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Responding to climate change in Caribbean fisheries and aquaculture through adaptation

Bryony L. Townhill[1], Silvana N.R. Birchenough[1], Georg H. Engelhard[1], Olivia Harrod[1], Ellen McHarg[1], Iris Monnereau[2], Paul J. Buckley[1]

1 Centre for Environment Fisheries and Aquaculture Science (Cefas), Lowestoft, United Kingdom.
2 Food and Agriculture Organization (FAO), Bridgetown, Barbados.

EXECUTIVE SUMMARY

The marine environment, and the fish it supports, play a key role in Caribbean culture, livelihoods and food provision. However, climate change is already affecting Caribbean fisheries and aquaculture through changes to important fish habitats, distributions, growth, and reproduction, all affecting fisheries yield. Storms and hurricanes are also having an impact by directly damaging habitats, aquaculture and fisheries facilities and affecting the safety of fishers at sea. These impacts are expected to be exacerbated in the future. There are also several compounding pressures that reduce the resilience of marine ecosystems to a changing environment, including overfishing, marine pollution, ghost fishing and Sargassum seaweed influxes. Here, we describe how vulnerable Caribbean fisheries are to climate change, based on their exposure to climate hazards, the fisheries and species sensitivities, and their adaptive capacity. To address these vulnerabilities, there are a range of climate change adaptation measures that could be deployed in the Caribbean to help ensure long term sustainable fisheries and aquaculture into the future, including autonomous, planned and no-regret options. Adaptation options can focus on institutional adaptation, livelihoods adaptation, risk reduction or management for resilience. There must also be a focus on building adaptive capacity within the fisheries and aquaculture sectors, so that fishers can maintain effective adaptation in the long term and be involved in management of their sustainable fisheries.

There are a number of adaptation projects that have been implemented in the region, which show how community involvement can be incorporated, with benefits to fisherfolk as well as the marine environment. Examples are given of the CC4FishProject, which aims to increase resilience and reduce vulnerability through adaptation and capacity building. The deployment of moored Fish Aggregating Devices (FAD) fishing in some countries is described, which can take pressure off overfished reefs, while maintaining or increasing income for fishers. Marine Protected Areas (MPAs) can be co-managed with coastal communities, to improve the environment, encourage tourism, and provide income to traditional users.

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Degraded habitats can be improved by planting mangroves or using artificial reefs, which provide coastal protection to communities. Examples are also described of the FEWER mobile phone app which sends alerts about bad weather or sea state to fishers, providing early warning of any dangerous conditions, and of the training course provided to all licensed fishers in Dominica. Lastly, an example of monitoring for pH changes in Belize is described, so that future strategies can be developed to safeguard the conch and lobster fisheries at risk from ocean acidification.

The cost of inaction to climate change is expected to be far higher than the cost of adapting, with the losses to fisheries caused by each hurricane in the millions of dollars, from lost and damaged gear, vessels, equipment and facilities, as well as loss of lives and livelihoods. There are few studies on the costs of adaptation, and while these are expected to be high, they are less in the long term than the damage expected from climate change. There are several barriers to adaptation in fisheries and aquaculture, which can mean that adaptation does not take place or is slow to be implemented. A considerable adaptation deficit exists, with financial, technical, institutional and governance dynamics hampering efforts. There are also many social factors that may inhibit adaptation of governments and fishers. Further studies are needed in the Caribbean to better understand these social and economic factors that obstruct adoption of adaptation measures, and to inform strategies to facilitate adaptation.

This report identifies a number of priority research gaps that are needed to successfully implement adaptation measures in the Caribbean region, including to identify climate vulnerabilities and risk, improve fisheries management, build sustainable aquaculture, improve the marine environment, diversify livelihoods in the long term, and build adaptive capacity. Actions are also proposed which can be carried out in the short term with limited resources, including by fisherfolk, marine managers, and coastal communities themselves. Some of these build on existing work or replicate successful projects elsewhere. Longer term goals are also identified, which need further investment or supporting legislation to implement, but are needed to ensure that fisheries and aquaculture have a sustainable future in the Caribbean. This includes reducing the existing pressures on the environment so ecosystems can be resilient to climate change.

For all adaptation actions, research, and capacity building, it is vital that the fisherfolk and coastal communities are involved at every stage. Particular attention should be paid to gender equality, inclusion of youth, marginalised groups or minorities, and the role that adaptation plays in reducing poverty. Traditional knowledge and culture must be included and used to inform action, and communities must be involved in policy development and planning, giving them skills to be involved in ecosystem-based management and co-management. In addition, monitoring, evaluation and learning should be embedded in the institutional mechanisms for tracking progress, and identifying the roles and responsibilities of the range of stakeholders and institutions.

We hope that the report provides targeted actions on adaptation for the fisheries and aquaculture sectors in the Caribbean region. Action needs to be taken now, and everyone in fisheries and aquaculture can play a part. There is already a lot of work underway, but further action is needed to secure people's livelihoods in the long term. With the right research, skills and experience, adaptation action in the Caribbean can ensure that fisheries and aquaculture livelihoods are secured for the long term.

1. Introduction

In the Caribbean, lives are closely associated with the sea (Nurse, 2011), so it is unsurprising that fisheries play a key role in sustaining livelihoods and providing food. Caribbean fisheries are typically small-scale or artisanal, which limits their socio-economic capacity to adapt to climate change, including to impacts from temperature rise, changes in ocean currents, increased frequency of high intensity hurricanes, sea level rise, ocean acidification, flooding and droughts (e.g. Oxenford and Monnereau, 2018). Many marine ecosystems that support fisheries are already degraded by overfishing and other activities, and climate change will only add further pressure. The fisheries and aquaculture sectors in the Caribbean must adapt to climate change to ensure that ecosystems are protected from further damage and are able to recover, while maintaining the ability to support food and livelihoods into the future.

A lot of work is currently ongoing in the Caribbean on climate change adaptation. A strategy for integrating climate change adaptation, disaster risk management, and fisheries and aquaculture, has been developed for the Caribbean (CRFM, 2020a), and a Climate Change Adaptation and Disaster Risk Management Protocol for the Caribbean Community Common Fisheries Policy (CCCFP) was approved in 2018. This report aims to further build on this work, by showing how science can be used to make informed decisions on the most appropriate types of adaptation. The aim of this technical report, and the accompanying summary Report Card, is to inform action in the Caribbean fisheries sector, to achieve sustainable livelihoods, income and food security, and to build a resilient and healthy marine environment that supports the sector.

This work is funded by the Commonwealth Marine Economies Programme of the UK Foreign, Commonwealth and Development Office. This detailed technical paper forms the basis of the Climate Change Adaptation for Caribbean Fisheries Report Card (CMEP, 2021). The report card provides a summary which can be used as a quick reference document to inform policy makers, marine managers and communities on the actions needed and the reasons behind these. This technical paper then provides further supporting detail and background information. This work follows on from the Caribbean Marine Climate Change Report Card (CMEP, 2017a), and the 12 supporting scientific reviews (CMEP, 2017b) which detail the impacts of climate change on the marine environment and those who rely upon it.

Section 1 of the present report introduces the topic and the purpose of the work. Section 2 summarises the current knowledge on climate change impacts on fisheries and aquaculture. Compounding pressures which can exacerbate climate change impacts are described in Section 3. Section 4 describes the risks and vulnerability of fisheries and aquaculture to climate change in the Caribbean, and how this varies across the region. The different adaptation measures that are currently being adopted are listed in Section 5, and a number of case studies are described in Section 6, demonstrating examples of successful adaptation actions from the region. The costs of climate action and inaction are discussed in Section 7, and the barriers to adaptation, and how these can be overcome are presented in Section 8. Section 9 lists research and knowledge building which is needed to support action and address gaps in evidence. Finally, Section 10 is on taking action and lays out a framework for adaptation in the region, with research priorities, short-term actions and longer-term goals.

This review is applicable to all countries and territories in the Caribbean region; however, specific examples are drawn out from several Small Island Developing States (SIDS): Antigua and Barbuda, Belize, Dominica, Grenada, Guyana, Jamaica, Saint Lucia, and Saint Vincent and the Grenadines.

2. Climate Change Impacts

Caribbean fisheries and climate change

The fisheries sector in Caribbean Community (CARICOM) directly and indirectly employs more than 250,000 people, mainly from rural communities (FAO, 2014a). Fisheries have an estimated total production of more than 171,000 tonnes annually, with much of the high value catch exported (FAO, 2014a). In the Caribbean, the fishing industry exploits reef fisheries, shrimp and ground fisheries, deep slope fisheries, and inshore and offshore pelagic fish (Monnereau and Oxenford, 2017). The main species caught are inshore reef and demersal fish, queen conch (*Aliger gigas*), spiny lobster (*Panulirus argus*), and pelagic fish such as tuna and bonito (FAO, 2014a).

More than half of commercial fish stocks in the Caribbean are thought to be overexploited or depleted, and illegal, unreported and unregulated (IUU) fishing is estimated at 20 to 30% of total reported catches (FAO, 2016). Fisheries in the region are also affected by pollution of coastal waters (e.g. sewage and agricultural runoff), invasive species, habitat destruction, and coastal erosion (Fanning et al., 2011; FAO, 2016). Marine habitats that are important to support healthy fisheries are in poor condition in some areas. As such, there is already pressure on the fish stocks in the Caribbean which climate change is exacerbating.

Monnereau and Oxenford (2017) provide a detailed review of the impacts of climate change on fisheries in the Caribbean, and Oxenford and Monnereau (2017) review how climate change affects a broad range of species of fish and shellfish that support these fisheries. They report that the effects of coral bleaching and increased frequency of high intensity hurricanes and storms are already obvious in the region, with further impacts predicted in the future from further temperature rise, ocean acidification and changing currents. A rise in sea surface temperature is expected to cause more frequent and severe coral bleaching events in the region, damaging and reducing habitats for reef fish. Increase in sea surface temperature is also expected to affect fish and shellfish directly, by impacting growth, reproduction and survival, and causing geographical shifts in species at their thermal limits. Changes in pH (ocean acidification) are expected to affect shellfish in particular, thus impacting yields of the most valuable species in the Caribbean. Coral reefs are likely to be impacted by reduced pH, with major knock-on effects for the biodiversity and fisheries they support. An increase in high-intensity hurricanes in the region will impact fisher safety at sea, and cause more frequent damage to coastal communities as well as to fishing gear, vessels and coastal infrastructure, with recovery of the fishing sector after a hurricane potentially taking a long time. Further, large-scale influxes of the floating seaweed, *Sargassum*, have been observed and linked to climate change, with many undesirable consequences. Figure 1 below shows the various impact pathways of climate change impacts on the fisheries sector. The potential impacts are wide-ranging and affect the physical ocean and biological systems. Fisherfolk and coastal communities are affected by changes to the fish and shellfish populations they depend upon, and also directly by the effects of storms, hurricanes, and sea level rise and coastal flooding.

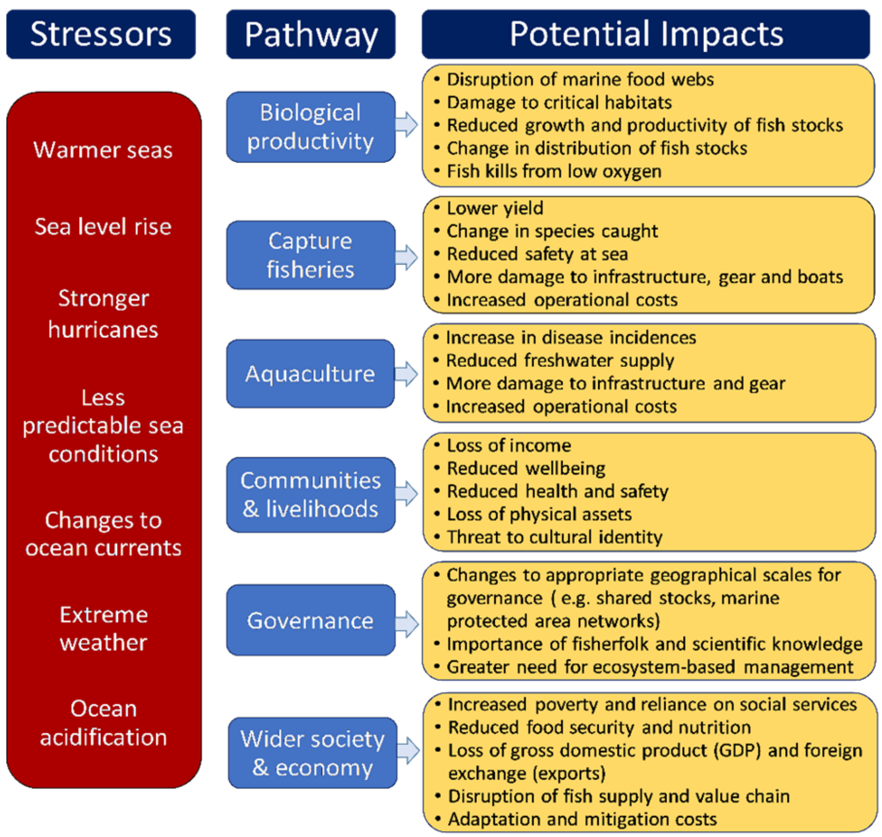

Figure 1. The range of potential impacts from climate change on fisheries and aquaculture. Taken from: Cox, Oxenford and Monnereau (2020). FAO Policy Brief on Climate Change and Fisheries.

Climate change stressors impact the fisheries sectors via various pathways: biological productivity; communities and livelihoods; governance, and wider societal and economic impacts. These impacts are expected to result in reduced catches, or a need for more intense fishing effort to maintain catches. This will decrease profits in the sector and reduce the availability of seafood for local consumption and export. While fishers are directly impacted, those working in the post-harvest sectors, boat building and other livelihoods dependent on fishing are also affected, along with their families and dependents. Conflict can also be caused by competition between communities, different States, and between the recreational and commercial sectors (Oxenford and Monnereau, 2018).

The region has been investing in improved data collection to better inform on imminent climate change events and longer-term change. For example, a number of Coral Reef Early Warning Systems (CREWS) stations have been deployed in parts of the Caribbean, with more to be installed soon. These installations are part of a wider global network of stations managed by the USA's National Oceanic and Atmospheric Administration (NOAA). Such systems, along with other local monitoring of rainfall, waves, tides, temperature and pH, add to the body of knowledge on marine conditions and the influences on coastal and fisheries management responses. Other data-capture methods such as advanced remote sensing through LiDAR[1] (recently acquired by the Caribbean Community Climate Change Centre (5Cs) partnered with a Belizean airline for the delivery of services throughout the Caribbean and beyond) will have utility in capturing topographic and nearshore bathymetric data of relevance to fisheries planning and management. The University of the West Indies, funded by the Food and Agriculture Organization (FAO), develops Sargassum Outlook Bulletins every two months predicting the volume and timing of sargassum influxes for the Eastern Caribbean.

Caribbean aquaculture and climate change

Aquaculture production in CARICOM States in recent years has been around 5% of total fish production (FAO, 2014a). Much of the aquaculture in the Wider Caribbean is centred on small-scale farming of freshwater shrimp, Nile tilapia (*Oreochromis niloticus*) and marine shrimp (*Litopenaeus vannamei*). There is also some farming of sea moss algae (*Gracilaria spp*. and others) and increasing aquaponics farming throughout the region. Some very experimental systems are underway for cobia (Rachycentron canadum), pompano (*Trachinotus carolinus*), dolphinfish (*Coryphaena hippurus*) and red drum (*Sciaenops ocellatus*) culture (CRFM, 2014). Only relatively few large aquaculture facilities exist in the Caribbean, with Belize, Jamaica, Haiti, Dominican Republic, Guyana and Suriname being the main aquaculture producers (CRFM, 2014). There is ambition to increase aquaculture production in the region, with the Caribbean Regional Fisheries Mechanism (CRFM) developing a work plan for aquaculture development in the Caribbean (CRFM, 2019a), which has been approved by the Ministerial Council. This outlines how aquaculture in the region can be developed sustainably over the next years to 2024, including policy, facilities, research, market feasibility, and climate change actions. FAO has been supporting aquaculture development throughout the Caribbean region over the past decade, mostly in the areas of aquaponics and seamoss farming.

