilising small boats and limited technology and non-selective gear such as traps, cast nets, and hook and line. This is especially characteristic of the reef-associated shallow shelf fisheries. Furthermore, most small-scale fishers within the Caribbean, especially the reef-associated shallow shelf fishers have one or more additional or alternate seasonal sources of income within the fishery sector, or from other sectors especially tourism and construction (see Gill *et al*., 2007; Gill *et al*., in press; Mumby *et al*., 2014).

There are however also a number of semi-industrial fleets comprising company-owned, larger capital-intensive vessels which operate mainly in offshore areas, targeting higher priced and value-added species such as spiny lobsters, conch, shrimp and prawns, and large tuna.

As fisheries resources change, it is argued that small-scale fisheries will be less able to adapt due to their limited financial resources and limited mobility (Daw *et al*., 2009). Likewise, single species fisheries will be less flexible in the face of declines (Holbrook & Johnson, 2014). Furthermore, fisherfolk dependent on local resources of a limited number of species are expected to be more vulnerable to fluctuations in stocks, whether due to overfishing, climate change, or other causes (Brander, 2010). However, one might also expect that the reliance on more than one source of income by the majority of fishers makes a fishery more resilient to declines in catch rates. Although we have no specific data for the Caribbean SIDS on the socio-economic implications of range-shifting or decline in marine species, we can hypothesize (as did Mahon, 2002) based on expected reductions in fish production associated with the host of negative impacts from climate change stressors (as reviewed in Section 3) that fisherfolk in general will face decreasing catch per unit of effort (CPUE) and their fishery-related income can be expected to be compromised.

As MacNeil *et al*. (2010) pointed out; the greatest fisheries losses from climate change are likely to occur among reef-based fisheries, at least in the near-future. Although there is a dearth of reliable catch data within the reef-associated fisheries in the Caribbean, reconstructed landings in this region by the 'Sea Around Us' project have revealed a 20% decline in landings of reef-related catch between 2000 and 2010, suggesting that degradation of essential reef and associated habitats has been a significant factor (Sea Around Us, 2015). Given these facts, reef fishers in the Caribbean SIDS can be considered to be in the front line of climate change impacts. In response, reef fishers may shift their focus to fishing different species, implying a potential shift in gear types or even vessel type. Given the on-going efforts in many countries, especially in the Lesser Antilles, to attract fishers away from already over-exploited reef-associated fisheries, the move is likely to be into the oceanic pelagic fishery, especially where facilitated by moored FADS (e.g. Antigua and Barbuda, Dominica, Grenada, Martinique, St Kitts/Nevis, St Lucia, St Vincent and the Grenadines) (CRFM 2015). Alternatively, as reported by Gill (2014) when investigating reef fisher responses to hypothetical reductions in fish size and abundance across nine different fishing communities in the Bay Islands of Honduras, Barbados and St Kitts/Nevis, fishers may simply remain in the fishery, reduce their fishing effort, or opt out of fishing altogether in locations where other employment opportunities exist, in order to maximize their total income from multiple sources. In contrast with the results reported for reef fishers in Tanzania (Cinner *et al*., 2011), a minority of Caribbean reef fishers stated that they would increase their fishing effort in the face of declining catches (Gill, 2014). As reef based fisheries will experience declining fish catches, SCUBA and hookah divers will have to access deeper fishing grounds potentially resulting in more fishers suffering from death or permanent disability from decompression sickness.

Deep-slope fisheries in the Caribbean region are of limited significance. The fishers use small-scale open boats where the drop off is close to shore (e.g. Grenada), to medium-sized vessels with inboards like those in Barbados (which are involved in offshore fishing during the pelagic season), to semi-industrial vessels used off Guyana where the deeper waters are at a significant distance from the shore. It is possible that the abundance and productivity of the fishery will be affected by climate change impacts on the early life stages of this group. This as they have a bi-phasic life cycle whereby their eggs and larvae would be similarly vulnerable to changes in ocean currents and SST change while newly settled larvae and juveniles of many deep slope fish use shallow coral reef habitats as nursery areas, and the adults may use reefs as spawning aggregation sites. These habitats are expected to be significantly affected by climate change impacts thus affecting fish production of these species. Due to SST changes, deep-slope fisheries can be expected to move to deeper waters. Changes in the productivity, and the distribution of deep-slope fish to deeper waters will likely result in reduced abundance and catchability for fishers. As deep-slope fish are caught with deep lines or in deep set traps, the harvest of deep-slope fish would therefore require more capital investments as fishers will need more mechanized reels and winches to haul gear from deeper water. In countries where the drop off is far out at sea, increased intensity of storms and hurricanes can affect the safety of fishers, and fishers might have to change to boats of a larger size. These changes will thus have both financial as well as safety implications for fishers.

Changes in the productivity and distribution of oceanic pelagic species, such as dolphinfish, tuna, and tuna-like species, are likely to result in reduced abundance and catchability, as stocks are predicted to move northwards and beyond the limited reach of small-scale fleets at least within the southern Caribbean SIDS. In the short-term, these typically full-time fishers will likely have to fish longer or travel further to maintain catch rates, or rely on moored FADS to aggregate fishes. The former will have both financial and safety implications for fishers. Over the longer-term fisherfolk may be expected to change from small-scale to medium-sized boats, resulting in higher capital investment and maintenance costs as well as higher potential losses in cases of extreme-weather events. A number of SIDS (e.g. Dominica, St. Kitts and Nevis and Montserrat) also have very limited EEZs and some have no access at all to 'high seas' (e.g. Cayman Islands and Jamaica), constraining the ability of fishers to expand their fishing ranges without new or revised bi-lateral or multi-lateral fishing agreements with their neighbouring countries. Thus reductions in oceanic pelagic species can be expected to have high impacts on revenues for fisherfolk as well as on other actors in the fish chain, and will have implications at the level of national governments for food security, fishing sector production and regional and international fishing access agreements.

Shrimp and groundfish species mostly rely on estuarine nursery areas, including mangroves and seagrasses, and offshore deeper soft bottom areas as adults. These key habitats are under threat from SLR and salt water intrusion due to increased storms and hurricanes, potentially degrading juvenile habitats. These species also have bi-phasic life cycles with free-floating pelagic early life stages and a benthic adult stage. As a result, they are share the same potential threats posed to their early life stages as for the other groups. Ocean acidification can also be expected to have an impact on the species. When considering the impacts of ocean acidification on shrimp species in another region, data revealed that shrimp actually showed a positive response with net calcification rate, increasing linearly with increasing CO_2 levels (Reis et al. 2009). However, other research has shown that even though the exoskeleton was heavier, it was less flexible and more brittle and as a result, more likely to fracture during sudden movements such as predator defence or sudden escape response. The impacts of potentially thicker exoskeletons on the fishery, especially with regard to processing, is still unknown.

The significant and unprecedented mass influxes of pelagic sargassum into the Caribbean in recent years (2011, 2014-2015), serve as an example of the multiple and far-reaching impacts that can be caused in the fishery sector by climate change and other anthropogenic stressors that together are altering ocean temperatures and productivity, and changing regional winds and ocean currents. From our own observations and those reported by Franks *et al*. (2012) and Ramlogan *et al*. (2017), direct impacts on the harvest sector at sea included: entanglement and damage to fishing gear (lines and nets); reduction in catches of key species such as flyingfish through reduced effectiveness of drifting FADs; interference with the normal operation of motor vessels including damage to inboard engines; and clogged mooring areas and harbours reducing the number of fishing days. The weed also brought unexpected bounty to the Lesser Caribbean SIDS including large numbers of very small juvenile dolphinfish, as well as jacks and other reef-associated small pelagics. Whilst catch of juvenile dolphinfish partially relieved low catches in the flyingfish fishery, these were primarily sold as low value fish and did not necessarily boost the revenues of fishers. Furthermore, their sale in local markets caused an outcry by many consumers, and could potentially affect the yield later on in the same season (since dolphinfish are essentially an annual species) and could also affect the sustainability of the fishery in the long term by this switch to harvesting immature individuals which could result in a recruitment failure.