Impacts from climate change on current aquaculture facilities are likely to be from sea surface temperature rise, pH and salinity changes, altered rainfall patterns, longer and more intense drought periods, and an increase in intense storms and hurricanes bringing high rainfall, flooding, storm surges and high waves (FAO, 2017). These can directly affect the aquaculture facilities and production, but also the supply chain, such as supply of fishmeal and fish oil (FAO, 2017).

An assessment of the ecological and economic potential for offshore mariculture in the Caribbean was carried out by Thomas et al. (2019) who recognised that temperature is a significant driving factor on the economic yields of marine fish farming. Typically, higher temperatures result in higher growth rates up to a critical thermal limit (Doney et al., 2012), and so some species may produce a higher yield under warmer temperatures, although there may also be higher feed costs (Thomas et al., 2019). However, if temperatures increase beyond physiological thermal limits, some current sites or species used in Caribbean aquaculture may no longer be suitable in the future. Increasing temperatures may also create an environment for new diseases to emerge (FAO, 2017). Low pH can reduce calcification rates and affect growth and development in organisms such as echinoderms, bivalves, corals, and crustaceans (Kurihara, 2008; FAO, 2017; Oxenford and Monnereau, 2017). However, impacts of ocean acidification on aquaculture in the Caribbean are expected to be relatively minor as there are few facilities that farm shellfish. Nevertheless, if there is an increase in queen conch aquaculture, this may be affected by changing pH in the future. Changes in rainfall could also cause problems to aquaculture

[1] Lidar, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

facilities by causing water shortages for freshwater facilities (FAO, 2017).

Storms and hurricanes can cause direct damage to aquaculture facilities by damaging or destroying them. Heavy rainfall and flooding can also cause overtopping of e.g. shrimp and tilapia ponds, releasing stock into rivers or sea. This can particularly be the case for the small-scale systems in the Caribbean which can be vulnerable to storm and hurricane damage if sited in exposed areas. This can result in the loss of stock, spread of disease, and unintended introduction of non-native species into the wild.

Along with fishing, aquaculture can play an important part in food provision after a storm or hurricane. Facilities that are resilient to such events could provide income and food immediately afterwards, which would be highly advantageous to Caribbean countries. However, there may be impacts to the export supply chain if transport or infrastructure are affected, such as markets, airports or ferries (FAO, 2017).

3. Compounding pressures

There are a number of non-climatic pressures on the marine environment which put stress on ecosystems and reduce their ability to cope with climate change. These include marine litter, pollution, habitat degradation, ghost fishing and the *Sargassum* seaweed, which cause damage to vital fish habitats, and lead to unnecessary mortality in fish and other marine life. Management strategies that reduce these non-climatic pressures can build resilience in the marine environment, allowing fish and their habitats to better cope with the impacts of climate change (IPCC, 2014a; UNEP, 2017). For example, studies have shown that corals are more resilient to bleaching if they have no, or reduced, exposure to non-climatic pressures (Nyström et al., 2008; IPCC, 2014a). Reducing these other pressures cannot prevent bleaching or coral mortality altogether, but it could delay the onset of these, allowing time for carbon emissions to be reduced (IPCC, 2014a). The COVID-19 pandemic has placed additional pressure on the Caribbean fisheries sector, removing many of the markets for fish and so affecting livelihoods. Adaptation to climate change must take account of these non-climatic pressures on fisheries in order to build a long-term sustainable future for Caribbean fisheries.

Marine litter and microplastics

There is a strong need to tackle and minimise the presence of litter in the marine environment. A large proportion of marine litter is composed of plastics, adding substantial pressure on the environment. Microplastics have been found in coastal areas, on beaches and in open-sea sediments worldwide. Most plastics that enter the sea, including microplastics, are from land-based sources (e.g. sewage, storm water) or from ocean-based sources, primarily from discarded fishing items (Li, 2018). Recent studies have estimated that land sources represent 80% of microplastic pollution in the ocean (Jambeck et al., 2015) with rivers representing the main pathways for the transport of plastics to the ocean (Lebreton et al., 2017). Field and laboratory studies have reported that microplastics are ingested by a large range of marine organisms across several trophic levels, including seabirds, marine mammals, fish, and invertebrates (GESAMP, 2015; Wright et al., 2013).

Microplastic monitoring in Belize during 2019 (Bakir, 2020) showed that microplastics were present in sediments, as well as in the economically important queen conch and the freshwater cichlid *Cichlasoma synspilum*, both fished for human consumption by local people. Plastic items were present in 41% of queen conch samples and 36% of riverine fish samples investigated.

To date, a total of 14 Caribbean countries (from Aruba to Haiti to the U.S. Virgin Islands) have banned plastic bags and/or polystyrene/Styrofoam as a strategy to tackle marine pollution (Diez et al., 2019). Other countries in the Caribbean have also banned single-use plastics as a unified strategy to minimise pollution.

Sargassum

Pelagic *Sargassum* seaweed mats floating just under the ocean surface are important ecological formations which comprise unique habitats for a variety of marine animals. These mats provide food, shelter, shade and nurseries for crabs, shrimp, sea turtles (Hu et al., 2016; Wang et al., 2019) and a diverse range of fish species including flyingfish (*Exocoetidae*), jacks (*Carangidae*) and herring (*Clupeidae*) (Hoffmayer et al., 2005). Until recently, *Sargassum* had been only washing up in small amounts on beaches in the Caribbean, or on beaches elsewhere the world (Birchenough, 2017). Since 2011, however, large influxes of floating *Sargassum* have regularly been observed in Caribbean waters, with substantial quantities washing up, and sometimes heaping up on Caribbean beaches

(Birchenough and Gregory, 2020) (Figure 2). In 2018, the combined weight of Sargassum was estimated at 20 million tonnes, covering an area of 8,850 km2 (Wang et al., 2019) (Figure 3).

Figure 2. a) Large accumulations of Sargassum sp. observed in Saint Lucia (image © M. Sanders); b) Large quantities of Sargassum fluitans, known as 'the Sargassum seaweed' in the Caribbean, washed up on a beach (image © H. Oxenford, extracted from Doyle and Franks, 2015); and c) Sargassum sp. accumulated onshore in Belize City (image © S. Birchenough).

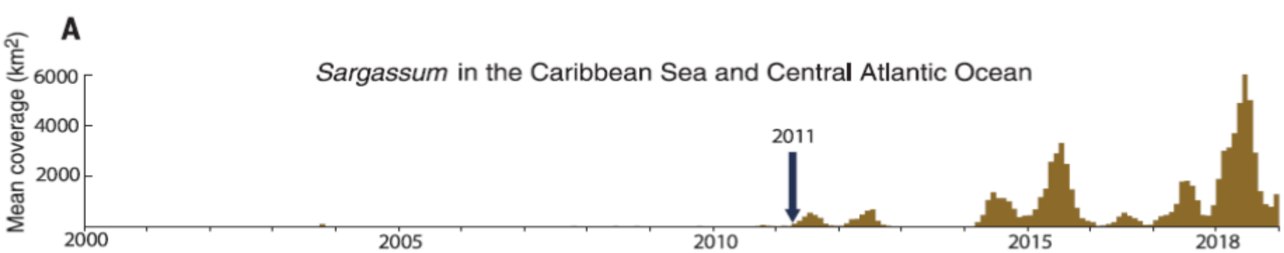

Figure 3. Monthly mean estimates of Sargassum in the Caribbean Sea and Central Atlantic Ocean (extracted from Wang et al., 2019).

The marked increase in *Sargassum* in recent years is thought to be attributable to high levels of nutrients that may be derived from the Amazon river and the equatorial and coastal upwelling regions along the African coast, but also to climate change (Desrocher et al., 2020). In particular, there is evidence that a combination of high nutrient levels and overall high sea surface temperatures (Wang et al., 2019) encourages the rapid growth of *Sargassum* mats as they move along the North Equatorial Recirculation Region (between West Africa and northern South America) towards the Caribbean Sea (Amaral-Zettler et al., 2017) (Figure 3).

Sargassum influxes have disrupted fisheries, have had devastating impacts on tourism, damaged critical nearshore ecosystems and coastal livelihoods, as well as caused health problems for populations exposed to rotting seaweed washed up on beaches (UNEP, 2018). Mats can prevent light from penetrating through to the seabed and can cause changes within ecosystems such as seagrass beds and coral reefs. The impacts on fisheries have largely been negative although some fishers have also indicated increases in fish catches.

Very small dolphinfish are now available throughout much of the summer in association with *Sargassum*, and the traditionally high abundance of larger dolphinfish in March and April has declined significantly. In contrast to dolphinfish, flyingfish landings have plummeted during periods of high *Sargassum* abundance due to a significant decrease in their catchability using traditional fishing techniques, likely exacerbated by reduced fishing effort because of lack of profit. Flyingfish appear to be using *Sargassum* as spawning substrate and are therefore no longer attracted to the floating Fish Aggregating Devices (FADs) used by the traditional fishery. There is no direct evidence that either the dolphinfish or flyingfish populations per se are being impacted negatively by the *Sargassum* (Oxenford et al., 2019).

Pollution and water quality

In the Wider Caribbean Region, 80% of marine pollution originates from land-based sources. The main inputs include untreated wastewater, agricultural run-off, and solid waste (UNEP-CEP, 2014). On average, 85% of domestic and industrial wastewater produced in the Wider Caribbean is discharged into the ocean untreated (Emanuel, 2010), and is expected to increase rapidly with future coastal development, urbanisation and population growth in the Caribbean islands (Kaza et al., 2018). Similarly, agricultural land cover is expected to increase by approximately 43% in Latin America and the Caribbean by 2050 (Estrada-Carmona et al., 2014; FAO, 2011). The excess nutrients and sediments deposited into the sea from these sources have severe negative effects on water quality and ecosystems in the region, causing further stress on habitats under pressure from climate change.

One ecosystem particularly heavily impacted by marine pollution are coral reefs. Marine pollution compounds the impacts of climate change on corals, exacerbating the climate stress on these habitats. Land-based pollution contains many different substances such as sediments, inorganic nutrients, and toxins. The effects of an increased load of coastal pollution can compromise coral reefs' ability to withstand the already stressful conditions associated with climate change, for example, increased frequency and bleaching events and extreme weather (Wear and Vega Thurber, 2015; Islam and Tanaka, 2004; Pantsar-Kallio et al., 1999). Excessive nutrient enrichment and sediment deposition in coastal seas are major issues faced by coral reefs, as this enhances macroalgae growth in a process known as eutrophication. Additional suspended material and algal growths block out sunlight needed for the corals to photosynthesise, while further depleting the amount of dissolved oxygen. This is exacerbated by extreme weather events that are increasing in frequency and intensity with the changing climate.

Seagrass meadows are another example of a coastal ecosystem at risk from marine pollution, which can exacerbate climate change impacts. Much like coral reefs, seagrasses are highly sensitive to environmental changes such as light availability and water quality, that can decrease growth rates and increase shoot mortality (Benham et al., 2016).

Marine pollution prevention and control should be considered a top priority for all SIDS in the Caribbean, and should be added to current legislation, policies, and enforcement across multi-sectoral developments (e.g. tourism, agriculture, coastal development and fisheries and many others) (Diez et al., 2019). Addressing the issue of marine pollution will improve resilience to climate change but requires collaborative approaches in areas such as infrastructure investments; capacity building; monitoring programmes; education and public awareness at a local, national and regional levels.

Habitat damage

Healthy marine and coastal habitats are vital for productive fish stocks, and any degradation or damage will have knock-on effects to the fish that can be supported. Mangroves and seagrasses are obligatory nursery habitats for many fish species (Oxenford and Monnereau, 2017), while coral reefs are critical habitats for reef fish. Direct damage has been caused to these habitats over recent decades from a combination of anthropogenic activities including sand mining, dredging, anchoring, sea defences, coastal development and damaging fishing practices (Miloslavich et al., 2010), on top of the damage caused by hurricanes (IMF, 2004). Fish and shellfish rely on these habitats for food, shelter, spawning and nursery areas, and as such, any degradation reduces the biodiversity and biomass that they can support (Oxenford and Monnereau, 2017). Habitat degradation also reduces the coastal protection that they provide through wave attenuation (Guannel et al., 2016). Carefully managing and, where possible, eliminating damaging activities can help stop further degradation and allow habitat recovery. There are active interventions such as planting coral, seagrass and mangroves, or installing artificial reefs, which can improve and accelerate rehabilitation of these habitats, in turn improving biodiversity and fish populations (e.g. Gratwicke and Speight), although these tend to be on a small scale.

Ghost gear

Lost, abandoned, or otherwise discarded fishing gear (also known as ghost gear) causes significant damage to the marine environment globally, including in the Caribbean (GGGI, 2017). It has been estimated that in Guadeloupe alone, 20,000 fish traps are lost each hurricane season (World Animal Protection, 2014). Ghost gear remains in the sea until it is removed, disintegrates, or becomes buried, catching target and non-target fish, and reducing the fish available for fishers (GGGI, 2017). It can also cause navigational hazards, pollutes the marine environment, and can kill endangered species such as turtles and cetaceans (GGGI, 2017). In the Caribbean, lost pots, traps, nets, lines and recreational fishing gear all contribute to ghost fishing (Matthews and Glazer, 2010), and cause economic losses to fishers directly by loss of gear, and indirectly by reducing the fish available to catch and sell. A very small number of Caribbean States have joined the Global Ghost Gear Initiative (GGGI), pledging to reduce the gear that is lost and remove the gear that is already in the ocean. The governments of Montserrat, Dominican Republic and Netherlands have joined, with many others taking part in initiatives to reduce ghost fishing (e.g. FAO/GGGI Workshop on the Best Practices to Prevent and Reduce ALDFG; Ocean Conservancy, 2019).

Interactions with COVID-19 impacts

Globally, the fisheries and seafood value chains have been impacted by COVID-19 due to reduced fishing activities and direct loss of business and market demand such as tourism (FAO, 2020a). Caribbean countries have been affected, mainly through negative effects on employment, consumption, and increased poverty levels. Many fishers have been unable to fish during times of national lockdowns, and there are fewer tourists in the Caribbean, meaning there is less demand for fish.

In Belize, the impact of COVID-19 has been different across the various fisheries. The fishing seasons for spiny lobster and for queen conch were closed before the lockdown (i.e. in February and 27 March 2020, respectively), and the catches of spiny lobster and queen conch had also been exported before this, and so these fishermen were not hugely affected. However, in the case of finfish species, local demand dropped by about 40- 50%, due to loss of people's incomes, and in some cases, the finfish prices also increased due to limited catches. Fishers with licences were authorised to continue fishing and selling their produce in existing local markets (including informal markets) during lockdown, however they have not always been able to sell their products due to a lack of transport and refrigeration (S. Espinoza, *pers comm.*). Estimates suggest that fish and seafood production could decrease by up to 60% compared to typical production conditions. Although current exports have declined since the second quarter of 2020, no direct data are available since June 2020. While some Caribbean countries have actively taken action to continue with surveillance for illegal fishing (S. Espinoza, *pers. comm.*), illegal fishing has been reported in the San Pedro (Ambergris Key) and Belize

City regions during the pandemic period. This trend could be partly due to the closure of government offices responsible for the granting of fishing licences. The main government actions to support the fisheries sector during the pandemic include waiving some licence requirements and focusing on stopping illegal fishing practices. Unemployment support and food assistance programmes are also being implemented. In Barbados, some online trading of fish has increased and this has improved connections between fishers and consumers.

The ongoing Oceans Economy Trade Strategy (OETS) Project (UNCTAD/DOALOS, 2020) aims to support its beneficiary countries (e.g. Belize, Costa Rica, Barbados) with some funding assistance. This project supports the fishing sector with their fish stocks, compliance with sanitary measures in the seafood sector, and improving ocean governance activities. It also aims to develop and implement traceability mechanisms in the seafood sector and increase training in practices such as hygienic practices in the handling, processing, storage and transportation of products. In Barbados, under the OETS Project, the United Nations Conference on Trade and Development (UNCTAD) worked with FAO to assess the tuna fishery against the Fishery Performance Indicators (FPIs) to improve the environmental, economic and social sustainability of the fisheries sector (Gentner, 2020). FAO is now implementing the follow-up of this project in Barbados and will support the country in developing a loining facility.