Adverse weather conditions alone, or resulting in the destruction of boats, loss of gear, or damage to landing sites, will reduce or temporarily stop fishing activities or prevent access to some fishing grounds (Mumby *et al*., 2014). As such any increase in these unfavourable or extreme events will impact the total revenue per vessel and the total fish yield. The costs associated with fishing, particularly maintenance and insurance, could also be affected, although it is worth noting that most small-scale fishing enterprises in the Caribbean currently have no access to affordable insurance (Tietze & VanAnrooy, *forthcoming*). These authors report on research in 11 Caribbean countries amongst 109 fishers which showed that only 3 fishers (3%) have insurance for their vessels and/or assets. The large majority of small-scale fishers in these 11 countries (97%) have not insured their boats or assets. For them, insurance is often not available or affordable, resulting in high economic risk to individuals.

Lost fishing days are already common in the first two to three months of the year, when high winds are frequently sustained for one to three week periods (Mahon, 2002). This has important implications for the oceanic pelagic fishery in particular, since this coincides with the seasonal peak abundance of regional migratory species (e.g. dolphinfish, flyingfish). Mahon (2002) further points out that fishing activity is also curtailed by the passage of storms during the hurricane season (July to October), which will impact the reef-associated shallow shelf fisheries, the deep-slope fisheries and the sub-surface longline fisheries which are all active during this period. The shrimp and groundfish fisheries of Guyana, for example, will however be less affected, given they occur south of the typical Atlantic hurricane belt. Worse weather conditions in the windy season could increase operational fishing costs by: increasing travelling times to fishing grounds, increasing fuel costs due to rough seas, and increasing labour costs due to rough working conditions.

Destruction and loss of fish traps during the windy season is one of the main costs caused by weather. The fisheries are predominantly small-scale and operate from undeveloped landing sites, mainly beaches where vessels can be hauled up, but also mangrove creeks and shallow back-reef lagoons where boats can be tied or moored safely within easy reach of shore. Erosion of beaches and/or loss of habitats that eliminate landing sites or make them less functional would likely also affect adjacent fishing communities. Generally, fishing communities occupy low-lying coastal lands, and so will be at greatest risk of exposure to most of the variety of disruptive impacts that have been identified for human settlements in the coastal zone. Fishing communities at exceptionally high risk are the permanent fishing camps on low lying offshore cays that may be completely submerged by sea level rise and are particularly vulnerable to extreme-weather events. Examples of these occur in Jamaica (Morant and Pedro Cays), Belize, Bahamas, and St. Vincent and the Grenadines. The Pedro Bank with a total area of 8,040 km^2, is one of the largest offshore banks in the Caribbean Basin (Espeut, 2006) and harbours large concentrations of conch, lobster and reef fish that are harvested by semi-industrial vessels as well as by some 1,500 artisanal fishers who make the long (80 km, 15-hr) boat trip from mainland Jamaica to live in fishing camps on one of two 'residential' cays for weeks at time (Allen & Webber, 2013). Not only are the cays and the makeshift fisher accommodations at risk of storm damage, but given the distance from the mainland the fishers themselves have limited opportunity to evacuate in time.

Coastal communities in the Caribbean have traditionally been focussed on fishing, and fishing is an important element of their culture, both internally (Price, 1966) as well as an appeal for the tourism industry (Breton *et al*., 2006). Attractive coral reefs are also extremely important for tourism, which is the mainstay of many Caribbean economies (Mumby *et al.*, 2014). The declining attractiveness of the harvest sector as a result of decreasing incomes and livelihood opportunities caused by climate change impacts, *inter alia*, can therefore be expected to impact on the fishing cultural identity of coastal communities, and affect the social cohesion of these populations.

Disruption of other sectors (e.g. agriculture, tourism, manufacturing) by climate change is also likely to have repercussions for the fishery sector. Reef fishing in particular often functions in the Caribbean as a social safety-net providing access to income and livelihood opportunity when other sectors fail or are disrupted by extreme weather events (Gill *et al*., in press). The displacement of labour into fishing, however, can lead to conflicts over labour opportunities and increased fishing pressure, as has already been observed as a result of hurricanes in the Caribbean (Mahon, 2002). Reducing abundance of fish and shellfish resources can also exacerbate conflict, not only intra-fisheries conflict amongst fishers competing for the same limited resource, including commercial versus recreational fishers, but also between the fisheries sector and other non-consumptive users (e.g. recreational divers). Disruption in other sectors where fishers, especially reef fishers, find additional part-time employment also means that fishers will lose income support and livelihood security.

Climate change impacts on the post-harvest sector

Processing of fish and shellfish in Caribbean SIDS is characteristically small-scale and carried out by individual fishers, fish cleaners, boners or vendors with minimal facilities who sell directly to local consumers. There are, however, many examples of small enterprises with individuals employing several others to process fish products for local markets, and examples of major company-owned, certified, fish processing plants with a significant workforce, often processing fish products for both the local market (supermarkets and restaurants) and for export. Whilst men typically dominate the harvest sector in Caribbean SIDS, women play a critical role in the post-harvest sector in fish processing and trade, and in ancillary activities, such as financing (McConney *et al*., 2013). As such, women will be the most disadvantaged by the negative impacts of climate change in the post-harvest sector.

Assessing the magnitude of potential change, especially over the long-term, to the post-harvest sector as a result of climate change is even more challenging than in the harvest sector, given the many other factors that affect business and trade, and the extraordinary heterogeneity of Caribbean SIDS. For these reasons, it is virtually impossible to make quantitative projections on social impacts of climate change in the post-harvest sector, emanating from impacts on post-harvest processing, trade and competitiveness of the fisheries sector.

However, it is possible to hypothesise what outcomes or chain of events may result from different types of impacts resulting from climate change in the region. For example, decreased landings will affect all actors involved in the fish chain from fish vendors at local level, to small-scale and large-scale processors and their workforces, to the transport and marketing of fish and shellfish products, to the consumer. Changes in the quantity and type of species caught (likely to be lower trophic level, lower value species) will change ex-vessel prices, value-added opportunities, employment, incomes, profits and food security.

Decreasing abundance of reef-associated fishes, expected to be the hardest hit by climate change initially, will have the greatest impact on the post-harvest sectors in local communities where these species are primarily sold. Likewise increases in ciguatera poisoning will affect trade in reef fishes and the health of local communities. Changes in availability of high value reef species (e.g. lobster and conch) (e.g. due to changes in distribution or ocean acidification) will impact export trade volumes and may necessitate shifting to different export markets due to their different preferences for particular species. It may also mean a change in the relative production for export and local consumption impacting the tourist market as they are major domestic consumers of these high value species. Furthermore, as profits decrease due to decreasing catches the willingness and attractiveness to invest in the processing sector will decrease.

Climate change is expected to affect the productivity of deep-slope fishes and result in their displacement to deeper waters, which together will likely result in reduced abundance and catchability for fishers. This will result in less employment and livelihood opportunities for fish processors. These species are generally high priced and are primarily sold directly to hotels and restaurants in the local tourism industry or exported. The tourism sector will have to look for alternatives, possibly driving up market prices of desired species. Alternatively, more fish will have to be imported to satisfy tourist demand. Processing plants exporting deep-slope fish can be expected to be affected by decreasing sales.

The shrimp and groundfish produced by the small-scale fishers are usually sold fresh or salted to local markets or sometimes to the commercial seafood processors. The shrimp caught by the industrial fleets are typically frozen, and exported mostly to the USA, whilst the groundfish are processed for local and regional markets. A decrease in production will affect the commercial seafood processors and thus affect employment opportunities for the local processing workers.

The influx of pelagic sargassum into the Caribbean in recent years has mainly affected the ocean pelagic fishery at sea. However, the pile-up of stranded rotting sargassum along the shorelines, has also affected the use of beaches as landing sites and haul-up areas, and impacted the post-harvest sector. For example, many shoreline markets had reduced access to receive fish, and were affected by the stench of hydrogen sulphide as piles of sargassum decomposed nearby. In some cases the gas was sufficient to cause respiratory and other illness in vendors and consumers and cause corrosive damage to electrical instruments. The economic impacts were particularly severe for small-scale processors that worked almost exclusively as flyingfish boners, whilst larger processors and restaurants used other fish species (Ramlogan *et al*., 2017). The floating sargassum mats attracted large numbers of juvenile dolphinfish as well as jacks and other reef-associated small pelagics. Whilst catch of juvenile dolphinfish partially relieved low catches in the flyingfish fishery, these were primarily sold as low value fish and did not necessarily boost the revenues of fishers or post-harvest workers. Furthermore, their sale in local markets sparked an outcry by many consumers who were unwilling to buy juvenile dolphinfish. Anecdotal evidence suggests that current catches of dolphinfish in some Eastern Caribbean countries are extremely low (e.g. Barbados) following particularly severe sargassum influxes throughout 2014-2015. Dolphinfish in Barbados are believed to have become so scarce (due to high catches of juvenile dolphinfish in recent years as a result of the sargassum) that adult-sized dolphinfish are now being sold auction style to the highest bidder at the main fish market. The limited availability of dolphinfish affects the income derived from this species by processors. Reductions in oceanic pelagic species as a result of changes in distribution can be expected to have high impacts on revenues for fisherfolk as well as on other actors in the fish chain.

Changes to the seasonal pattern of landings and/or increasing uncertainty regarding supply will further affect all the actors in the chain across all fisheries, and may require significant changes in business strategies, particularly for the larger-scale processing operations. Furthermore, coastal erosion, flooding and extreme weather events can all damage post-harvest infrastructure and assets (e.g. docks, storage facilities, market complexes, processing plants, ice plants, and essential public amenities such as electricity, water and communications), which in turn would disrupt or prevent post-harvest activities and may result in loss or wastage of fishery products.

Climate change impacts at the national level

Climate change has the potential to impact the fisheries sector at the national level in the Caribbean region by various pathways, for example, by alterations in revenues for governments due to changes in total fish production volumes available for the local and export market; the ability of nations to achieve food security; and the necessity to make changes to fisheries policies and legislation.

Declining catches could result in a decline in GDP for Caribbean countries (e.g. Jamaica, Bahamas). Fisheries exports provide substantial foreign exchange for national governments in developing nations (Kurien, 2005), but also provide additional revenues from taxation, license fees, and from fees paid by foreign ships for access to resources (Allison 2011). Governments employ various means of recovering revenue from fisheries internally e.g. by means of licensing and/or registration fees for fishers, vessels, processors and value-added and export taxes. This implies that changes in fish catch and subsequent exports not only affect fisherfolk, their dependents and all other actors in the fish chain but can also have implications for the national budget. The region is a net importer of fish with an astounding 8.5 billion USD deficit between exports and imports of fish products to the region (FAO, 2016). Decreases in foreign exchange for countries due to declining exports of high value fish species could thus have implications on their food import bill. This is particularly true for reef species such as conch and lobster, the deep-slope and ocean pelagic fisheries.

Jamaica serves as a good example, being a large exporter of conch. Conch represents Jamaica's most important fishery resource with exports amounting to over 500 metric tonnes per year on average for the last decade and generating annual gross revenues of around 3-4 million USD. In 2009 the Jamaican government imposed a conch export levy of 75 US cents per pound (reduced to 50 US cents per lb. in 2016 to enhance investments in the conch sector in the country). The export levy was imposed to establish a fisheries management and development fund to facilitate the sustainable management and development of the fisheries sector. Declines in conch production would therefore also translate into declines in government finances for fisheries management. For other Caribbean countries that do not have a large fisheries export sector, however, tax income from the fisheries sector is often very limited. In fact, many countries in the region frequently subsidize fisher expenses such as providing fuel tax exemptions for fishing vessels, sales tax exemptions, and special income tax deductions or loans for boat repairs. In these fisheries, although unwise, subsidies may be increased to ensure that they remain financially viable with declining yields. Alternatively, governments may be required to retrain fishers to move to other sectors.

Fisheries play a crucial role in domestic food security in this region, with an average annual fish consumption per capita of around 20 kg for Caribbean SIDS. As such, climate change impacts might require renewed visions for food security and improving food sovereignty in the region, as potentially less wild caught fish will be available for local consumption. This is also likely to have spill-over impacts on human-health. This is particularly relevant for countries with large reef fisheries as these are largely destined for local markets. As fisheries face increasing pressures from climate change impacts as well as other challenges, coupled with human population increases, it becomes more critical to access the potential financial value-added from fish trade, and for countries to consider the policy options regarding the relative advantages of trading fish domestically or internationally versus having fish available for the domestic market. This is relevant for countries that have large export oriented fisheries (e.g. Guyana, Jamaica, Belize)).

One can also hypothesize that as climate change exerts increasing pressures on marine ecosystems which result in decreased fisheries production (Cheung *et al.*, 2010) the ability of fisherfolk to gain livelihood and employment from the sector will be compromised in turn leading to more demands on government social security and unemployment benefits. This is applicable to all four fisheries yet most relevant for the reef fishery as this fishery employs the largest number of fishers in the region.

Climate change can also lead to an increasing level of tension between different stakeholder groups using marine space and the resources for different purposes. For example, climate change impacts on critical habitats and key species might exacerbate existing tensions between extractive and non-extractive user groups requiring policy decisions on how resources are to be shared among groups. The non-consumptive use of coral reefs by the tourism sector for recreational diving versus extractive use by the reef fishery serves as a good example. This may impact on current marine resource management legislation and require a more comprehensive system of Marine Spatial Planning, taking the value of ecosystem services into account. Recreational spearfishing can also be a cause of conflict with reef fishers. Another challenging example is the trade-off between commercial capture of ocean pelagics and recreational catch and release of certain species in the region such as the billfishes. Recreational catch and release of billfishes is a major economic activity in the region with a large number of international billfish tournaments being organized each year which can generate significant income and surpass the capture value of billfish taken by commercial fishing operations (FAO, 2016b).