The pandemic has also re-emphasised the need for economic diversification. Some countries are exploring new products, potentially expanding to new markets and new partnerships. Some fisheries have been considering how they can complement ongoing initiatives. For example, the Marine Conservation and Climate Adaptation Project (MCCAP) is currently providing training and equipment to fishers in support of deep slope fishing in Belize. The OETS Project could provide an opportunity to continue or complement such training, which is seen as a priority by Belize in the context of COVID-19 recovery. These examples will continue to support COVID-19 recovery strategies in the Caribbean region.

While it is not clear for how long the impacts of the pandemic on fisheries will continue, some of the strategies employed by fisherfolk to adapt to the situation will complement climate change adaptation strategies; this includes, for example, diversifying livelihoods and adding value to catches. Adaptation strategies can be complementary, and improve sustainability of fisheries, livelihoods and the environment.

4. Vulnerability of Caribbean fisheries and aquaculture

This section addresses vulnerability of fisheries in different Caribbean countries due to climate change, and aims to identify commonalities as well as country-specific patterns, to identify where, and how, adaptation action may need to be prioritised. Further information on vulnerability and risk assessments is found in Annex 1.

Approaches for quantifying climate vulnerability or risk: CVA and CRA

Understanding the separate components of climate risk, as well as what capacity there is to deal with risk, is important if effective adaptation measures are to be designed and implemented, to build resilience against climate change.

In 2001, the Intergovernmental Panel on Climate Change (IPCC, 2001) established a framework for conducting climate change risk assessments to understand how the different components of climate risk affect linked ecological-economic systems. This approach called the Climate Vulnerability Assessment (CVA), was used in several highly impactful studies on fisheries, including in the Caribbean (e.g. Allison et al., 2009; Monnereau et al., 2015, 2017). A new, Climate Risk Assessment (CRA) approach was introduced more recently (IPCC, 2014b) and is aimed at better capturing climate risk and risk management (and removing focus from vulnerability); it is rapidly gaining ground and being adopted by an increasing number of countries and institutions (IPCC, 2019). On these grounds we characterise both frameworks and highlight their compatibilities (Table 1).

Table 1. The key components of two approaches for quantifying climate risk in fisheries: the climate vulnerability assessment (CVA) and climate risk assessment (CRA). Components that are similar between the two approaches are shown side-by-side. Variations on both frameworks exist, as both CVAs and CRAs can be flexibly adapted to accommodate specific case studies. Further information on the differences is found in Annex 1.

Category	**Climate Vulnerability Assessment (CVA)**	**Climate Risk Assessment (CRA)**
Physical driver	Exposure I	Hazard (H)
Ecological and socio-economic effects	Sensitivity (S)	Exposure(E)
Capacity to adapt – or lack thereof	Adaptive Capacity (AC)	Socioeconomic Vulnerability (V)
Combined assessment	**Overall Vulnerability (V)**	**Overall Climate Risk (R)**

Unravelling the sub-components of climate risk or vulnerability

(1) Climate Exposure (CVA) or Hazard (CRA)

Between regions, countries or communities, key differences may exist in the physical effects or 'hazards' of climate change that a system is exposed to. Under the CVA framework, this is captured by the 'Exposure' metric (E); under the CRA framework, this is captured by the 'Hazard' metric (H) (IPCC, 2001, 2014). In the Caribbean, the physical effects or 'hazards' of climate change include rising sea surface temperatures, increased extreme weather events, changes in rainfall patterns, sea level rise and flooding, and ocean acidification, in addition to other factors. More detail on these is found in Annex 1.

Climate Exposure (CVA) or Hazard (CRA) compared across the Caribbean. Monnereau et al. (2015) compared exposure across the various countries of the Caribbean, based on metrics including sea level rise, sea surface temperature change and ocean acidification (Figure 4). It was reported that both the Greater Antillean islands and the main Lesser Antillean Arc (less so Barbados) are experiencing highest levels of hazard exposure (shown darkest blue in Figure 4). While storminess was not included in their study, the same countries are also particularly exposed to Atlantic hurricanes which tend to hit these islands at full force; for example, the hurricane season of 2017 caused destruction in many of these countries, with Antigua and Barbuda, Saint Martin, Anguilla, the US Virgin Islands, Puerto Rico and Dominica sustaining the brunt of the damage (UNDP, 2017).

Climate exposure or hazard can vary within countries; in many of the Eastern Caribbean countries, the Eastern (Atlantic) sides are more directly exposed to impacts from hurricanes (illustrated for Dominica in 5; Pinnegar et al., 2019). However, in many of these countries, the human populations are more concentrated along the west coasts (facing the Caribbean Sea), where the coastal areas are very narrow in many places and the associated risks from flooding are higher.

(2) Species Sensitivity (CVA) or Ecological Exposure (CRA)

How sensitive or robust are different species and habitats that fisheries depend upon, to the impacts from climate stressors? And following any disturbances, how is their potential to recover? This is captured, in a CVA, by the metric 'Species Sensitivity'; in a CRA it can be captured by either 'Species Sensitivity' or 'Ecological Exposure'. While all species in an ecosystem are typically interconnected, some are – based on their biological characteristics – more likely to be adversely impacted by climate stressors or other disturbances than others. Such key traits include:

Thermal tolerance. Some species are more tolerant of increased temperatures than others.

Habitat specificity. How specialised the habitat requirements of the species are.

Recovery potential or population resilience. The reproductive and turnover rates of the species.

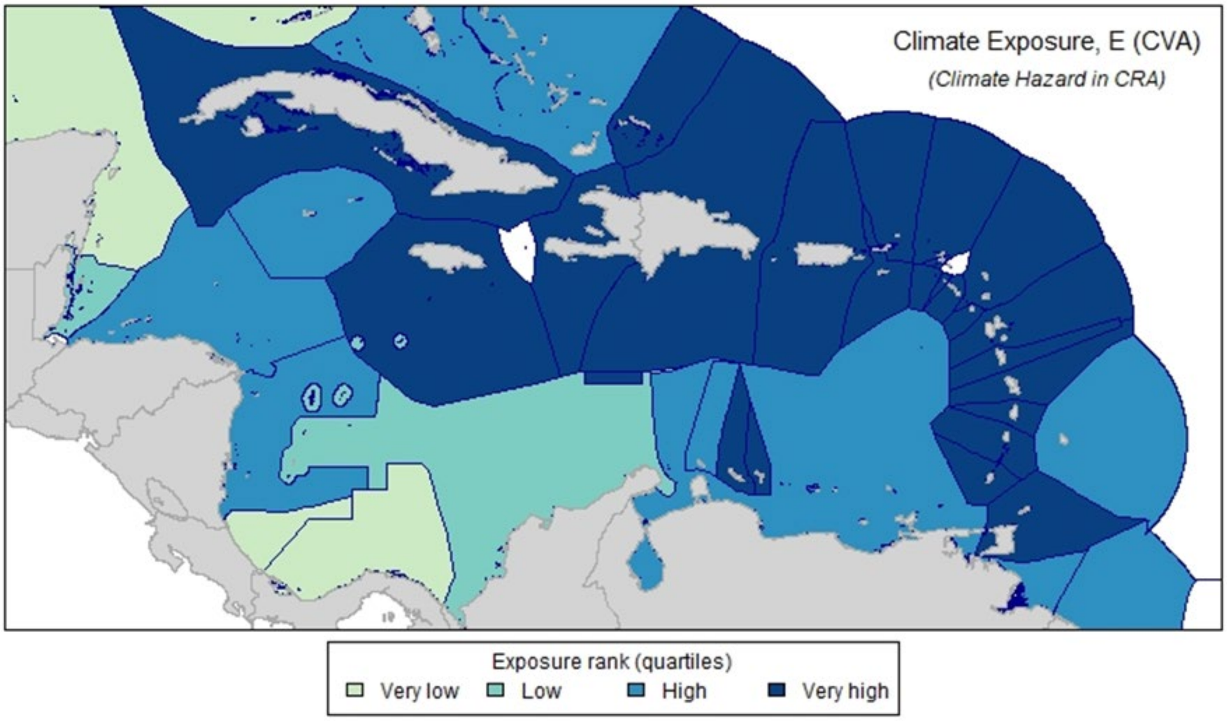

Figure 4. Climate Exposure (CVA, equivalent to Climate Hazard in CRA) of the fisheries sectors in 33 Caribbean countries or territories. Each country is delimited by its Exclusive Economic Zone (EEZ) boundary. Colours represent relative exposure if Caribbean countries are ranked across 173 countries globally. Redrawn from Monnereau et al. (2015). NB These boundaries are subject to some objections which have been submitted to the UN.

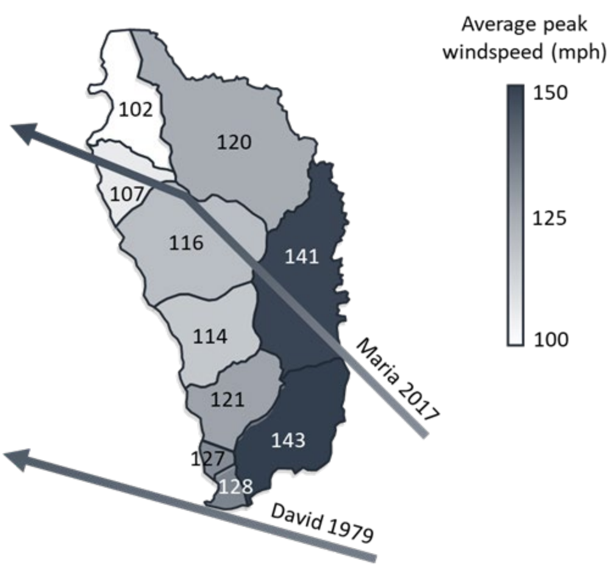

Figure 5. Climate Exposure (CRA, equivalent to Hazard in CRA) compared between each of the ten parishes of Dominica, based on peak hurricane windspeeds (redrawn from Pinnegar et al., 2019). Arrows indicate the tracks of the centres of Hurricanes David (1979) and Hurricane Maria (2017). While both hurricanes were most devastating in the eastern and southern parts of the island, country-wide damage was experienced (CoD, 2017).

For a given fishing fleet, coastal community or region, the overall species sensitivity of the fisheries catches will depend on the combination of species that are caught, combined with each species' sensitivity and their relative importance in the catches. For example, in Dominica, which has typical species for the Eastern Caribbean (Figure 6), species sensitivity was found to be highest for parishes where fisheries depend largely on coastal, reef-associated fish with specific habitat requirements, which are especially located along the west coast in Caribbean waters. It was lower for parishes where fisheries mainly catch offshore, highly mobile pelagic species, which are especially located along the east coast in Atlantic waters (Pinnegar et al., 2019). In some communities such as Scott's Head (near the south-west tip of the island), species sensitivity was intermediate, as fisheries catch a mixture of pelagic and demersal fish caught in both Caribbean and Atlantic waters.

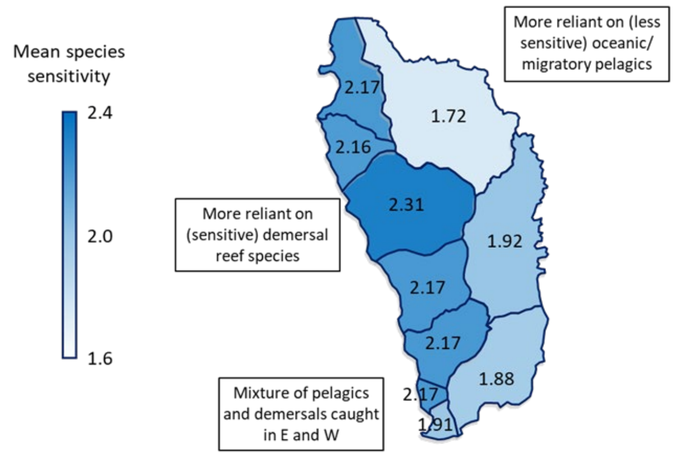

Figure 6. Mean Species Sensitivity (CVA, equivalent to Ecological Exposure in CRA) of the fisheries sectors in each of the ten parishes in Dominica. Colours represent average species sensitivity across all species caught by parish, based on thermal tolerance, habitat specificity and population resilience (scaled 1 to 4), and weighted by each species' relative importance in the catches. Redrawn from Pinnegar et al. (2019).

(3) Fisheries Sensitivity (CVA) or Fisheries Exposure (CRA)

Fisheries Sensitivity (in a CVA) or Fisheries Exposure (as termed in a CRA) capture the extent to a which a community, region or country are dependent on fisheries, either for food security or for sustaining livelihoods, and therefore are exposed to, or sensitive to, any changes in the marine environment due to climate change. Key components include:

Jobs in the harvest sector: Full or part-time fishers.

Jobs in the post-harvest sector and associated businesses: Fish supply chain such as processors, vendors, boat builders, etc.

Diversity of catches: Single or multi-species fisheries. Whether a broad range of species, or very few.

Fisheries Sensitivity (CVA) or Exposure (CRA) compared across the Caribbean. Monnereau et al. (2015) compared fisheries sensitivity across Caribbean countries (7), based on metrics that included: level of dependence on fisheries, levels of stock overexploitation, coastal vulnerability, coastal health and protection, and coastal development threat. They reported particularly high sensitivity for Grenada, the Bahamas, Belize, and Antigua and Barbuda because of high fisheries dependency. In Belize, sensitivity was reportedly high due to concerns about coastal health and protection. Coastal vulnerability was highest in Montserrat, the British and US Virgin Islands, and Anguilla.

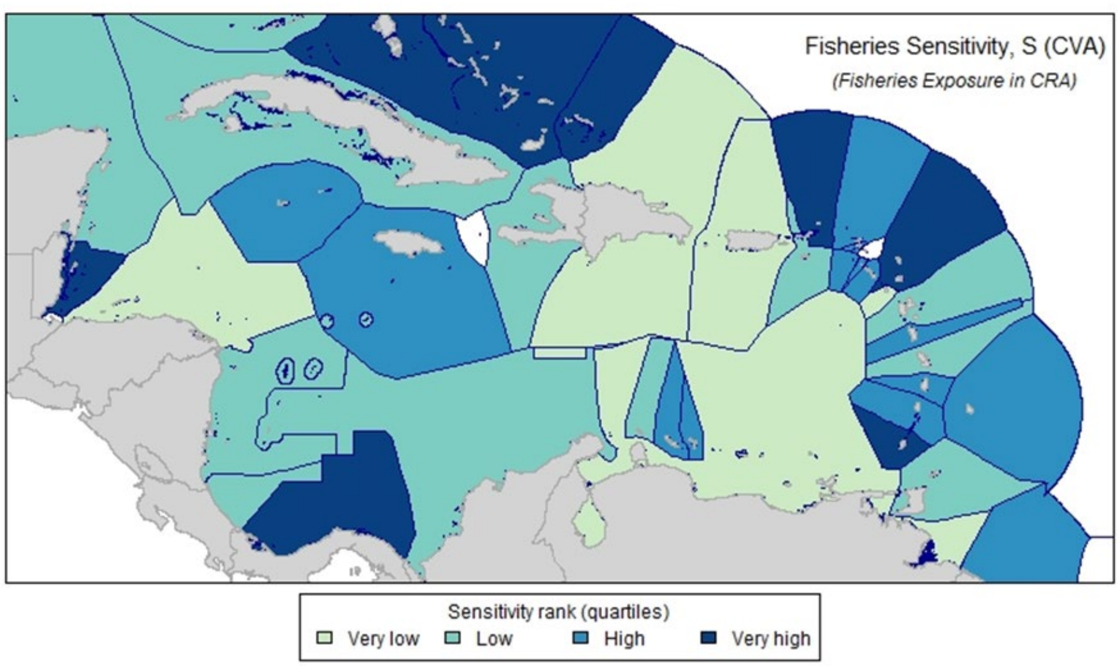

Figure 7. Fisheries Sensitivity (CVA, equivalent to Fisheries Exposure in CRA) of the fisheries sectors in 33 Caribbean countries or territories. Each country is delimited by its EEZ boundary. Colours represent relative sensitivity if Caribbean countries are ranked across 173 countries globally. Redrawn from Monnereau et al. (2015). NB These boundaries are subject to some objections which have been submitted to the UN.

In some medium to large-sized countries including Venezuela, the Dominican Republic and Honduras, fisheries sensitivity was reportedly lower, mainly due these countries being less dependent on fisheries and marine resources, compared to some SIDS, where the majority of people live near the coast with lifestyles closely associated with the sea, and where fish might provide a significant percentage of animal protein. However, in these larger countries, individual coastal communities may still be highly dependent on fisheries and their sensitivities may not be fully captured by country-wide metrics.