Existing fishery management systems may be challenged by the impacts of climate change. For example, there are many co-management and coastal community management arrangements with full stakeholder engagement across the Caribbean (McConney *et al.*, 2003; Pomeroy & McConney, 2007). These may be compromised if stakeholders become increasingly unwilling to invest in community or participatory management (itself important in enhancing adaptive capacity of the sector), because they see that fish stocks are being subjected to climate-driven processes beyond the control of local management (Macfayden & Allison, 2009). On the other hand, the (perceived) threat of climate change impacts may also stimulate local management to minimise impacts and enhance adaptation (Macfayden & Allison, 2009).

Fish resources, particularly in the Caribbean, are commonly transboundary and shared amongst multiple nations. Changes to their distribution and connectivity due to climate change could ultimately impact on their current management arrangements including multi-lateral or international agreements. Changes in fish stock abundance may also impact existing allocation arrangements between countries. For example, changes in ocean pelagic species such as tuna and tuna-like species, distribution as a result of changes in sea surface temperatures and circulation patterns could lead to a need for renegotiating ICCAT (International Commission for the Conservation of Atlantic Tunas and tuna-like species) quotas among member states (Mahon, 2002). Likewise, it could affect the relevance of limit and target reference points agreed to in the recently adopted Eastern Caribbean sub-regional Flyingfish Management Plan (CRFM, 2014). With regard to dolphinfish, the recent influxes of sargassum related to climate change, have raised concern about the large numbers of small juveniles that are now being caught by pelagic fleets in the Lesser Antilles and the need to agree upon and impose a minimum legal size for this species in the sub-region. This has prompted adoption of regional guidelines for a minimum size for dolphinfish by the CRFM Ministerial Council (10th Ministerial Council meeting of the CRFM, June 2016).

Climate change also challenges the effectiveness of many current fishery management regulations, and will increasingly exacerbate the ongoing decline of fish resources in the region, caused by overfishing (including IUU fishing) and degradation of the marine environment. With over half of the commercially harvested fisheries stocks in the region already overexploited or depleted and some 40 percent considered to be fully exploited (FAO, 2016), the need for more effective fisheries management that is able to adapt to change, and fisheries policies that take climate change impacts into consideration is abundantly clear. The effectiveness of management regulations such as closed areas or seasons, gear limitations, and minimum sizes may be affected by climate change impacts. For example, closed areas (fishery reserves, marine protected areas) may currently be protecting critical locations such as nursery grounds, fish spawning aggregation sites (SPAGs), regions that feature high species diversity or high rates of endemism, and areas that contain a variety of habitat types in close proximity to one another (Sadovy, 2006). However, as climate changes the locations and or ecological health of these critical areas may also change, highlighting the importance of integrating climate change projections with protected area management. For example, the location of protected SPAGs might need to be revised or MPAs enlarged to ensure sustainability. Likewise, closed seasons that are currently designed to protect all or part of a spawning stock may need to be changed as climate change impacts a species phenology. Queen conch serve as an example of where different water temperature regimes in the western and eastern Caribbean are likely responsible for the very different reproductive strategies displayed by conch from these two areas (Aldana-Aranda *et al*., 2014). Further, as mean size of individuals in fish assemblages decline under climate change (see Cheung *et al.*, 2013), minimum legal sizes or gear restrictions may require changes to achieve the desired outcome.

Sea level rise and/or adverse weather alone can result in the destruction of fishing assets, yet the small-scale fisheries sector has limited or no access to affordable insurance. This puts fisherfolk at risk and has implications for governments. A government may offer insurance when private insurers decline to insure fishermen because of the perceived highly uncertain risk in the industry. To date, however, disaster management in fisheries has been mainly response-oriented and safety-at–sea training, and equipment such as vessel monitoring systems (VMS) and early warning systems are not prominent in small-scale fisheries across the region. The fact that fishers may be forced to travel further to maintain catches will also impact on policy decisions for national fleet development, which may in turn require government incentives and training programmes to retool fishers, within the context of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (FAO, 2015c).

Effective communication, especially among disaster management authorities, fisheries authorities and coastal communities has often faced challenges that pose threats to the fisheries sector as a whole, and particularly to the lives and assets of fisherfolk. As climate change impacts are expected to worsen it is important for fisheries departments to address these shortcomings. Antigua and Barbuda, for example, is developing a national radar system for vessel monitoring to improve safety-at-sea by means of improved communication and tracking, and Montserrat is piloting a vessel monitoring system for its small open vessels to improve fisher security (A. Ponteen, Chief Fisheries Officer, pers. comm.).

The projected increase in incidences of ciguatera fish poisoning (CFP) under increasing SSTs also has national level implications regarding food safety of consumers, both local and within the tourism sector. As such it will be important to develop a reliable system of reporting of cases of fish poisoning in order for countries to determine risk and develop a strategy for avoiding CFP.

National level policies and legislation necessary to improve the resilience of the fisheries sector in the face of climate change need to build on to the existing regional policies that have developed over the past years in relation to climate change and the fisheries sector. The FAO/CRFM/WECAFC/CDEMA/ CCCCC *Strategy and Action Plan for disaster risk management and climate change adaptation in fisheries and aquaculture in the CARICOM region* was developed in 2012 (see McConney *et al.,* 2015). The Strategy builds on the CARICOM *Liliendaal Declaration on Climate Change and Development*[2] (which sets out key climate change related interests and aims of CARICOM member states) and the *Comprehensive Disaster Management (CDM) Strategy and Programming Framework 2014-2024*[3] of CDEMA. The Caribbean Community Common Fisheries Policy (CCCFP) was approved by the CRFM Ministerial Council in 2014 and has been endorsed by the Council for Trade and Economic Development (COTED) as the definitive fisheries policy for the Caribbean Community. The CCCFP also addressed the need for improved resilience of the fisheries sector to climate change and for improved research and education programmes to raise awareness of the impact of global warming. Building on these regional level developments mainstreaming of climate change in plans, policies and legislation is also necessary at the national level. This is being developed in several countries in the region. Policy decisions about whether to support the development of an aquaculture sector will also be impacted by declining capture of wild fish. Aquaculture is currently not well developed in Caribbean SIDS, perhaps with the exception of a few countries such as Jamaica and Belize (CRFM, 2011), but may become a feasible option to support food security and employment under future climate change.

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Table 1: Summary of ecological and fishery characteristics of the four main fishery groups in Caribbean SIDS

Fishery group	Species	Essential habitat	Fishing gears	Scale of sector	Post-harvest
Reef- associated shallow shelf	Reef fishes (e.g. snappers, groupers, parrotfishes, grunts, squirrelfishes, triggerfishes, surgeonfishes). Shellfishes (e.g. mainly conchs and spiny lobsters). Nearshore, schooling pelagic fishes (e.g. jacks, scads, sardines, pilchards, ballyhoo, mackerels, small tunas).	Early Life History (ELH) stages are pelagic using open water habitat. Juveniles and adults use coral reefs & associated ecosystems (seagrasses, mangroves, sand flats, algal hard grounds and reef rubble) in shallow, clear-water, shelf areas.	Handlines. Surface trolling lines. Nets (seine, cast, gill, tangle). Diving (free diving, SCUBA or hookah) using spearguns, snares or metal poles. Fish pots (mostly wood frame with wire mesh Z- or A-shaped Antillean traps). Lobster traps (wooden slat traps). Casitas (artificial habitats to aggregate lobsters)	Fishers mostly small-scale commercial, swimming from shore or using small open vessels (<12 m in length) powered by outboard engines and making single day trips to coastal reef areas. A few semi-industrial operations, using larger vessels (motherships) with steel or wooden hull and inboard engine (or sail in case of Belize) engaging in 6-9 day fishing trips. Accompanied by fleet of small dories or canoes departing and returning daily from the mothership. Harvest on offshore banks mostly for valuable shellfish such as lobster or conch (e.g. Jamaica, Belize) or multispecies reef fish and shellfish (e.g. Bahamas). Industrial freezer boats (approximately 30 meter vessels) on 20 day trips also active in Jamaica. Product kept on ice or frozen. Some subsistence fishers. Recreational fishers (especially divers) but poorly recorded.	Multispecies finfish mostly sold fresh, unprocessed, directly to local customers or at local markets or to local hotels and restaurants. Higher value shellfish (conch and lobster) generally sold either directly to the local tourism industry or to processing plants for subsequent export to international markets (e.g. USA and EU).
Deep slope	Benthic finfishes such as deep-water snappers (e.g. red, queen, vermillion, silk, blackfin), deep-water groupers (e.g. red, black, yellowfin, yellowmouth) and other deep demersal species (e.g. amberjacks, black jacks).	ELH stages are pelagic using open-water. Juveniles are benthic most using shallow reef nursery areas. Adults are benthic living in deep rocky or rubble areas usually along the continental shelf edge or deep banks below depth of euphotic coral reefs.	Hand operated, multi-hook bottom longlines (palangues or pillar sticks). Deep sea fish traps (often steel frame).	Fishers mostly small-scale commercial. Vessels range from small open vessels (<10 m) with outboard engines (e.g. in Grenada where the drop off is relatively close to shore), to medium-sized vessels (< 18 m) with inboard engines (e.g. in Barbados where the vessels are used seasonally in the offshore pelagic fishery). Day trips or overnight trips with fish landed fresh. Semi-industrial vessels used off Guyana where shelf edge is at a significant distance from the shore. Trips last several days and fish kept on ice. Some recreational fishers (e.g. in Barbados targeting glasseye and Atlantic bigeye snappers), but poorly recorded.	Species generally high-priced. Some sold fresh on local market, but primarily sold directly to local hotels and restaurants in the tourism industry or frozen and exported.

Fishery group	Species	Essential habitat	Fishing gears	Scale of sector	Post-harvest
Shrimp and groundfish	Shellfishes (seabob and other penaeid shrimps / prawns). Benthic finfishes (e.g. weakfishes such as bangamary and Guyana sea trout; croakers such as butterfish; and sea catfish).	ELH stages are pelagic using open-water or estuaries. Juveniles generally associated with brackish estuaries & mangroves. Adults live in shallow, soft-bottom, muddy or sandy continental shelf areas found along the Caribbean coastlines of Guyana and other South and Central American countries.	Double rigged commercial bottom trawls with Turtle Excluder Devices (TEDs) and Bycatch reduction Devices (BRDs). Chinese seines (fyke nets) fixed to poles set in river mouths utilizing strong currents. Multifilament drift and bottom-set gillnets. Pin seine nets. Small-scale bottom longlines & handlines.	Company-owned industrial bottom trawling fleets, steel hulled, 19-30 m in length and powered by inboard diesel engines. Fishing trips 5-10 days, shrimps and groundfish kept on ice. Small-scale fishers have relatively small, open, flat-bottom vessels (6-12 m in length) with outboard or inboard engines. Fish single day trips around tides within or adjacent to large estuaries.	Shrimp caught by the industrial fleets are typically processed (frozen mainly with head-off), and exported mostly to the USA, whilst the groundfish are processed for local and regional markets. Shrimp and groundfish produced by the small-scale fishers are usually sold fresh or salted to local markets or sometimes to the commercial seafood processors.
Oceanic pelagic	Open water, highly migratory, epipelagic (surface) species (e.g. flyingfish, dolphinfish, wahoo) Open water, highly migratory sub-surface species (e.g. billfishes, tunas, sharks, swordfish).	Some species are known to have restricted spawning areas, but these differ among species. ELH, juveniles and adults use offshore, open ocean, surface and sub-surface waters.	For medium and large-sized species: Surface trolling lines (hand operated). Surface and sub-surface rod and reel. Anchored fish aggregating devices (FADs). Sub-surface longlines. For flyingfish: Drifting fish attracting devices together with surface gillnets or dipnets and handlines.	Small-scale commercial fishers using small open vessels with outboard engines, including canoes and pirogues, make day trips up to 40 km from shore and land fresh fish. Several countries also have small semi-industrial ice-boats (Barbados) and semi-industrial longline fleets (e.g. Barbados, Grenada) targeting the surface and sub-surface pelagics respectively. They carry ice and make trips of up to 2 weeks (fishing up to 560 km from shore). Several countries (e.g. Trinidad and Tobago, St Vincent, Belize) also license industrial foreign vessels targeting the large pelagics, but these vessels fish largely in the Atlantic on the high seas and freeze fish at sea. The medium and large-sized pelagic fishes are targeted (some catch and release) by charter and private recreational fishers and international fishing competitions (e.g. Dominican Republic, Jamaica, Lesser Antilles).	Most of the pelagic species are sold fresh or processed and frozen for the domestic market including the tourism sector. Some species however (yellowfin tuna, bigeye tuna and swordfish) are exported fresh by air to high-priced markets in the USA.

Table 2: Summary of climate change impacts specifically on the groups of commercially important fish and shellfish and their fisheries in Caribbean SIDS.

Fishery group	Essential habitat	Fishery resource	Harvest sector	Post-harvest sector
Reef- associated shallow shelf	Degradation of coral reefs (mass coral bleaching and associated mortality, reduced accretion / loss of reef framework), loss of mangroves (from SLR and increased storm severity). Result will be reduced carrying capacity of habitats to support juveniles and adults. Open water will have: Warmer SST and possible changes to surface currents, affecting spawning strategies, pelagic larval development times and ELH distribution. Lower aragonite saturation levels affecting calcification and open water food webs. Higher pCO_2.resulting in hypercapnia (alteration of cell behaviour and life processes).	Damaged habitats will mean smaller standing stocks of reef-associated species over the short and long-term. Greatest impact on reef attached species and less for nearshore pelagics. Impacts on ELH stages will mean less successful recruitment and more inter-annual variability in size of populations. Species with short annual reproductive periods that aggregate for spawning (e.g. many snappers and groupers) and those with longest pelagic larval phases will be most impacted (e.g. spiny lobster). Demersal, relatively immobile species will be most impacted by hypercapnia and reduced calcification (e.g. conch). Possible increased occurrence of ciguatoxic reef fish. Already over-exploited condition of this group across the Caribbean and continuing degradation of coastal habitats by other anthropogenic activities means that this group will be least resilient to future climate change.	Reef fishers are expected to face decreasing total catches, lower catch per unit of effort (CPUE) and their fishery-related income and food security can be expected to be compromised. Decreases in catches may result in reef fishers shifting their focus to fishing different species, implying a potential shift in gear types or even vessel type. Due to increased intensity or frequency of weather events fisher suffer losses of gears (mostly traps) causing financial losses to fishers. Declining fish catches will also result in divers having to access deeper fishing grounds resulting in more fishers suffering from death or permanent disability from decompression sickness. Reduced abundance of fish and shellfish resources can also exacerbate conflict, for example between reef fisheries (consumptive users) and other non-consumptive users (e.g. recreational divers).	Changes in availability of high value reef species (e.g. lobster and conch) (e.g. due to changes in distribution or ocean acidification) will impact export trade volumes and may necessitate shifting to different export markets due to their different preferences for particular species. It may also mean a change in the relative production for export and local consumption impacting the tourist market as they are major domestic consumers of these high value species. As these fish are mostly sold at the local markets they (and associated sectors) will suffer from decreased livelihood and employment as catches decrease.
Deep slope	Degradation of coral reefs (see above). Impacts to open water (see above).	Impacts on pelagic ELH stages will mean Less successful recruitment to benthic juvenile nursery areas. Damaged juvenile nursery habitats (coral reefs) will result in decreased recruitment to adult populations and likely result in	If the adult populations move to deeper areas down the slope to avoid warmer temperatures fishers will have to use equipment that allows them to fish at deeper waters (e.g. using mechanized reels) and fishing trips become less	These species are generally high priced and are primarily sold directly to hotels and restaurants in the local tourism industry or exported. The tourism sector will have to look for alternatives, possibly driving up