(4) Adaptive capacity (CVA) or Socioeconomic Vulnerability (CRA)

This aspect looks at the extent to which communities, regions or national economies are able to anticipate and respond to changes, and their ability to minimise, cope with, and recover from the consequences, if impacted by climate change. This is termed 'Adaptive Capacity' (AC) in the CVA framework (IPCC, 2001; Allison et al., 2009); in a CRA, the reverse – challenges associated with adaptive capacity – is referred to as 'Socioeconomic Vulnerability (V). Thus, improving adaptive capacity (or reducing socio-economic vulnerability) will be tightly linked with building resilience[2]. Adaptive capacity comprises elements such as levels of social capital, human capital and the appropriateness and effectiveness of governance structures (Haddad, 2005; Vincent, 2007). Key components are linked with health (e.g. life expectancy rate, access to drinking water, quality and capacity of the public health system), education (e.g. literacy, school enrolment ratios), governance (e.g. political stability, democracy and accountability, enforcement, regulatory quality and rule of law), and size of economy, with both total economy size and per-capita gross domestic product (GDP) being of relevance (Allison et al., 2009; Monnereau et al., 2017).

Adaptive Capacity (CVA) or Socioeconomic Vulnerability (CRA) compared across the Caribbean. Across the Caribbean region, Monnereau et al. (2015) assessed adaptive capacity based on governance and the total size of the Exclusive Economic Zone (EEZ); on the levels of protection of the marine environment through Marine Protected Areas (MPAs); on foreign direct investment; on the effectiveness of fisheries management; and dependency on foreign aid and remittances. Adaptive capacity was lowest (indicated darkest blue in Figure 8) in Haiti (linked with challenges with governance, foreign investment, dependence on foreign aid and remittances and fisheries management), in Guyana (linked with challenges with governance, marine protection and fisheries management), and Saint Vincent and the Grenadines (particularly linked with fisheries management).

It is of note that adaptive capacity is highly diverse between countries, and in many cases contrasting between neighbouring countries, as exemplified by many countries in the Greater and Lesser Antillean island chains. Monnereau et al. (2015) also emphasised that levels of (socioeconomic) sensitivity are variable between countries. As a result, recommendations for adaptation measures aimed at reducing sensitivity and improving adaptive capacity will also have to be country-specific, in line with the Liliendaal Declaration, which promotes the implementation of specific adaptation measures to address key vulnerabilities in the region.

(5) Overall Climate Vulnerability (CVA) or Climate Risk

The overall Climate Vulnerability (V, as termed under the CVA framework) or overall Climate Risk (R, as termed under the CRA framework) of a community, region or country are the result of the combination of each of the above components (Figure 9)[3].

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[2] Conversely, in the CRA framework this is captured by 'Vulnerability' (or Socio-economic Vulnerability) – where the term refers to the challenges within a community, region or country to anticipate, respond to, and recover from the impacts from climate change (IPCC, 2014b). Thus, 'Vulnerability' in a CRA is equivalent to 'reverse AC' in a CRA (and differs from 'Overall Climate Vulnerability' in a CVA, see below).

[3] Thus under a CVA, overall vulnerability V is defined as the means of climate exposure, sensitivity and adaptive capacity (where the reverse of AC is typically used, given that lower adaptive capacity implies higher overall vulnerability); under a CRA, overall risk R is defined by its components hazard, exposure and (socioeconomic) vulnerability (IPCC, 2014b). For specific details on how the different components are combined

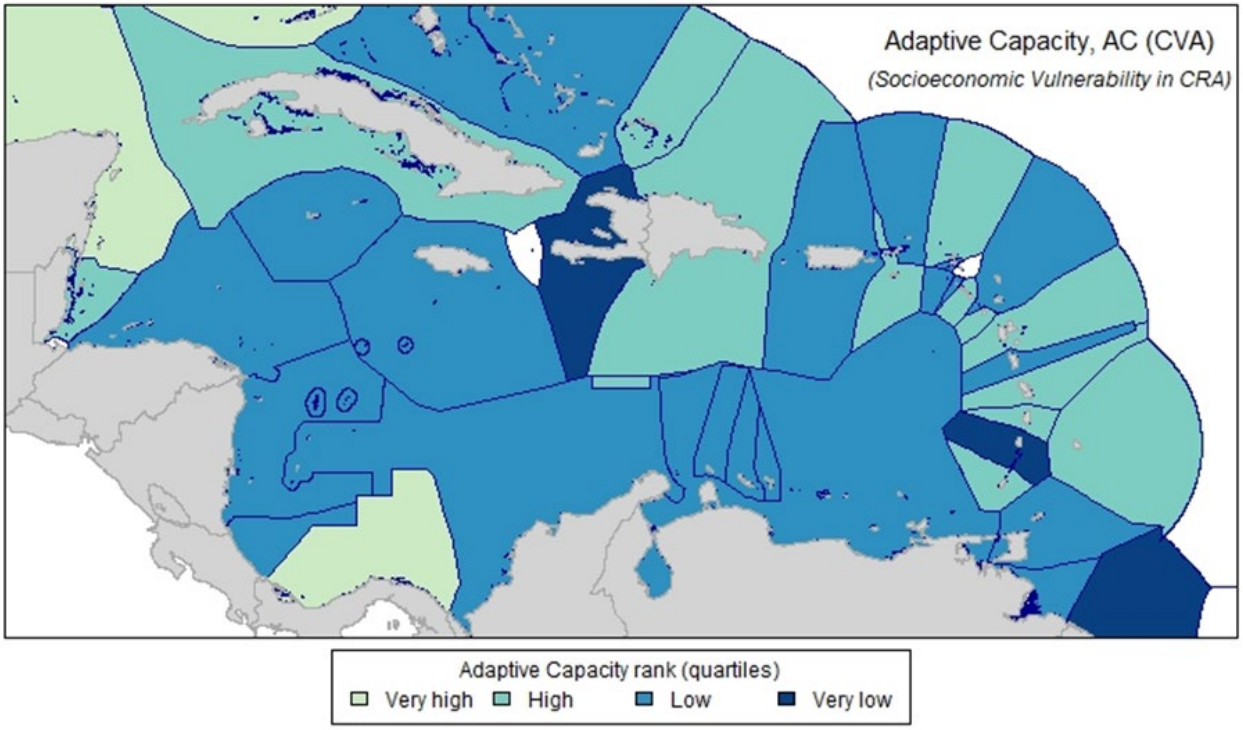

Figure 8. Adaptive Capacity (CVA, associated with Socioeconomic Vulnerability in CRA) of the fisheries sectors in 33 Caribbean countries or territories. Each country is delimited by its EEZ boundary. Colours represent relative adaptive capacity if Caribbean countries are ranked across 173 countries globally. Redrawn from Monnereau et al. (2015). N.B. These boundaries are subject to some objections which have been submitted to the UN.

It is important to note that fisheries in all Greater and Lesser Antillean countries are categorised either as having 'high' or 'very high' overall vulnerability. This is due to combinations of vulnerability components that are somewhat different between these countries.

An important component shared across almost all these countries is the very high physical hazard exposure due to high levels of warming, risk of sea level rise and flooding, and increasing frequency and intensity of tropical storms and hurricanes (compare with Figure 4).

Within the region, almost all Eastern Caribbean SIDS have fisheries with 'very high' overall vulnerability: these countries are not only highly exposed to the physical hazards but also have small population sizes, a high dependency on marine resources for various sectors of the economy, and often low adaptive capacity due to a lack of total resources and institutional capacity. As a result, a single extreme event can cause country-wide damages and may take a very long time to recover from, in turn, adding additional challenges to adaptive capacity. When hurricane Maria hit Dominica in 2017, the country's fisheries were still in a recovery phase from damages incurred by tropical storm Erika, which had hit the country in 2015. Other Eastern Caribbean countries characterised by very high climate vulnerability (risk), include Antigua and Barbuda, Saint Lucia, Saint Vincent and the Grenadines, Grenada (Agostine et al., 2014), and Trinidad and Tobago. However, in several larger, Central Caribbean countries such as Haiti and Jamaica, overall climate vulnerability is similarly, very high. These countries share many of the challenges with exposure, sensitivity, and adaptive capacity with Eastern Caribbean SIDS.

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to calculate overall V or R under the two frameworks, see e.g. Allison et al. (2009), Monnereau et al. (2017), or Payne et al. (2020).

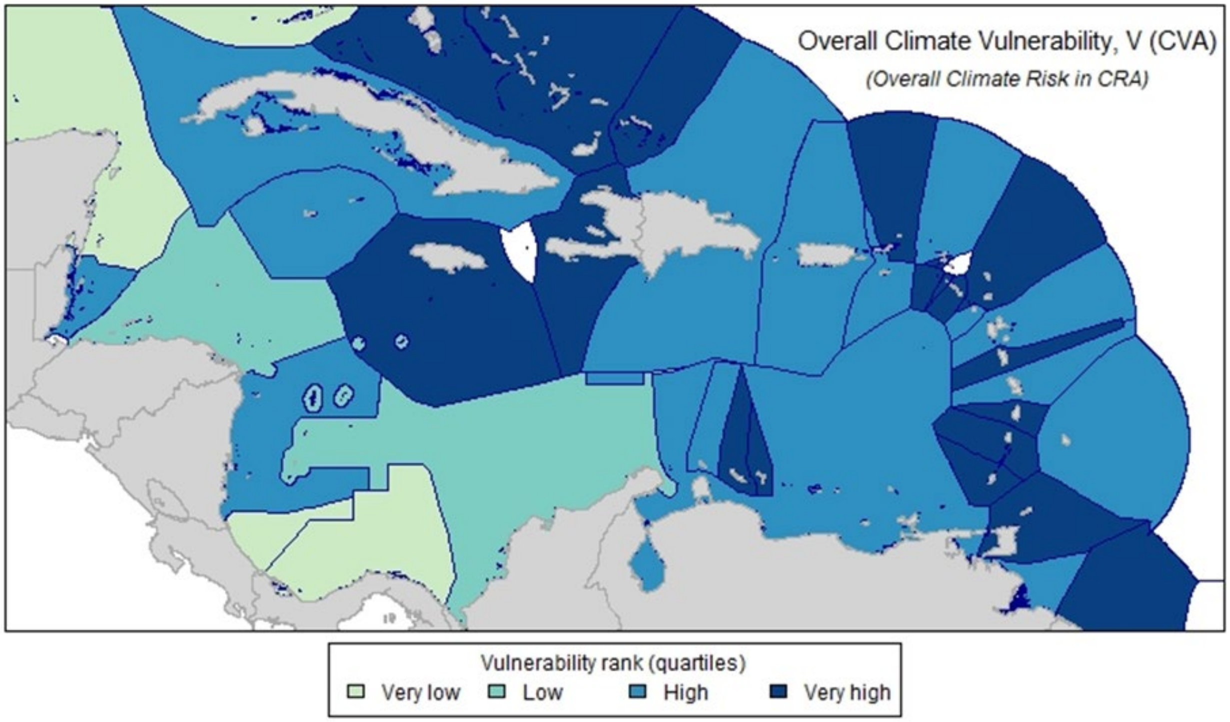

Figure 9. Overall Climate Vulnerability (CVA, equivalent to Overall Climate Risk in CRA) of the fisheries sectors in 33 Caribbean countries or territories. Each country is delimited by its EEZ boundary. Colours represent relative overall vulnerability if Caribbean countries are ranked across 173 countries globally. Redrawn from Monnereau et al. (2015). NB These boundaries are subject to some objections which have been submitted to the UN.

Climate change is having substantial impacts on Caribbean fisheries, reflected in high to very high climate vulnerability. Individual countries, regions and communities differ in many of the specific components of vulnerability, with their fisheries sectors facing different challenges. As set out in the next section, adaptation measures aimed at successfully countering climate vulnerability and building resilience, will have to take account of these differences, and will have to be specific to countries, communities and types of fisheries, while drawing on the commonalities that are shared across the Caribbean.

5. Adaptation

A vulnerability assessment identifies specific aspects that make a sector or fishing community most at risk from climate change. The results can then be used to identify the adaptation measures that can address these. Adaptation measures can be either autonomous or planned, with autonomous adaptation instigated and developed by fisherfolk, communities themselves or non-governmental organisations, in response to changes in the natural system. Planned adaptation is more likely facilitated by institutions or governments, and more proactive and anticipatory (IPCC, 2007; FAO, 2014b). There are also 'no regrets' measures, which are generally focused on building resilience, where the environment or society benefit as a whole, as well as climate change adaptation in the fisheries (FAO, 2014b).

Adaptation measures can be categorised into institutional adaptation, livelihoods adaptation, and risk reduction and management for resilience (Poulain et al., 2018) (Figure 10). Institutional adaptation is planned and includes measures which must be taken by the government or legal level, providing the enabling environment and support for adaptation on the ground. Institutional adaptation also includes fisheries management, fishing and aquaculture infrastructure planning, and coastal planning. Livelihood adaptation can be either autonomous or planned, and can be within the sector, or between sectors. Measures include diversifying livelihoods away from fishing or aquaculture, but also adapting the sector to reduce climate risks and vulnerability. For example, decreasing fish waste and adding value to existing catches supports building climate-smart

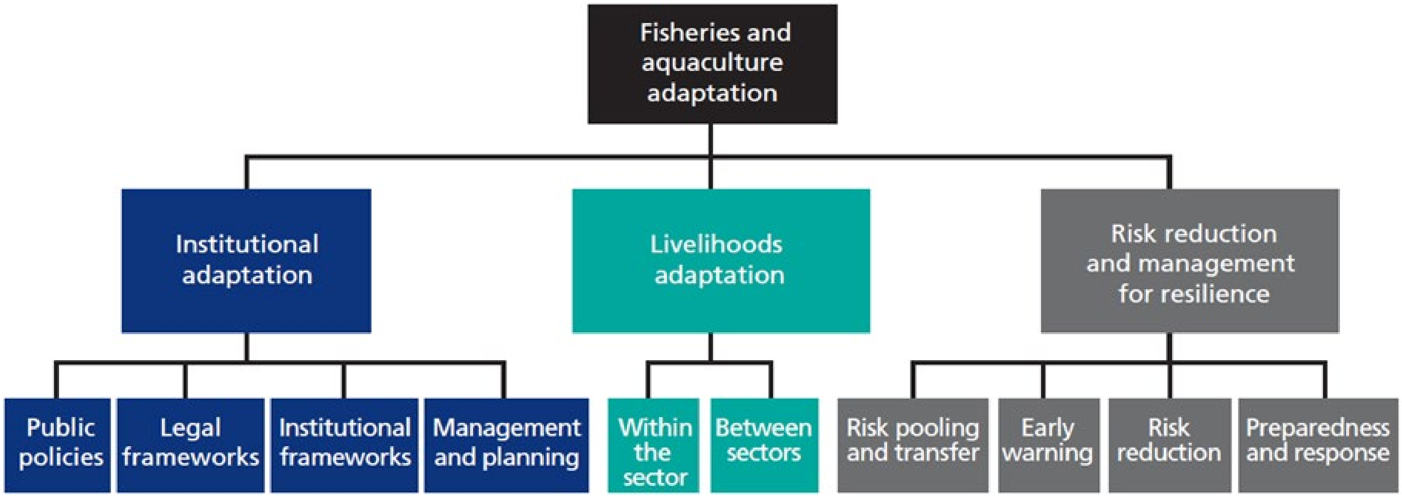

Figure 10. Categories of adaptation activities for fisheries and aquaculture. Taken from Poulain et al. (2018).

fisheries or aquaculture through 'on the ground' actions taken by fishers or with fishers as beneficiaries. Risk reduction and management are generally planned and include reducing the impacts of hurricanes and storms on communities or infrastructure and developing insurance schemes. This also includes no-regrets measures within ecosystem-based fisheries management which improve ecosystem health, increase fish populations, and build resilience to climate change in marine ecosystems.