Fishery group	Essential habitat	Fishery resource	Harvest sector	Post-harvest sector
		population declines over the medium-term for these long-lived species. Adult populations likely to move deeper down the slope to avoid warmer temperatures. Timing and location of spawning aggregations likely to be negatively impacted.	economically feasible as CPUE goes down due to increased investments. Fishers will thus face declining productivity of the fishery resulting in decreasing total catches, lower catch per unit of effort (CPUE) and lower fishery-related income.	market prices of desired species. Alternatively, more fish will have to be imported to satisfy tourist demand. Processing plants exporting deep-slope fish can be expected to be affected by decreasing sales.
Shrimp and groundfish	Estuarine habitats including mangroves will be impacted by SLR and by changes in rainfall patterns resulting in loss of some mangrove areas, changes to salinity and increased eutrophication. The latter, together with warmer temperatures could result in development of hypoxia or anoxia (resulting in 'dead zones') and development of toxic algal blooms. Impacts to open water (see above).	Impacts on pelagic ELH stages will mean Less successful recruitment to inshore benthic juvenile nursery areas. Damaged juvenile nursery habitats (estuaries / mangroves) will result in decreased recruitment to adult populations and likely result in population declines. In some cases mass fish kills might be expected in estuarine areas. Adult populations could move further offshore to deeper aeras to avoid warmer temperatures. Shrimp have shown a heavier exoskeleton as a result of increased CO_2 yet they are also expected to be less flexible and more brittle and as a result it is more likely to fracture during sudden movements such as predator defence or sudden escape response.	The impacts of potentially thicker (yet more flexible and brittle) exoskeletons for the harvest sector is still unknown. If the adult populations move further offshore to deeper areas to avoid warmer temperatures access for fishers will become more difficult. Travel times to the fishing grounds will become longer and fishing trips less economically feasible and safety of fishers will be impaired.	A decrease in production will affect the commercial seafood processors and thus affect employment opportunities for the local processing workers as well as affect the foreign exchange generated by this sector.
Oceanic pelagic	Impacts to open water (see above). Alteration of oceanic food webs (especially decline in ELH stages of reef fishes, and those prey	Alteration of oceanic pelagic food webs could result in lower carrying capacity of open water environment and therefore less abundant oceanic pelagic species. Populations of these highly migratory species likely to shift their distribution range	Declining productivity of the fishery as pelagic fish will shift in distribution will result in fishers facing decreasing total catches, lower catch per unit of effort (CPUE) and their fishery-related income.	The economic impacts of for example sargassum are particularly severe for small-scale processors that work almost exclusively as flyingfish boners, whilst larger processors and restaurants use other fish species.

Fishery group	Essential habitat	Fishery resource	Harvest sector	Post-harvest sector
	items reliant on planktonic pteropods). Oxygen minimum layer (OML) will become shallower under increasing SST.	polewards and thus become less abundant in the Caribbean over the medium-term and perhaps even leave the region over the long-term. Living space for sub-surface species (e.g. billfishes, tunas) will be compressed towards the surface with shallowing of oxygen minimum layer. Increased sargassum may increase recruitment success of pelagic species and support higher population sizes. However, it will likely reduce the effectiveness of artificial FADS deployed by fishers.	Fishers will have to travel further distances decreasing safety of fishers and requiring further investments into the safety of fishers. Worse weather conditions in the windy season could increase operational fishing costs by: increasing travelling times to fishing grounds, increasing fuel costs due to rough seas, and increasing labour costs due to rough working conditions as well as increased needs for insurance schemes for fishers and a need to move from small-scale to medium sized vessels.	Changes to the seasonal pattern of landings and/or increasing uncertainty regarding supply will further affect all the actors the post-harvest sector and may require significant changes in business strategies, particularly for the larger-scale processing operations. Changes in availability of high value tuna and tuna-like species (e.g. due to changes in distribution) will impact export trade volumes and may necessitate shifting to different export markets due to their different preferences for particular species.

What is already happening? 1. Sargassum influx - Lesser Antilles (Grenada, St Lucia, Barbados)

Climate-induced changes to ocean currents and ocean warming has recently been linked to unprecedented influxes of pelagic sargassum seaweed into the Caribbean Sea (since 2011), which has resulted in signifcant disruption of the fishery sector in Caribbean SIDS.

The harvest sector has been impacted by extensive floating mats of sargassum at sea which have caused entanglement and/or damage to fishing gear, engines and vessels; have clogged fishing harbours and mooring sites and impeded the movement and normal operation of vessels reducing access to fishing grounds and reducing the number of fishing days by local fleets; have reduced the catchability of flyingfish through rendering the drifting FADs used by fishers ineffective, thereby significantly reducing the landings of one of the most important pelagic species taken in the Lesser Antilles; have increased the catchability of small juvenile dolphinfish which are not protected by any fishery legislation, thus potentially impacting the longer term sustainability of this fishery; and have brought unexpected bounty to the nearshore reef-associated fisheries in the form of new and more abundant jacks, ballyhoo and some coral reef species.

The pile-up of sargassum along the shorelines, in some cases many metres deep, not only affected the use of beaches as landing sites and haul-up areas, but also impacted the post-harvest sector. Many shoreline markets had reduced access to receive fish, and were affected by the stench of hydrogen sulphide as the stranded sargassum decomposed. In some cases the gas was sufficient to cause respiratory and other illness in vendors and consumers. The economic impacts were particularly severe for small-scale processors that worked almost exclusively as flyingfish boners, whilst larger processors and restaurants used other fish species. The drastic reduction in flyingfish landings had implications for local food security.