In considering adaptation options, it is vital that maladaptation is avoided. This is where an action may appear to be beneficial in the short term, but can make poverty worse and cause negative social or environmental impacts in the long term (Charles, 2019). Examples of maladaptation in marine fisheries include diversifying fishing activities to exploit more vulnerable stocks; stocking hatchery-bred fish into a stressed system with negative impact on the wild population; destroying natural habitats and sea defences to build fisheries infrastructure; and management which reduces access or catches, leading to illegal fishing (Poulain et al., 2018). An example in marine aquaculture is stocking animals which can carry disease, reduce the genetic pool, or impoverish the wild environment (Poulain et al., 2018). Maladaptation can be avoided by carefully considering the potential short and long-term impacts on the environment and communities caused by implementing an action or intervention, prior to applying the adaptation measure.

The adaptation measures described in Table 2 are taken from the FAO's Fisheries and aquaculture adaptation toolbox (Poulain et al., 2018), the Technical Report on Vulnerability of the fisheries sector to climate change impacts in SIDS and the wider Caribbean (Monnereau et al., 2015), the CC4Fish project Policy Brief on Climate Change and Fisheries (Cox et al., 2020), a compilation of adaptation actions by the FAO (2014b), the FAO's Climate Smart Agriculture Sourcebook (FAO, 2017) and a review of aquaculture adaptation strategies by Galappaththi et al. (2020). The outcome of the risk and vulnerability assessments (Chapter 4) can be used to identify the most appropriate measures for Caribbean islands or local areas, based on the specific areas of the assessment which show the greatest sensitivity.

Table 2. Adaptation measures which could be implemented in the Caribbean. The speed of response at which they could be implemented, and the scale of the resource required (H = high, M = medium, L = low) have been estimated for each measure.

Institutional adaptation		**Speed of response**	**Scale of resource (H,M,L)**
Public, legal and institutional policies and frameworks	**Climate adaptation planning**. Include adaptation in the fisheries and aquaculture sectors in national adaptation plans, policies or legislation (e.g. fisheries into Nationally Determined Contributions).	**<2 years**	**L**
	Public investments. Increase investments in research, science communication, adaptation measures, building adaptive capacity, hydrographic monitoring, and developing new fishing and aquaculture technologies.	**<2 years**	**H**
	Public-private partnerships. Promote partnerships to encourage investment, improvement and employment in the fisheries and aquaculture sectors.	**2-5 years**	**L**
	Increase capacity of fisheries divisions. Increase the financial and resource capacity of fisheries authorities, including in training and equipment, to strengthen institutional, regional and national capacity on mechanisms to implement climate change action and monitoring.	**2-5 years**	**M**
	Mainstream climate change. Include consideration of climate change monitoring and action in national and regional fisheries and aquaculture policies and legislation, as well as multi-lateral access agreements for shared stocks. Countries implement the Climate Change Adaptation and Disaster Risk Protocol of the fisheries sector of the Caribbean Community Common Fisheries Policy (CCCFP).	**2-5 years**	**M**
	Adaptive and responsive climate-smart legislation. Fisheries legislation may need to be flexible to changes in spawning seasons, quotas, species harvested, and the gear or techniques used.	**>5 years**	**L**

Management and planning	**Consider community concerns**. Include coastal communities in assessing community vulnerability and capacities, fisheries management, and subsequent planning decisions for development projects, where their livelihoods and access to fish may be affected.	**<2 years**	**L**
	Climate-smart aquaculture planning. Ensure that aquaculture facilities are climate-smart (e.g. make use of rainwater systems), well planned in advance, in areas protected from flooding, landslides or storm surges. Use native species that are resilient to future increases in temperature, resistant to disease and that will not cause environmental damage if accidentally released into the wild. Use systems with reduced stress so that animals are more tolerant of environmental changes and disease. Ensure back-up generators for oxygen and water pumps in case of electricity failures due to storms or hurricanes.	**<2 years**	**M**
	Climate-proof infrastructure. Locate fisheries infrastructure away from coastlines vulnerable to flooding, and/or make them robust enough to withstand sea level rise, inundation and high winds. Create hurricane preparedness plans for fishing communities. This includes having safe harbours for fishing boats during storms or hurricanes, or having winches, trailers or cranes in place to remove boats and equipment to a designated safe area prior to an extreme weather event. Have areas designated for storing equipment, such as engines. Appropriate codes of practice, engineering standards and maintenance can reduce the likelihood of flooding and minimise the impacts in such events. Ensure the use of rainwater harvest system, solar powered energy and use of hurricane straps where possible.	**Some aspects <2 years, some may take longer**	**L-H**

	Strengthen co-management. Strengthen partnerships between government, fisherfolk, and fisherfolk organizations and move towards co-management of fisheries. Fisherfolk organisations can play a part in working with government in data collection, designing management measures, and ensuring compliance to create climate-smart fisheries.	**2-5 years**	**L**
	Improve gear marking and reduce and remove ghost gear. Hurricanes and storms can lead to loss of fishing gears impacting the health of the marine ecosystem as the gears continue ghost fishing (e.g. in the case of lobster traps). The best practice on management and recovery of lost gear (GGGI, 2017), and marking of fishing gear (FAO, 2019), will reduce the fish mortality and negative impacts on the marine habitats associated with lost gear in the region, as well as reducing costs to fishers.	**2-5 years**	**L**
	Integrated coastal zone management. Develop policies which incorporate environmental, economic and social needs, and which safeguard protection of remaining habitats. Include aquaculture in coastal zone management, taking into account future temperature rise and temperature preferences of aquaculture species.	**2-5 years**	**L**
	Data collection and stock assessments. Improve data collection and aim for sustainable fisheries across all stocks. Apply the precautionary approach, especially for data-poor fisheries. In the long term, aim to complete stock assessments, including for reef fish, and put scientifically-determined management measures in place to prevent overexploitation and ensure sustainable fisheries are maintained. Continue monitoring of fish stocks to ensure they remain at sustainable levels, and to assess whether climate change is	**2-5 years**	**M**

	affecting populations. Ensure incorporation of using fisherfolk traditional knowledge.		
	Apply the ecosystem approach. Apply fisheries management that incorporates all fish stocks, different life stages, as well as habitats and that includes spatial management such as marine reserves and closed areas to ensure ecosystem and fisheries health. Apply temporal restrictions where necessary, and gear restrictions to prevent habitat damage and overexploitation of fish.	**2-5 years**	**M**
	Implement marine protected areas. Implement effective management of protected areas to improve the health of ecosystems and fisheries, in consultation with fishing communities. Ensure that fishing communities are part of the decision-making process, and are beneficiaries of the areas, through improved fisheries or tourism income. Ensure that communities are supported to adapt their livelihoods if necessary.	**2-5 years**	**M**
	Move to renewable energy and energy efficiency. Increase use of renewable energy and rainwater harvesting in fisheries markets, aquaculture farms and other facilities will help to reduce the carbon footprint and energy costs of the industry. Using solar panels on boats, energy efficient engines, and streamlined hull designs will improve fuel efficiency and reduce operational costs.	**>5 years**	**L-M**
	Prevent illegal fishing. Develop effective enforcement to reduce and prevent illegal, unreported and unregulated (IUU) fishing, and include estimates of these in stock assessments.	**>5 years**	**H**
Livelihood adaptation			
Within the sector	**Improve the fisheries value chain**. Add value to fisheries and aquaculture products, such as drying, salting, packaging, exporting and marketing small	**<2 years**	**L**

	scale fisheries products. Improve fish handling and storage to increase shelf life, reduce losses and increase value. Create job opportunities along the value chain.		
	Use less destructive fishing gears. Reduce or eliminate the use of destructive fishing gears and techniques, that fish for undersized fish or damage habitats, and move to more sustainable and selective fishing gears, such as pots.	**<2 years**	**L**
	Market diversification. Change to catches of more sustainable fish species and move away from overexploited species. Change to catching non-native species, or species moving into areas with warming waters. Move aquaculture towards low trophic level and least environmentally damaging species. Work at the consumer level to promote and market these species as more sustainable species.	**2-5 years**	**L**
	Develop sustainable FAD fishing. Where reef and inshore fish stocks are depleted, or reefs are degraded, develop sustainable fishing of high-value pelagic species on fixed Fish Aggregating Devices (FADs). Oceanic pelagic species are considered less vulnerable to climate change than reef fish and can be managed across boundaries by regional fisheries organisations. Community-managed FADs can be used by multiple fishers with little initial outlay per fisher. Careful management can maximise catches with a small number of FADs, ensuring that juvenile fish are not caught.	**2-5 years**	**L**
	Traceability of fish. Improve traceability and record keeping of catches to add value to fish products, especially for export. Certification schemes or eco-labels can increase the value of fish and allow export, by showing that they are from a sustainably managed fishery, and that safety standards are met.	**2-5 years**	**M**

	Increase aquaculture jobs. Consider a move away from unsustainable capture fisheries livelihoods, by developing facilities such as aquaponics, sustainable mariculture and aquaculture. This can also support a reduction in fish imports.	**2-5 years**	**M**
	Sustainable aquaculture practices. Use feeds that do not further deplete wild stocks, such as insect-protein feeds, or shift to non-carnivorous species.	**2-5 years**	**L**
Between sectors	**Develop skills in tourism**. Additional employment opportunities in the eco-tourism industry can be created, in consultation with communities, making the most of knowledge of the marine environment and the use of fishing boats. This can particularly be the case where reef fishing is reduced and ecosystem health is improving, and eco-conscious tourists can be attracted.	**<2 years**	**L**
	Develop non-fishing livelihoods. Provide training and education to fishers, particularly to youth or school-leavers, to provide alternative or additional sources of income and careers. With community involvement, target men and women and capitalise on the skills of young people, or on developing skills of older fishers to help them move away from fishing, and access retirement funds.	**2-5 years**	**L**
Risk reduction and management for resilience			
Risk pooling and transfer	**Fisheries and aquaculture insurance schemes**. Improve access to fisheries insurance across the Caribbean. Schemes are being trialled which provide a pay-out in the event of a storm or hurricane. Further schemes could be developed which provide insurance to individual fishers or aquaculturists to reduce the losses from storm damage, and allow a return to fishing or fish farming as soon as possible.	**<2 years for some schemes, longer in others**	**H**

	Business skills training. Improve the capacity of fisherfolk in business skills and savings. Increase opportunities and incentives for fishers to save in advance rather than being reliant on loans. Fisheries cooperatives could be supported and developed to facilitate this.	**2-5 years**	**L**
	Social security. Create and extend the ability and awareness to access social security and national insurance schemes to fishers and aquaculture businesses. Some countries have made this compulsory for fishers.	**2-5 years**	**L**
Early warning	**Effective early warning systems**. Implement early warning systems for fishers, for example via mobile phone apps (e.g. FEWER fisheries app), VHF radios, or other effective communication means. Ensure that fishers have access to new technologies, equipment and training.	**<2 years**	**L**
	Monitor regional sea temperatures, pH, sea level, rainfall and wave height. This is needed so that researchers and managers can better understand the impacts of climate change on ecosystems and fisheries, and adapt management as necessary. Real-time monitoring of acute events such as storm surges, waves and rainfall are needed for accurate early warning systems and effective disaster preparedness.	**>5 years**	**H**
Risk reduction	**Safety training for fishers**. Train all fishers in safety at sea, such as the use of life jackets, navigation, the use of VHF radios, and standard operation procedures in case of emergencies. Equip vessels with VHF radios and vessel tracking systems, especially those going further offshore.	**<2 years**	**L**
	Training in disaster plans. Strengthen disaster preparedness of fishing communities, fishing cooperatives and fishers by carrying out training in disaster	**2-5 years**	**L**

preparedness and developing disaster preparedness plans.		
Aquaculture sector disaster preparedness plans. Aquaculture sector plans should also be developed, on a country-specific basis, but also by each facility, to improve climate change resilience. These plans should contain specific information such as early harvest and storage in the event of a hurricane warning, protecting facilities from flooding, maintaining fish feed supply, back-up power supply, and maintaining markets after an event.	**2-5 years**	**M**
Fisheries sector disaster preparedness plans. Fisheries sector-specific disaster preparedness and response plans should be developed that include detail on exactly where boats and equipment are to be protected or stored and how they will be moved to those places, how alerts will reach all fishers, including those at sea, and communication chains within and between communities. These plans should be specific to the fishing industry to ensure that the specific aspects of safety at sea, protection of equipment, food provision and remote communities are all considered.	**2-5 years**	**M**
Develop climate modelling. Further develop downscaled climate models and projections for the Caribbean region, so that the impacts on commercial fish, shellfish and aquaculture species can be assessed. Projections on a regional or national scale are required across the Caribbean. Coastal inundation/flood modelling can be used to assess the effectiveness of coastal protection measures, such as sea walls or habitat restoration, and to identify infrastructure and communities most at risk. Requires cooperation in data collection and sharing.	**2-5 years**	**H**

	Build resilient ecosystems. Improve management of coral reef ecosystems, and other fisheries habitats by reducing the compounding pressures (Section 3) on the marine and coastal environment. By improving water quality, reducing habitat damage and marine litter, the health of ecosystems that support healthy fisheries can be improved. As well as stopping further degradation, restore natural coastal habitats such as seagrasses, mangroves and corals, to improve the fish they can support, but also to enhance their natural coastal defence value. Healthy ecosystems can also encourage eco-tourism, creating alternative livelihoods for fishers. Requires collaboration across governments and industry.	**>5 years**	**M-H**
	Improve sea defences. Where natural sea defences are not sufficient, use nature-based and other engineering solutions to reduce coastal erosion and provide coastal protection.	**>5 years**	**H**
	Build back better. When fisheries infrastructure such as markets, jetties, lockers and buildings is damaged, ensure that they are more robust to storms when they are replaced or repaired, and that they are designed to not cause damage (e.g. change currents).	**>5 years**	**H**

Adaptive capacity

As well as implementing the adaptation measures above, building adaptive capacity in the sector is vital for maintaining effective adaptation in the long-term (Poulain et al., 2018). Adaptive capacity allows fishers to make informed decisions themselves about undertaking autonomous adaptation, respond to planned adaptation measures, and recover from shocks to their livelihoods, such as from hurricanes. Adaptive capacity in the fishing industry and coastal communities can be strengthened by providing training in business skills such as bookkeeping, social security and financial management (as is currently carried out under the CC4FISH project). Increasing education in marine and coastal science, sustainable fisheries and climate change in schools will allow younger people entering the industry to make informed choices about sustainable fishing practices. Fisheries cooperatives can be used to develop financial support schemes, provide training such as in alternative livelihoods, safety at sea, adding value to fish products and sustainable fishing techniques. Training can be provided when fishers register or renew fishing licences, as is the case in Dominica, where fishers learn about sustainable fishing, bookkeeping, fish handling and preservation. Awareness raising and good science communication in climate adaptation and sustainable fishing is necessary and can give communities the knowledge they need to adapt to climate change.

6. Case studies

Below are some examples of existing adaptation measures that have been implemented in the Caribbean, with aims to improve climate resilience in the marine environment, fishers and fisheries. They demonstrate how community involvement can be incorporated into projects to ensure buy-in and build adaptive capacity as well as having direct benefits for the marine environment and fisheries.

Climate Change Adaptation of the Eastern Caribbean Fisheries Sector (CC4FISH) Project

The CC4FISH project aims to increase resilience and reduce vulnerability to climate change impacts in the Eastern Caribbean Fisheries Sector, through mainstreaming climate change in fisheries governance, and capacity building of fisherfolk fisherfolk organisations and aquaculturists, and building knowledge and awareness of climate change impacts and vulnerability of the fisheries sector. The CC4FISH Project is implemented by the Food and Agriculture Organization and funded by the Global Environment Facility (GEF). The project is implemented in seven Eastern Caribbean countries: Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines and Trinidad and Tobago. Regional partners are the University of the West Indies (Centre for Resource Management and Environmental Studies), Caribbean Network of Fisherfolk Organisations, Western Central Atlantic Fisheries Commission (WECAFC) and Caribbean Regional Fisheries Mechanism (CRFM). The start date was January 2017, with a projected end date of 30 September 2021.

The project operates at the individual, household, community, national and regional levels, working on 3 main areas:

1. Understanding and raising awareness of climate change impacts and vulnerability:

• Vulnerability and Capacity Assessments (VCAs) of fishing communities carried out in four project countries, and a toolkit developed to enable VCAs for fisheries to help identify priority areas for adaptation interventions at the local level;

• Modelling to assess the impacts of Sargassum on key fish species;

• The production of a Sargassum Outlook Bulletin to predict Sargassum arrivals every 2 months to better prepare government and fisheries sector responses;

• Development of a 'Sargassum Uses Guide' detailing the pros and cons of at least 14 different potential uses of Sargassum, and ways to improve food safety and economic benefits.

2. Increasing fisherfolk, aquaculturists' and coastal community resilience to climate change and variability:

• Training nearly 1100 fisherfolk in communication technology (VHF radio, GPS and mobile/cellphone), and provision of 1100 VHF radios to improve safety at sea, as well as building repeater systems to increase the range of VHF radios in 4 project countries;

• Training 1200 fisherfolk in safety at sea, engine repair, value adding activities, fish handling and processing and other capacity building activities to enhance safety of fisherfolk; increase income through value adding and decrease fish waste;

• Enhanced private sector engagement;

• Third-party fishing vessel insurance assessments to decrease risk to fisherfolk;

• Communication with fisherfolk to learn about best practices in adaptation, marine protected areas, co-management, and fish aggregating devices (FAD) fishing;

• Building of two aquaponics demonstration farms to build capacity and increase fish availability;

• Restoration of the Dominica shrimp hatchery, previously severely affected by Tropical Storm Erika and Hurricane Maria, to build capacity and provide seedlings to other shrimp farms, thus enabling other entrepreneurs in Dominica to start small-scale aquaculture businesses;

• Aquaculture strategies developed for three project countries, outlining options for sustainable aquaculture development;

• Introduction of aquaponics school systems to support learning and incorporating youth.

3. Mainstreaming of climate change adaptation in multi-level fisheries governance:

• A training of trainers session 'Regional Fisheries and Aquaculture Emergency Response Training (FARE)' was carried out, to enhance preparedness and facilitate Post-Disaster Damage and Needs Assessments (PDNA) after hurricanes, ensuring timely and appropriate incorporation of the fisheries sector in PDNAs to enable relief and rehabilitation assistance;

• A Regional Dialogue on Nationally Determined Contributions (NDCs) in 2019 to improve incorporation of the fisheries sector into the NDCs which allows for climate financing for the fisheries sector in the near future;

• The project is developing Fisheries Management Plans for four participating project countries, which each incorporate the ecosystem approach to fisheries, climate change adaptation, and disaster risk management plans;

• Development of four Sargassum Management Plans and two FAD Fisheries Management Plans, with the project providing further support to several other plans, policies, or legislations;

• Support in development of the Protocol on Climate Change Adaptation and Disaster Risk Management in Fisheries and Aquaculture under the CCCFP.

For successful implementation, project participants worked closely with stakeholders. The project employed a National Project Coordinator in each country to work together with fisheries authorities and ensure effective execution of project activities.

The project has generated a number of important results that potentially contribute to lasting, post-project sustainability at both the regional and national level, notably:

• Many national stakeholders were trained to become trainers or facilitators of capacity building within their countries, and were provided with extensive repositories of resources, such as in Information and Communications Technology (ICT) tools to enhance safety at sea, *Sargassum* management tools, , Fisheries and Aquaculture Response to Emergency tools, Safety at Sea training material and capability to conduct Vulnerability and Capacity Assessments;

• Enhanced relationships were built between key government agencies, which include the Fisheries Division, Coast Guard, and National Telecommunications Regulatory Commission (NTRC) of participating countries, as well as between fishers, fisherfolk organisations and government agencies;

• Fisheries policies were developed that are inclusive of climate change adaptation and disaster risk management, with legislation and fisheries-sensitive climate change policies introduced at the national and regional level.

Moored FAD fishing

Moored Fish Aggregating Devices (FADs) can be used to divert fishing pressure from reef species to pelagic fish. Pelagic fisheries are thought to be less affected by climate change than reef fisheries, and so it is thought that reducing fishing pressure on reefs can increase reef resilience to climate change. FADs can create a fishery that provides a more consistent and higher income to fishers than reef fishing, however it is critical that a fishery is developed following the precautionary approach to ensure sustainable management. Several countries in the Caribbean have developed or are developing a moored FAD fishery for pelagic fish, which is reducing pressure on their overfished coral reef and inshore fisheries, as well as providing income during closed seasons.

The Caribbean Fisheries Co-Management (CARIFICO) programme funded by the Japan International Cooperation Agency (JICA) developed FAD fisheries in many Caribbean countries, with best practice followed and community involvement from the start (Tamura et al., 2018). There were several practices followed which can be learnt from by other countries wishing to use FADs. In Antigua and Barbuda, wide consultations were undertaken which improved relations between fishers and the Fishery Division, improving information exchange on catch and effort. In Saint Kitts and Nevis, conflicts between fishers were addressed by developing clear rules and new legislation on FAD deployment and use. Training within the programme on FAD deployment, use and maintenance was vital, and increased fishers' skills. In Saint Lucia, submerged FADs have reduced damage from boats. In Grenada, a fishermen's association was formed, reducing conflicts, and giving fishers access to gear.

While they can benefit reef fisheries and diversify fisher livelihoods, moored FAD fisheries need to be developed carefully to ensure that they do not cause overfishing to pelagic stocks. Sadusky et al. (2018) describe a number of factors that must be considered in a new fishery to ensure it is sustainable and remains profitable. For example, community meetings must be held frequently to get buy-in and create a sense of shared responsibility; FAD fisheries should have management plans which describe data and monitoring of the fishery and catches, to be used in stock assessments and shared with regional management organisations; the fishery and the management plan should be developed in full consultation with fishers; and co-management of FADs can help to maintain a sustainable and profitable fishery. Additionally, new fisheries should remain small until robust stock assessments are made. There is extensive Caribbean Regional Fisheries Mechanism (CRFM), CARIFICO and international guidance available as to how to start a FAD fishery, considerations for a management plan, and which of the data to record.

Marine protected areas increasing resilience of fisheries to climate change

Marine Protected Areas (MPAs) can increase the health of coastal and marine habitats, making them more resilient to climate change pressures, and therefore better able to support healthy fisheries into the future. MPAs can sometimes displace fisherfolk, in particular if they do not engage with fishing communities or become driven by tourism activity rather than improvements to local fisheries. It is important that they are designed and maintained to provide benefits to traditional users and communities.

The Soufriere Marine Management Area (SMMA) on the west coast of Saint Lucia is an example of an effective MPA that was developed with and maintains community support. The SMMA has achieved worldwide acclaim and is one of the best examples in the Caribbean. In the 1980s and 1990s, there was conflict caused by increasing pressure from tourism and fishing on the marine resources in the area. Water quality was being degraded and there was pollution from waste disposal, the landscape was altered by hotels and buildings, and the reef fisheries became depleted (Soufriere Marine Management Association, 2002). All of this had implications for the reef ecosystem and for human health, which affected the amount of income generated from tourism, as well as the scientific and recreational value of the area. To resolve these conflicts, a fully participatory process was held with consultations, meetings and research activities, resulting in a zoning arrangement for the area. There are distinct zones in the SMMA, including marine reserves, fishing priority areas, multiple use areas, recreational areas and yacht mooring sites. There are also legal provisions, used to manage the multitude of activities (Soufriere Marine Management Association, 2002).

The SMMA is managed by a not-for-profit non-governmental organisation, the Soufriere Marine Management Association Inc., which is mandated to conserve the natural environment and ensure sustainable use within the fishing and tourism sectors. Technical support is provided by the Saint Lucia Department of Fisheries (Soufriere Marine Management Association, 2002). There is a management plan for the area and an SMMA manager. The management plan includes information on income sources, job responsibilities, monitoring, maintenance, and public awareness needs. Initially, external funding was required to establish the SMMA, but after three years it became self-sustaining by a user-fee (Soufriere Marine Management Association, 2002).

Compensation was originally given to the fishers affected by the protected areas, but after five years, catches increased dramatically (Roberts et al., 2003). The fish stocks in and around the reserve are regularly monitored, with surveys showing increases of commercially important species in and outside the reserve (Roberts et al., 2003). This indicates that the habitats and fish stocks are healthy and should have increased resilience to climate change.

Challenges are emerging within the SMMA from climate change, the expansion of the tourism industry, and financial constraints, and it has been recommended that the socio-economic benefits to the local community need to be improved to ensure its objectives are met into the future (Thurlow and Jones, 2020).

Another example of implementing MPA management for fisheries is in Belize, where they operate a rights-based, Managed Access approach to fisheries (Bahri et al., 2021). The conch, lobster and fin-fish fisheries are at risk to climate change impacts related to coral, mangrove and seagrass habitats, and so Managed Access now covers all fishing areas of Belize, to sustainably manage fisheries and improve the health of the habitats on which they rely. Pilot studies were carried out where fishers who historically fished an area were given rights to fish but had to be actively engaged in management and co-management committees. This led to higher sustainable catch rates, reduction of illegal fishing, and the declining trend of seagrass, mangrove and coral cover stopped (Bahri et al., 2021, and references therein). Following the pilot studies, Managed Access has been rolled out to the whole of Belize. Climate-smart adaptive management of the fisheries has been implemented, with data-limited stock assessments where necessary. The fisheries management law in Belize was changed in 2020 to incorporate the Managed Access and MPA programmes.

Coastal resilience in Grenada and Saint Vincent and the Grenadines

At the Water's Edge is a project established by The Nature Conservancy (TNC, 2018). The overall goal is to encourage government and communities to work together to improve the region's resilience to the effects of climate change. By improving the climate resilience of the marine habitats, healthy fisheries can be supported that are also resilient to climate change, while providing coastal protection from storms.

The three main aims of the project include the mobilisation of communities, utilising both national and local initiatives to create community action plans, and the development of an online mapping tool to assess connections between physical, and social vulnerabilities. The second aim was to test hybrid reef technology in the Caribbean. Local wave data was collected to help design artificial reef structures that reduce wave energy and support coral growth and biodiversity. The final aim was to restore coastal vegetation. This would be achieved by training locals to plant and care for mangrove seedlings in particularly vulnerable areas, encouraging the community to care for their natural resources.

Grenville Bay in Grenada was selected as the pilot site for the study, as the communities here rely heavily on the limited natural resources for the primary economic sectors of tourism, agriculture, and fishing. The two developing islands are on the front line of climate change, the impacts such as erosion, flooding and coral reef damage put essential resources at risk.

To meet the goal of mobilising communities, residents of the Grenville Bay area created their own action plans to increase resilience to climate change impacts. Advice was provided by local experts, TNC, government officials, and other specialists. Data was collected by TNC to create an interactive online mapping tool that demonstrates vulnerabilities due to climate change in the Caribbean. Participation from the community was encouraged to incorporate local knowledge and culture in the data collection. The Grenada Red Cross Society and National Disaster Management Agency also contributed to the project via a Vulnerability Capacity Assessment to establish individual community resilience plans.

The construction of artificial reefs in Grenville Bay were designed to reduce coastal erosion, using an eco-engineering approach (Figure 11). A detailed hydrographic model of wave and current patterns in the Grenville area was developed by TNC and the Environmental Hydrological Institute, using data from sixty years of wave dynamics, storm history and high-resolution bathymetry. The initial structures were installed in 2015 and monitored for one year before completing the full installation. The pilot phase of the reef protection project was funded by The German Federal Foreign Office, with support from the Grenada Fund for Conservation and Grenada Red Cross Society. In total, 30 metres of breakwater structures were constructed, using local materials such as stone from the nearby Telescope Quarry, and labour from Grenville welders and fishers.

The completed breakwater is designed to reduce 80-90% of wave energy for 30 years and is one of the world's first examples demonstrating how small island communities and governments can work together to protect vulnerable coastal environments from the impacts of climate change.

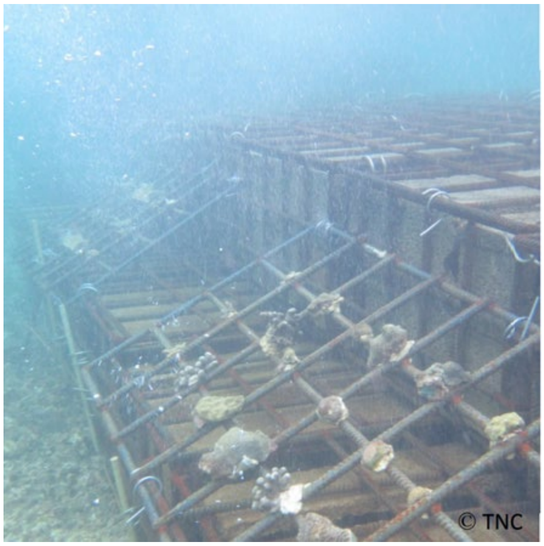

Figure 11. Complete breakwater structure provided by artificial reef in Grenville Bay, Grenada. Corals were transported from the original reef to increase biodiversity of the new artificial habitat (The Nature Conservancy).

The Grenada Fund for Conservation hosted twenty meetings with residents of the Grenville Bay area to discuss project phases, followed by two training sessions to teach community members how to collect and cultivate new mangroves in vulnerable coastal locations. 16 volunteers collected over 3000 mangrove seedlings in three days and were subsequently replanted in PVC pipes for additional support. These mangroves should grow to provide an effective natural coastal defence, helping to protect fishing communities and their equipment during storms and hurricanes.

Caribbean Track of the Pilot Programme for Climate Resilience

As part of the CRFM-led marine component of the Caribbean Track of the Pilot Programme for Climate Resilience (PPCR), a series of ecological, economic, and social assessments of climate change impacts on marine resources and the fisheries sector were undertaken. The assessment's multiple lines of evidence suggest large risk and impacts of climate variation on the Caribbean Sea's fish stocks and fisheries. Economic assessment results suggest a large pre-existing "adaptation deficit", as the estimated economic impacts of climate change appear small relative to documented losses and damages under current climate conditions. There are, however, opportunities to improve climate resilience across the seafood value chain by empowering resource users to self-organize and build local adaptive capacity, promoting seafood product differentiation and identifying enablers for governance effectiveness. Several improvements and extensions to the ecological and economic modelling undertaken under this project are possible and recommended; additionally, it has been found that information from this and previous research is available to inform adaptation planning and targeted measures. As such, assessment results also formed the basis of a communications campaign and monitoring and management recommendations undertaken as part of the project.

Fisheries Early Warning and Emergency Response (FEWER) app

To improve safety at sea, the FEWER mobile phone app is being rolled out to fisherfolk in the Caribbean, under the Pilot Programme for Climate Resilience (PPCR, 2020). The app sends alerts of bad weather conditions or sea state to fishers, giving them early warning of any potentially dangerous conditions. Users can share information on local conditions and about missing persons (Figure 12). Having information direct to mobile phones is valuable, as many fishers do not check weather conditions each day before they go to sea.

The app was developed by ICT4Fisheries Consortium and funded by the Inter-American Development Bank. Training has been provided to fishers on using the app and on protecting their phone while at sea. The training also included how to call the Coast Guard.

Initially, the app is being rolled out in Saint Vincent and the Grenadines, Saint Lucia, Grenada and Dominica. As it is proving useful to fishers, and improving safety at sea, it is hoped that it will be utilised across the Caribbean.

Basic Fisherman Training Course

In Dominica, each fisher who wishes to get a fishing licence, must undertake a training course run by the Fisheries Division. The course closely follows a comprehensive manual (Norris and Theophille, 2016) and contains information on a wide variety of topics including fish behaviour, local and global fishing, fishing technology, business management, social security, fisheries cooperatives, fish products, handling and storage, sustainable fishing, laws, co-management of the FAD fishery, climate change, safety at sea and marine radios. By ensuring that all fishers undertake the course, it helps to improve safety at sea, as well as increasing fishers' understanding

Figure 12. An advert for the FEWER mobile app. Taken from PPCR (2020).

about sustainable fishing practices and environmental issues. The CC4FISH project has been funding further roll out of the Basic Fishermen Course in 2020-2021 in Dominica.

The Basic Fisherman Training Course was originally developed by the Fisheries Division in 2005 but has been developed further through funding from CARIFICO and JICA. It was shared with other Eastern Caribbean countries, and Antigua and Barbuda have since developed their own training course. In Dominica, the Fisheries Division found that following the training course, the number of fishers lost at sea reduced, and fishers became more competent in fishing further offshore, reducing pressure on reef fish. In this way, the training course has improved the adaptive capacity of fishers by allowing them to invest in offshore fishing, as well as reducing fishing pressure on the inshore marine environment.