Whilst influxes of floating sargassum in the Caribbean undoubtedly had benefits to the open ocean ecosystem, by providing enhanced shelter and forage for a myriad of pelagic species, the mass strandings and sinking of decaying sargassum trapped nearshore caused entrapment and death of endangered sea turtle, smoothering an eutrophication of coral reefs and seagrasses and significant biological oxygen demand, resulting in mass mortality of reef-associated fish and invertebrates

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Web commons

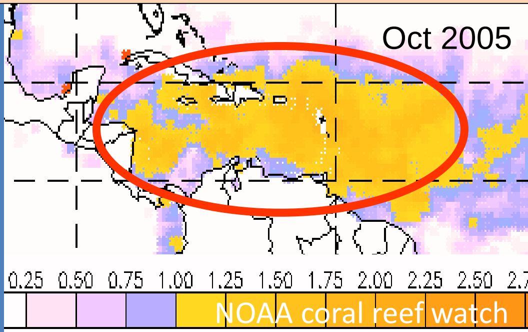
What is already happening? 2. Coral reef bleaching - Caribbean SIDS (Belize, Barbados, St Lucia)

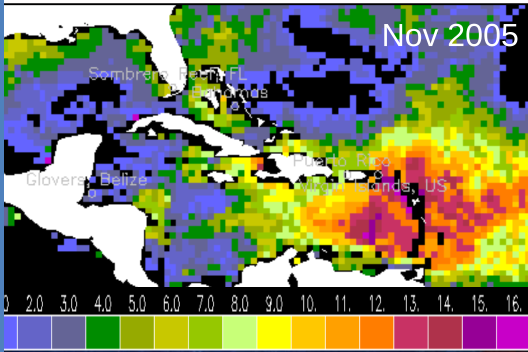
Climate-induced sea surface warming is impacting coral-reef fishes in multiple ways including effects on individual performance; changes to their phenology (e.g. timing of spawning, length of pelagic larval duration); changes to recruitment dynamics and population connectivity; and disruption of trophic linkages. Most obvious in the Caribbean to date however, is the significantly enhanced degradation of their essential habitat (coral reefs) through anomalously high SSTs in excess of 1°C above normal maximum temperatures, occurring throughout the summer months and causing mass bleaching and subsequent mortality of corals from accumulated heating stress.

The most immediate impacts have been loss of biodiversity and changes to fish community composition as a result of coral mortality, with coral-dependent fishes suffering the most rapid population declines as coral is lost. The more long-term impact of coral declines in the region is loss of reef architectural complexity. This results in loss of living space and critical shelter, altering the biomass of fish that can be supported by reefs and changing the predator-prey relationships and thus the species composition. This loss of reef structure has already been shown in the Caribbean to result in significant declines in the biomass of commercially important reef fish and thus the potential sustainable yield.

Coral bleaching is increasingly affecting coral reef health in the Caribbean, with basin-wide heating of surface waters 1-2°C above normal maximum temperatures in 2005 and 2010 and mass coral bleaching occurring throughout the northern Caribbean and Lesser Antilles SIDS which persisted for many months and resulted in high levels of coral mortality. In 2005 alone, 70-80% of corals suffered bleaching in the Lesser Antilles and by the following year corals had suffered as much as 25-52% mortality, representing the most severe bleaching episode ever witnessed. This emphasizes the vulnerability of SIDS, with a high reliance on healthy coral reef ecosystem services, to elevated sea water temperatures associated with climate variability and global climate change.

Coral bleaching is exacerbating region-wide declines in coral reef health and affecting fisherfolk livelihoods through decreased availability of reef-associated fishery species, as well as potential declines in additional employment opportunities in the tourism sector, which is also being negatively impacted by many aspects of climate change.





What is already happening? 3. Tropical Storm Erika in 2015 in Dominica

During the past decade, unusually frequent extreme weather events have affected the Caribbean, region contributing to the vulnerability of coastal fishing communities to natural disasters. It is projected that further enhanced hurricane intensity in the region is likely with continued global warming and increasing SSTs. However, the current understanding of tropical cyclone generation and frequency is still limited.

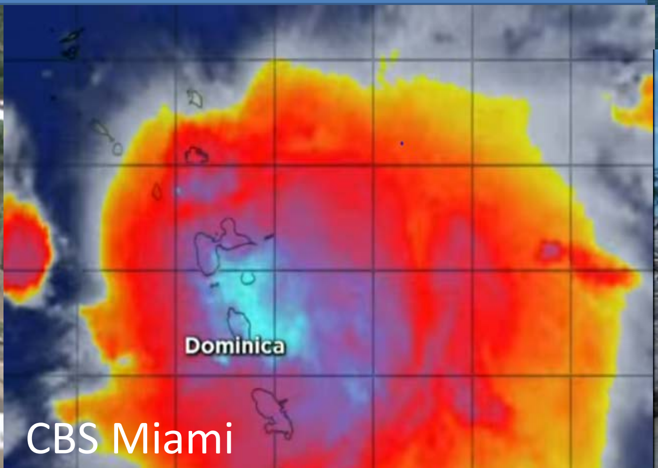
Increased frequency and severity of storms will result in more cases of dangerous storm surges and coastal flooding, leading to injury, ill-health and even death, and resulting in disrupted livelihoods of coastal fishing communities. Fisherfolk are especially vulnerable with additional losses or significant damage to boats and fishing gear, loss of fishing days, and at increased risk of accidents ashore and at sea during rough weather.

Hurricanes and storms can also affect adult fish and shellfish migrations and completely change larval dispersal patterns by altering mesoscale surface currents, such as already reported for spiny lobsters in Cuba. Hurricanes and storms can also cause massive damage to essential nursery and adult habitats (coral reefs, seagrass beds and mangroves) of commercially important fish and shellfish species, resulting in short and long-term declines in potential fishery yield.

In August 2015 Dominica was severely affected by Tropical Storm Erika. The storm surges and unprecedented coastal flooding which followed, resulted in several deaths and caused massive disruption to the livelihoods of coastal fishing communities. The 1500 fishers in Dominica suffered loses of approximately US$ 2 million in damages to their boats and engines alone. In addition, they lost significant revenues due to lost days at sea because of unfavourable weather and because of loss and damages to their fishing boats, engines and gear.

West coast Dominica air tour

Dominica Government (GIS)



CBS Miami

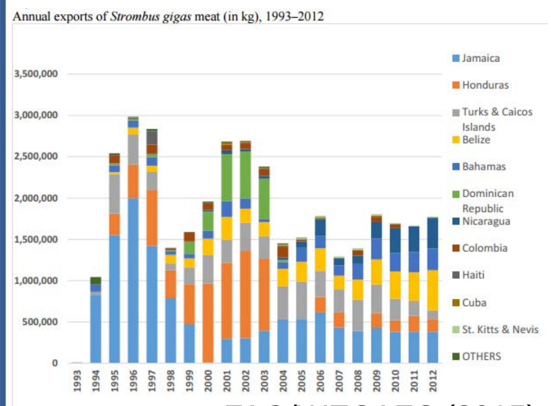
https://youtube.com/user/Q95FMRADIO?feature=hovercard

What could happen? 4. Impacts of ocean acidification on the conch fishery of Jamaica

Ocean acidification is occurring globally because of the current high levels of carbon dioxide in the atmosphere which dissolve in the surface waters of the oceans causing fundamental changes to seawater chemistry. These changes in the relative concentrations of hydrogen, bicarbonate and carbonate ions in seawater readily diffuse into the tissues of water breathing marine organisms where they can have a multitude of rather dramatic impacts on their physiology. These not only include negative impacts on the ability of calcifying organisms to build shells and exoskeletons, which will require increasing amounts of energy, but also include affects to a host of other life processes (e.g. oxygen consumption, growth, reproduction) and predator escape behaviours that are only just beginning to be understood. However, it is believed that molluscs and urchins are the fishery species at greatest risk in the short-term, whilst crustaceans and fishes will certainly be affected as the acidity of oceans continues to rise.

Increased acidity of the seawater in the Caribbean basin has already been recorded and accompanied by a sustained decrease in the carbonate saturation state over the last three decades (1988-2012). Although there are no published studies on Caribbean queen conch (*Strombus gigas)* responses to ocean acidification, based on studies of conch species found on the Great Barrier Reef, they are likely to build thinner shells, have slower growth rates, and have impaired predator escape behaviour under near-future ocean acidification levels. This will almost certainly increase their mortality rates and affect population size and productivity, reducing potential maximum sustainable yields to the valuable conch fisheries in the region. This could have significant soico-economic consequences, especially where the conch fisheries are substantial foreign exchange earners.