Fisheries insurance

Traditionally, fishers in the Caribbean have been unable to buy insurance for their vessels or livelihoods, because there is generally no insurance available. Fishers tend to rely on loans to replace damaged or lost gear after a hurricane, or work in different sectors until they can afford to rebuild or replace boats and equipment. In 2019, a pilot began for a new insurance scheme for the fisheries sector in the Caribbean. The Caribbean Oceans and Aquaculture Sustainability Facility (COAST) is a parametric, or index-based insurance, which aims to make the fisheries sector resilient to climatic events by releasing funds directly to those in the fishing industry in the event of bad weather, storm, or hurricane (CCRIF, 2019a). These pay-outs provide compensation for lost income and damaged fishing equipment.

Initially funded by the US State Department, with development by the World Bank and CCRIF SPC (formerly the Caribbean Catastrophe Risk Insurance Facility), the COAST insurance scheme was piloted in Saint Lucia and Grenada, and designed to provide immediate economic relief if a threshold level of rainfall, storm surge or wind were to be reached during a storm or hurricane (CCRIF, 2019a). These pay-outs have been predefined, based on the likely financial loss to vessels, gear, and infrastructure (Sainsbury et al., 2019). The aim is to roll out the insurance to other countries and territories across the Caribbean.

In both Grenada and Saint Lucia, the COAST products had been tailored to the fishing industry by detailed collection and analysis of fisheries data (World Bank, 2019a,b). Data on fisheries and disaster risk management were collated to inform development of the insurance in each case. This helped ensure there were mechanisms in place to distribute insurance pay-outs to the fishers quickly and effectively, and to understand the gaps in fisheries management that could be filled by future work. COAST aims to "foster a stronger blue economy in the region" by "incentivizing policy reforms for climate-smart fisheries practices and coastal resilience" (World Bank, 2019a,b). The insurance scheme also promotes the idea of building back better within the industry, which will help to increase resilience to future storms (CCRIF, 2019a).

CCRIF SPC state that insurance promotes food security, resilient fisheries, sustainable management, and disaster risk reduction in the Caribbean (CCRIF, 2019a). Having insurance that protects incomes and can help fishers to return to fishing quickly after a storm or hurricane, reduces need for high-interest loans, and allows fishers to save and invest in their livelihoods. If infrastructure is rebuilt more resilient to future events, this frees money used for repairs and replacements, allowing it to be invested in fisheries and environmental management. The hope is that this increase in adaptive capacity within the fishing industry will enable fishers to implement adaptation measures, build resilience and increase sustainability within fisheries.

Ocean acidification fisheries impact studies

The absorption of CO_2 is changing the chemical state of the seawater by altering the pH. This process of 'ocean acidification' is known to affect marine species, especially those that depend on carbonates to form their shells and skeletons, such as corals, the commercially important queen conch and spiny lobster, as well as some fish (Oxenford and Monnereau, 2017). Further adverse effects on species and habitats result from ocean acidification interacting with other climate change impacts, including increased storm frequency and rising sea surface temperature.

In 2015, the Commonwealth Marine Economies (CME) Programme funded a study in Belize to assess the vulnerability of commercial species to ocean acidification by collecting water samples for setting baselines for water carbonate chemistry and nutrient contents; documenting species of economic importance (e.g. spiny lobster and queen conch), mainly their mineralogy and morphometrics to inform the state of these species to support future climate changes assessments; documenting the economic profile with respect to the fisheries in the area and further influences resulting from extreme weather events; and providing knowledge and capacity building in Belize to support current and future monitoring programmes. Training and capacity building activities support the development of the Belize management plan and future strategies to safeguard fisheries and habitats of conservation importance (Birchenough et al., 2018).

Fishing activities in Belize support some 15,000 people, comprising fisherfolk, fish processers, and salespeople. Belize piloted a managed access area scheme from 2011-2016, which has been scaled up nationwide since 2017 to revolutionise fisheries management. The effects of ocean acidification on the fisheries of Belize are largely unknown, so this project is the first step in understanding the levels of pH change in Belize and the effects on spiny lobster and queen conch. By setting up a monitoring programme, the effects on the fisheries can be closely monitored, and necessary adaptation or mitigation measures can be implemented before there is large economic damage to fisheries. Further work will include continued collection of water and biological samples and economic assessments, and will expand to habitat assessments (coral reefs and seagrass beds), as well as integration with current fisheries data assessments.

7. Economics of climate change and fisheries adaptation

Costs of inaction

The economic costs of climate change inaction in the Caribbean are projected to total US$10.7 billion per year by 2025, including increased hurricane damages, loss of tourism revenue and infrastructure damages (CCCCC, 2012). By 2050 and 2100, the annual costs are predicted to have further risen to US$22 billion and US$46 billion respectively (CCCCC, 2012).

However, the costs of inaction will certainly vary between sectors and countries within the region, based on local contexts, differing exposure to extreme climate events, as well as varying infrastructure and assets (Shelton, 2014). The extent of hurricane damage, for instance, will be considerably more severe in countries with more assets, and extensive large population areas (Shelton et al., 2018).

Table 3 indicates that Haiti, Grenada, Dominica and Saint Kitts and Nevis demonstrate the highest costs as a proportion of GDP (2004) by 2050 due to inaction on climate change. It is predicted that for these countries, costs will exceed 75% of GDP by 2100 (Bueno et al., 2008). The net effect of such costs is equivalent to a perpetual economic recession in all CARICOM States

(CCCCC, 2012). However, this study remains broad in its estimations, focusing on hurricanes, tourism, and infrastructure, and tells little of the extent to which these costs fall on the fisheries sector.

Within the fisheries sector, hurricanes cause issues for catching, processing, markets, as well as having social and health implications relating to food security and wellbeing (Shelton et al., 2018; Few et al., 2020). Common impacts include loss and damage of vessels, gear, and facilities such as cold storage (Shelton et al., 2018). For example, the total damages and losses on Dominica by Hurricane Maria in 2017 were estimated to be US$931 million and US$382 million respectively (Commonwealth of Dominica, 2017); of this, the fishery sector accounted for US$2.4 million in damages and US$0.5 million in losses. Hundreds of vessels, gear, and vendor equipment were damaged or destroyed (Theophille, 2019). Estimated recovery needs of the sector amount to US$2.5 million, made up of repairing and replacing vessels, gear, vendor equipment and infrastructure. In addition to this, 40% of vessels and up to half of all fishers were left unable to fish, leading to loss of income and production (Commonwealth of Dominica, 2017). Likewise, in September 2019, Hurricane Dorian inflicted US$2.5 billion in damage and US$718 million in losses in the Bahamas (ECLAC, 2020). For the fisheries sector, total damages were estimated at US$11 million to 7 processing facilities and their inventories, vessels and fishing gear, while losses amounted to US$7 million (ECLAC, 2020).

These examples highlight the extensive costs incurred by the fishing sector as a result of extreme weather events. Furthermore, increasing hurricane strength, caused by climate change, has potential to cause an additional US$1.4 billion damage in the Caribbean from wind damage alone (Shelton et al., 2018). These high and increasing costs from extreme weather events could be reduced through investing in adaptation.

Costs of adaptation

In terms of adaptation to climate change within the Caribbean region, there is a tendency to focus on infrastructure and planning costs resulting from sea level rise, rather than the investments needed by the fishery and aquaculture sectors. For instance, it is noted that for the 21st century, 301 km of improved coastal defences would be needed to protect cities in the Caribbean from sea level rise, with estimated construction costs of US$1.2 to $4.4 billion, and further maintenance costs of US$111 to $128 million (Simpson et al., 2010). Conversely, the evidence base relating directly to costs of fisheries and aquaculture adaptation in the Caribbean region is very small. An international ECONADAPT review (2015) of adaptation costs and benefits found that evidence on horticulture, viniculture, livestock, forestry, and fisheries (aquaculture) was extremely limited. Less than one thousand published studies on the costs and benefits of adaptation exist overall, and only a small number of these concern fisheries and aquaculture (Watkiss et al., 2019).

Nonetheless, Sumaila and Cheung (2010) did consider global and regional costs of fisheries adaptation under both a mild and a severe climate change scenario. For the Latin America and Caribbean region, they predicted potential annual losses in landed values between US$1.21 and $2.72 billion, depending on the severity of climate change, with associated annual losses of income between US$0.33 and $0.77 billion (Sumaila and Cheung, 2010). Such losses are assumed to occur for the most part due to changes in productivity, shifts in species distributions and ocean acidification (OECD, 2010). To offset these losses, estimated annual direct adaptation costs between $1.25 and $4.48 billion will be required for the fishing sector in the Caribbean, depending on the level of climate change (Sumaila and Cheung, 2010).

However, these estimations are constructed from the costs of returning revenue to non-climate change levels, using data from previously applied adaptation measures (OECD, 2010). Furthermore, Watkiss et al. (2019) argue that while this approach focused on fisheries, the analyses of costs and benefits here are insufficient. Corroboratively, Sumaila and Cheung (2010) admit that more data is needed and that these estimates act only as a first approximation, with average costs based on the data of only seven developing and five developed countries. Although lower productivity and catch losses are often well reported after hurricanes, impacts on the processing sector, trade and markets take longer to quantify and the evidence here is limited (Shelton et al., 2018). For instance, additional research is needed into the role of alternative and informal markets, which may emerge in response to damaged refrigeration and market infrastructure, helping minimise loss of fishers' income,

Table 3. Annual costs of inaction by 2050 and by 2100 for Caribbean countries as a % of 2004 GDP. Adapted from Bueno et al. (2008).

Country	Annual cost of inaction by 2050 as a % of GDP	Annual cost of inaction by 2100 as a % of GDP	Country	Annual cost of inaction by 2050 as a % of GDP	Annual cost of inaction by 2100 as a % of GDP
Anguilla	20.7	41.4	**Haiti**	61.2	123.2
Antigua and Barbuda	25.8	58.4	**Jamaica**	27.9	56.9
Aruba	10.1	20.1	**Martinique**	3.8	8.1
Bahamas	13.9	31.7	**Montserrat**	21.7	49.5
Barbados	13.9	27.7	**Netherlands Antilles**	16.1	36.0
British Virgin Islands	9.0	18.1	**Puerto Rico**	2.8	6.0
Cayman Islands	20.1	53.4	**St. Kitts and Nevis**	35.5	89.3
Cuba	12.5	26.8	**St. Lucia**	24.3	49.1
Dominica	34.3	77.3	**St. Vincent and the Grenadines**	23.6	47.2
Dominican Republic	19.6	4.3	**Trinidad and Tobago**	8.0	16.0
Grenada	46.2	111.5	**Turks and Caicos**	37.9	75.9
Guadeloupe	4.6	9.5	**U.S. Virgin Islands**	14.2	32.4

as seen in Dominica following Hurricane Maria (Turner et al., 2020). As a result, the full economic impact on the fishing sector is difficult to estimate and generally based on several assumptions. There have been studies in Vietnam (Kam et al., 2012) and Fiji (Dey et al., 2016) on the costs of adaptation, but more economic studies are needed in the Caribbean to fully assess the specific costs of adaptation actions, and how these relate to the costs of inaction within the fisheries sector. Such information can help to understand how adaptation will affect the overall costs of climate change to the region (Figure 13). Research on the costs of re-tooling the fishing industry is needed, such as alternative forms or types of fishing that adjust to changing conditions, so catches can be maintained at optimum levels to satisfy food, livelihood and environmental needs.

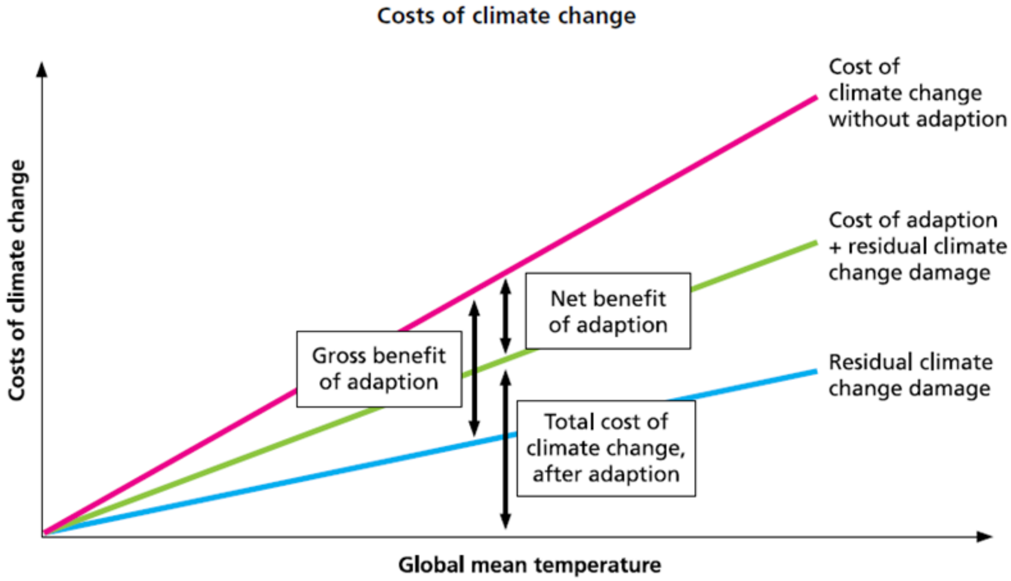

Figure 13. The costs of climate change, with adaptation, and without adaptation. Taken from Stern (2006).

8. Barriers to adaptation

Given the vulnerabilities and likely impacts of climate change in the Caribbean region, adaptation by governments and fishers is necessary. Despite this, a considerable adaptation deficit exists in SIDS, with financial, technical, institutional and governance dynamics hampering efforts (Howard, 2018). According to Turner et al. (2020), adaptive capacity tends to be applied only to assets and information provision, with little attention given to the social factors which may inhibit adaptation of governments and fishers.

In general, barriers to adaptation are defined as surmountable constraints to the adaptation process which can be overcome with reasonable effort, creativity, prioritisation, and resources (Moser and Ekstrom, 2010). Barriers differ from limits, which cannot be overcome without unreasonable action or expense (Moser and Ekstrom, 2010). Furthermore, barriers are generally not caused by climate change directly, rather they arise from various actors and policy mechanisms involved in the adaptation process (Howard, 2018). They will therefore differ spatially and contextually; for instance, each Caribbean country and regional organisation will face differing challenges, processes, and governance (CCCCC, 2012). It is crucial to better understand the different barriers surrounding Caribbean fisheries adaptation to ensure that the impacts of climate change on the region can be minimised.

Most studies surrounding barriers to adaptation focus on developed countries, with few directly addressing the differences between island regions. This means that there is limited evidence that can be used to address adaptation planning deficits in small islands (Howard, 2018). Barriers to adaptation in SIDS can be classified as being either caused by (1) a lack of resources, (2) the existence of institutional or governance structure, (3) the presence of informational and knowledge constraints, and (4) the manifestation of social and cultural norms.

Resource Barriers

Resources are crucial for almost every stage of adaptation, but particularly in science-based planning, implementation, and monitoring phases (Moser and Ekstrom, 2010). Resource constraints are often financial, but can also be technical, expertise- or time-related (Moser and Ekstrom, 2010).

For most Caribbean countries, paucity of funds plays a significant role in impeding more ambitious climate change adaptation projects, with high levels of debt resulting from hurricane and post-disaster recovery (Looney, 2019). The International Institute for Sustainable Development (IISD, 2019) highlights that since 2000, the Caribbean region has faced at least eight climate-related disasters, which resulted in an annual cost between 33% and 200% of the affected country's national economy (measured as annual GDP), and the estimated total loss from catastrophic climate events is US$3 billion per year to the region. Consequently, and with some exceptions, Caribbean countries often have a high level of indebtedness, limiting financial allocations to adaptation programs (CCCCC, 2012). Among the highest in the world, average Caribbean debt in 2018 was over 70% of the regional GDP (IISD, 2019). Furthermore, allocating public as well as private financial resources means that decision makers are facing trade-offs between conflicting aims. This conflict is intensified when resources are scarce. For example, it is shown that existing development concerns often detract from climate change adaptation while economic growth or poverty alleviation take priority (Howard, 2018). With Caribbean countries generally exhibiting high levels of absolute poverty between 20% to more than 70% (CCCCC, 2012), short-term economic growth has understandably taken precedence over the years. Despite the understanding that mitigating disasters is cheaper than responding to them, there is still relatively limited expenditure on mitigation (IDB et al., 2005); this is perhaps due to the benefits of mitigation not being experienced immediately, therefore funds are prioritised towards immediate disaster recovery instead.