The conch fishery in Jamaica is currently their most important fishery resource, with exports from the well managed semi-industrial fishery on Pedro Bank amounting to over 500 mt per year and generating annual gross revenues of around US$ 3 million. The industry also provides employment for an estimated 2,000 persons, mostly as fishers and processors, and generates significant revenue in export taxes which is used to fund fisheries management in the country. Significant declines in conch production will thus have large impacts on livelihood and employment of fisherfolk and those working in the post-harvest sector as well as foreign exchange revenues for the Jamaican government.



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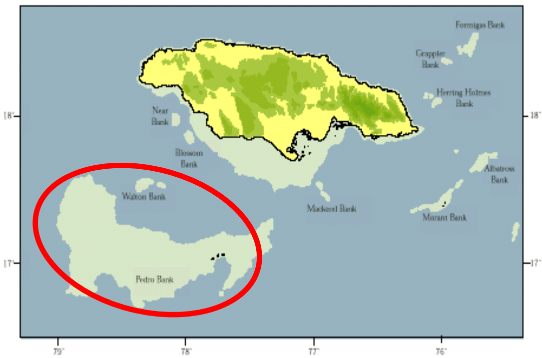

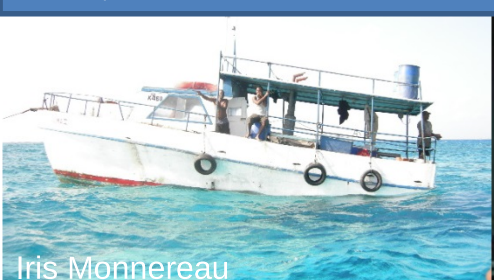

What could happen? 5. Changes in distribution of oceanic pelagic species (Grenada)

The effects of climate-induced rises in sea surface temperature (SST) and concomitant decreases in dissolved oxygen will have multiple impacts on water-breathing ectotherms (i.e. 'cold blooded' animals with gills, whose metabolic rates are determined by ambient temperature) . These impacts are expected to be particularly severe for tropical marine species because they have narrow thermal tolerances and are already living at or near their upper thermal and anoxic limits.

Increasing SSTs have high potential to impact migration, spawning, distribution, larval survival and recruitment of oceanic pelagic species in the region as they are forced to adjust and to move to more favourable conditions away from tropical latitudes. The sub-surface species may also be forced towards the surface by decreasing levels of dissolved oxygen. Important commercial fisheries for large oceanic, highly migratory pelagic fishes (e.g. yellowfin tuna, skipjack tuna, swordfish, billfish); and regional large pelagics (e.g. wahoo, dolphinfish, blackfin tuna and mackerel species) all occur within the Caribbean and can be expected to respond by changing their horizontal and/or vertical distribution to escape unfavourable conditions.

Grenada has one of the largest offshore pelagic fisheries in the region, mostly comprising small-scale vessels operating relatively close to shore along the west coast where there is easy access to the deep-water drop off. For example the catch in 2012 was estimated at 1,716 mt, with significant amounts of large yellow-fin tuna being exported fresh to high-priced markets in the USA. If these regional and international pelagic stocks move northwards in response to increasing sea surface temperature, catches can be expected to decrease considerably across all species as they move beyond the reach of the small-scale vessels of this southerly Caribbean SIDS, and beyond the limited EEZ even if the medium-sized longline fleet were to expand. On the other hand it is also possible that the sub-surface species such as the large tuna and billfishes may be forced closer to the surface by a rising oxygen minimum layer, which could increase their catchability, at least in the short-term, and further threaten the long-term sustainability of the stocks. Changes to the availability and catch rates of these species will have large impacts on fisherfolk and the post-harvest sector, especially given their limited capacity of adapt by expanding the fishing range of the current fleet. There will also be impacts for the recreational fishery in Grenada, which currently hosts important regional and international catch and release tournaments.


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Iris Monnereau


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True Blue Sportfishing
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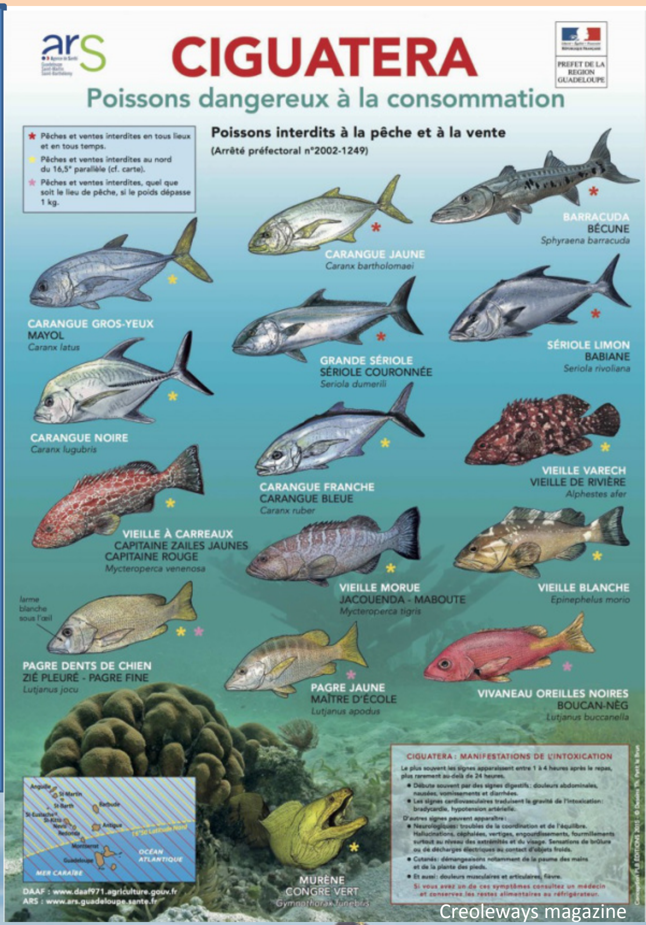
Iris Monnereau

What could happen? 6. Increased number of cases of ciguatera poisoning (St Vincent)

Climate-induced increases in sea surface temperature (SST) is also being linked to increases in the incidence of marine diseases. For example increasing SSTs and disturbance events such as hurricanes are considered to be a significant factor in the increased occurrence of the benthic dwelling, tropical diatoms responsible for producing the potent neurotoxin (ciguatoxin) that bioaccumulates up the fish food chain and causes ciguatera fish poisoning (CFP) in humans consuming ciguatoxic reef fish. CFP, which occurs in tropical regions around the globe, is among the most common non-bacterial foodborne illness associated with the consumption of marine products worldwide and affects an estimated 200,000 - 500,000 people a year. Detection is very difficult and the potency of the neurotoxin is not affecting by cooking. Consumption of tainted fish can lead to gastrointestinal distress followed by severe neurological and cardiovascular symptoms needing hospitalization, and these symptoms can persist for months or even years and, in rare cases, result in death.

Although CFP is well known in the northern islands of the Caribbean, it is currently quite rare in the southern Lesser Antilles. Like St. Vincent and the Grenadines. However, incidences of CFP could become much more common in this region under projected rises in SST and increased severity of storms, and thereby have serious implications for the safety of reef-associated and deep slope fish consumption by the local population and the tourism industry. Significant health concern is clearly a national issue and will also impact on the markety, affecting both harvest and post-harvest sectors of the reef-associated and deep slope fisheries.



Creoleways magazine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