As a result, most adaptation planning in SIDS is funded by international donors, with local adaptation generally limited to ad-hoc implementation of fragmented projects (Howard, 2018). However, interviews with senior policy makers in Caribbean SIDS indicate that international donor funding is insufficient to meet adaptation needs, particularly in sustaining implementation, monitoring and evaluation of interventions (Howard, 2018). Larger adaptation projects are often deemed 'development' by funders, and so are often not eligible for adaptation funding. Instead, donor funding often targets incremental adaptation, limiting the scope of projects subject to funding and leaving Caribbean policy makers with restricted control over how funds can be used in sustained or developmental adaptation (Howard, 2018). Furthermore, despite industrialised nations pledging $100 billion of annual assistance from 2020 onwards under the Paris Agreement, all indications are that this pledge will not be met (Looney, 2019). With many developed nations now facing the economic effects of Covid-19, it seems even less likely that governments' aid contributions will be sufficient to meet the increasing adaptation needs of SIDS. Equally, in 2007 Caribbean countries established the Caribbean Catastrophe Risk Insurance Facility (CCRIF SPC), which is used to meet short-term needs after natural disasters through member country contributions. For example, the fund distributed $29.6 million to the six countries affected by Hurricanes Irma and Maria in 2017 (Looney, 2019). Such pay-outs are useful for the immediate recovery following an event but are not sufficient for full adaptation needs. The use of cross-Caribbean collaboration can thus alleviate some reliance on international donors.

Nonetheless, a large adaptation financing gap remains, with flows to the fishery sector low compared to other sectors, such as water provision and agriculture (Watkiss et al., 2019). This may be reflective of the relatively small perceived contribution of the fisheries sector to the overall economy (in terms of GDP) in Caribbean countries generally, with much fishing across the region being subsistence based. For instance, in most Caribbean countries, fisheries contribute less than 1% of GDP. Even in Belize, where fishery products account for 3%, large foreign exchange sectors such as tourism receive more attention and resources for development (FAO, 2020b). This measurement overlooks the significance of the fisheries sector and its role in providing livelihoods and food security beyond GDP, highlighting the importance of enhanced data collection and additional measurements to better understand the sector's contribution. Even so, for fishers to adapt, significant capital investments are required. For example, moving to harvest deep-slope fish would require different equipment including mechanized reels and winches. Similarly, increased storm intensity may require fishers to use larger boats for safety (Monnereau and Oxenford, 2017). These changes have financial implications including higher investment and maintenance costs, and the risk of increased losses in cases of extreme weather (Monnereau and Oxenford, 2017). Moreover, most small-scale fishers lack access to affordable insurance in the Caribbean (Tietze and Van Anrooy, 2018). Tietze and Van Anrooy (2018) found that only 3 of 109 fishers surveyed across 11 Caribbean countries had insurance for their boats or assets, suggesting that 97% of small-scale fishers are not insured. Subsequently, individual fishers are subject to high economic risk if they invest in larger vessels, and inequality will exist in the ability to adapt based on financial constraints. This is evident in the Hurricane Maria recovery of Dominica, by which fishers who had access to existing capital or credit were able to return to fishing through purchasing new equipment, while others were unable to do so after their losses (Turner et al., 2020). In Saint Vincent and the Grenadines, there is evidence of plans to provide subsidies for fishermen to purchase larger boats, enabling greater distances and time at sea (FAO, 2020b). Such plans would relieve some of the financial pressure on fishers and may allow better returns, aiding fishers to adapt more easily. However, contrary evidence from Antigua and Barbuda suggests that larger vessels may in fact have a greater chance of negative returns than smaller vessels, which would mean greater risk (Horsford, 2007). Nonetheless, financial barriers can play a large role in determining whether Caribbean fishers are able to adapt their equipment to climate change and extreme-weather events.

Not only is more investment needed to adapt, but there are also market pressures which come into play. Jamaica for example has experienced a steep decline in aquaculture production since 2008, often blamed on cheaper tilapia and pangasius imported from other countries (FAO, 2020b). If Caribbean countries are unable to compete with these competitive international prices then adaptation is not as profitable, and therefore incentives to adapt are reduced.

Governance and institutional barriers

Lack of leadership and governance can further undermine the ability and willingness of coastal managers to make decisions surrounding adaptation, leading to barriers in initiating and sustaining the adaptation process (Moser and Ekstrom, 2010). Without senior leadership and 'adaptation champions' within institutions, it is difficult to gain and sustain momentum (CoastAdapt, 2017).

In addition, lengthy bureaucratic processes and lack of transparency can hamper adaptation management (GCAP and Vivid, 2018). Howard (2018) highlights that in some cases, the Caribbean suffers from institutional crowdedness as well as institutional voids. That is, overlapping policies and administrative mandates exist, while in other areas critical legislation is lacking. Many SIDS do not have any formal adaptation planning requirements and without these, coordinating adaptation across sectors is very difficult (Howard, 2018). Addressing this barrier presents further challenges because legislative and institutional reform can be slow. For example, the legislation can take years to be approved (Howard, 2018). Without clearly defined property rights and enforcement, there is less incentive for fishers to be sustainable, enabling illegal, unreported, and unregulated (IUU) fishing. Similarly, cross-country bi-lateral or multi-lateral agreements may also need reform. For some SIDS such as Dominica, Saint Kitts and Nevis and Montserrat, fishers are unable to move far from shore due to their countries' restricted exclusive economic zones (EEZ) and others lack access to 'high seas' at all, including the Cayman Islands and Jamaica (Monnereau and Oxenford, 2017). This necessitates revising fishing agreements with neighbouring countries, contributing further obstacles. Communication and collaboration barriers are thus evident due to the complexities of stakeholders and networks involved, all with different objectives, authorities, and resources (GCAP and Vivid, 2018). Hence, fragmentation of adaptation planning and differing interests can lead to conflicts and slow down the adaptation process (Howard, 2018).

In the case of formal local government, for some Caribbean SIDS this is non-existent or poorly developed (Howard, 2018). As a result, local capacity to undertake substantial adaptation is often minimal. However, community-based governance networks are emerging to combat this and when linked to formal governance institutions, they have been effective in coastal resource and disaster risk management (Howard, 2018). This is evidenced by Hurricane Maria recovery in Dominica, where social ties within communities allowed cooperation in hauling boats to land after storm warnings and the collective replacement of lost fish aggregation devices (FADs) afterwards (Turner et al., 2020). Furthermore, strong social links to nearby islands meant that transboundary relationships existed, facilitating access to more diverse goods and assets after the hurricane, enabling quicker recovery (Turner et al., 2020). Despite this, Turner et al. (2020) indicate that previously active fishery cooperatives have declined in capacity, limiting their role in collective action. Furthermore, social capital links to government are distributed unevenly, which has led to perceptions that assistance and assets to support fishery recovery are not allocated to those who need it most (Turner et al., 2020). As such, effective local social organization with ties to formal government can facilitate adaptation, but their absence can be a substantial barrier.

Importantly, institutional responses to build social capital and strengthen local organisations can be limited by knowledge gaps regarding fishers' adaptation needs and behaviour (McConney et al., 2015). Thus, in seeking to overcome one form of barrier, additional obstacles can be uncovered, in this case an informational deficit.

Information and knowledge barriers

Informational barriers surround whether and how information is created and communicated, and lack of content and frequency of communication can obstruct those involved in adaptation (Moser and Ekstrom, 2010).

Most generally, limited awareness of climate change and the need to adapt by political leaders and the wider public can lead to adaptation being neglected in Caribbean SIDS. Howard (2018) posits that adaptation would receive more attention on the planning agenda if members of the public and political leaders better understood the severity of climate change. According to regional content analysis of climate change policy from multiple Caribbean SIDS, the second leading area of focus is awareness of climate change, indicating progression to this end (Howard, 2018). However, public attention tends only to focus on climate change when an extreme weather event occurs, and Turner et al. (2020) suggest that individual fishers are not inclined towards lobbying and activism. Dominican fishers who remained unemployed after Hurricane Maria expressed that advocacy would not solve their situation, with alleged fear of victimisation and the political implications of "being too activist" (Turner et al., 2020). This attitude is problematic, as policy agendas should be greatly influenced by public opinion and interest (Howard, 2018). Without sustained public attention, there is little to drive policy makers to prioritise adaptation and support long-term changes in attitudes and behaviour.

Lack of data presents further difficulties in planning climate change adaptation. Socio-economic data regarding the social impact and financial consequences of climate change on the fisheries sector is insufficient (Monnereau and Oxenford, 2017). Additionally, skilled human resources are needed to develop technical scientific information and decision-making tools to aid adaptation policy (Howard, 2018), such as the Caribbean Climate Online Risk and Adaptation TooL (CCORAL)[4] and Coastal Resilience Natural Solutions Toolkit[5]. For Dominica, access to crucial information remains an obstacle due to human resource constraints and insufficient data sharing between institutions (Turner et al., 2020). Although international researchers and agencies provide useful collaboration opportunities, there is still a need for more information on socio-demographics and livelihood activities in fisheries (Turner et al., 2020). Furthermore, anecdotal evidence suggests that traditional knowledge on mitigation measures is passed amongst fishing communities and across generations by word of mouth, but this has not been well-documented; the informal adaptation measures taken by fishers requires more academic attention, to better account for adaptation capabilities, but also to ensure that traditional measures are not undermined by land use changes in physical planning and development.

For individual fishers, knowledge barriers can limit adaptation options. The greatest impacts may indeed be felt by subsistence or small-scale fishers, with livelihood adaptation responses difficult to implement due to information barriers (Watkiss et al., 2019). While livelihood diversification within and between sectors is presented as a key opportunity to adapt, there are scarce alternative job opportunities for fishers (Monnereau and Oxenford, 2017). Asiedu and Nunoo (2013) highlight that in Ghana, 73% of interviewed fishers were willing to change jobs, but 50% lacked the skills needed to work outside of the fishing sector. Although not based in the Caribbean, this study indicates that failure to possess specific skills will likely act as a barrier for fishers seeking employment in other sectors.

Social and Cultural Barriers

As previously indicated, social networks and capital can be vital to coordinating hurricane management and recovery (Turner et al., 2020). Importantly, social links could also enable adaptation; they can be used as an informational resource to seek advice and support by fishers seeking to adapt. In order to diversify into aquaculture for example, fishers may depend on networking and social position as their existing knowledge and skills may not be sufficient (Conejo-Watt et al., forthcoming).

However, having more scientific understanding and specific knowledge will not necessarily lead to adaptation actions being taken. Too much information can be overwhelming, leading individuals to stick to their defaults (Downey and Shah, 2011), and more information is unlikely to make a difference if values, emotion, reasoning, or culture are challenged (CoastAdapt, 2017).

Strongly held values and beliefs affect perception, interpretation, and valuation of information, directly influencing adaptation decisions (Moser and Ekstrom, 2010). They frame how society and institutions govern

[4] A Caribbean focused tool to support decision making surrounding climate change resilience. Caribbean Community Climate Change Centre. http://ccoral.caribbeanclimate.bz/

[5] A toolkit developed by The Nature Conservancy to provide scientific and spatial information for public agencies, communities, and stakeholders, to inform decision making. https://coastalresilience.org/natural-solutions/toolkit/

risk and manage social change, either helping or hindering adaptation (GCAP and Vivid, 2018). For example, the perception that activism would not solve post-hurricane unemployment amongst fishers means that they may not be prioritised on the political agenda (Turner et al., 2020). Similarly, if Dominican fishers perceive that nobody cares for them, they are reluctant to participate in formal data collection or information sharing, which then impedes their access to assistance and loans in extreme weather events (Turner et al., 2020). In Belize, fishers must submit catch log sheets after each fishing trip, but in practice this is irregular, and fishers claim that there is no feedback on the outcome of the information they provide. Consequently, social perceptions and lack of understanding and trust surrounding reporting further exacerbates informational, institutional, and financial barriers.

Moreover, the cultural identity of many Caribbean coastal communities is centred around fishing, both internally and through tourism (Monnereau and Oxenford, 2017). As a result, the fishing identity of these communities has implications for adaptation. For instance, in Ghana 27% of fishers interviewed indicated that they were unwilling to change jobs (Asiedu and Nunoo, 2013). Similarly, a recent English study found that some fishers were strongly opposed to aquaculture, rooted in a deep sense of cultural tradition associated with wild fishing (Conejo-Watt et al., forthcoming). Consequently, more traditionally minded fishers are reluctant to consider alternative paths which threaten this way of life (Conejo-Watt et al., forthcoming). If individual fishers in the Caribbean experience strong social and cultural ties, it is likely that there will be some reluctance to move away from or modify their usual fishing practices, despite the impact of climate change on the sector. Social research is needed on suitable alternative fishing methods or livelihoods that still meet financial and Caribbean cultural needs, and how people can be trained or reskilled in these areas.

The ability to adapt and deploy different resources, depends not only on community characteristics, but also on individual attributes including wealth and gender (Turner et al., 2020). For instance, women play a key role in the post-harvest sector, processing and trading fish, and as a result, hurricane damages to market infrastructure and loss of basic tools predominantly impacts women (Commonwealth of Dominica, 2017; Monnereau and Oxenford, 2017). Following Hurricane Maria, Dominican fishers adapted to the loss of refrigeration and market infrastructure by selling their catches directly to avoid relying on external assistance to repair the Roseau market (Turner et al., 2020). Consequently, predominantly female fish vendors, often likely to be on the brink of poverty, can lose out on income (Turner et al., 2020). This necessitates the comprehension of gender and poverty dynamics in determining strategies to build adaptive capacity, so as to avoid exacerbating inequalities through shocks and subsequent responses (Turner et al., 2020).

Overcoming these Barriers

The barriers to adaptation are generally interrelated and cannot be addressed individually (Howard, 2018), as highlighted by the example of Dominican fishers' cultural beliefs impeding their willingness to provide data (Turner et al., 2020). As a result, the adaptation planning process should be treated as a series of simultaneous activities instead of a strict linear succession of events (Howard, 2018).

Howard (2018) surveyed planners in the Caribbean to understand the relative importance of different pre-defined barriers to adaptation. His findings indicate that although physical, resource and institutional barriers were weighted highest, there is little difference in the significance attributed by planners to the different barrier categories, with almost all regarded as very significant or significant. Overall, Howard's study (2018) indicates that this ranking exercise is not sufficient for determining priority areas for adaptation policy in Caribbean SIDS.

Furthermore, the importance and relationship between these barriers will depend on the specific context. In general, the interaction between the barriers as well as local dynamics are more important for adaptation planning than the importance rank assigned. In-depth qualitative studies are needed in the Caribbean to better understand the socioeconomic factors influencing or obstructing adoption of adaptation measures.

To begin to overcome the social and cultural barriers, it is vitally important that fishing communities are included in any climate adaptation projects that affect them, to make full use of their knowledge, needs and priorities (FAO, 2017). The adaptation projects must be informed by research, and to get community buy-in, they must be involved from the start to understand the long-term benefits and risks, and speed the uptake of adaptation measures (FAO, 2017). Involving communities in management of their marine resources and monitoring of any adaptation measures can also ensure continued support in the long-term. Long term monitoring, revision and adaptive management also ensure that the measures remain effective and improve over time, particularly with regard to MPAs (Belokurov et al., 2015). National fisheries departments know the vulnerabilities in their fishing communities well, but many lack the resources or knowledge to assist with or implement adaptation projects. This may be especially the case with aquaculture. Training and financial assistance in these areas would help departments to support fishers and coastal communities in climate adaptation, linking with cooperatives to maintain resilience in the long term.

Education and training of fishers and coastal communities can help overcome the knowledge and information barriers, by enabling fishers to make informed decisions on adaptation. For example, the Pilot Program for Climate Resilience (PPCR, 2019) has produced various leaflets and knowledge products explaining climate change impacts, and the actions that fishers should take to develop resilience in their livelihoods. Such products can be useful if they are widely disseminated and reach their target audience, and can be part of wider programmes on education and training. Notably, training can be particularly successful when delivered by fellow fisherfolk, for instance the 'fisher teaching fisher' initiative in Antigua and Barbuda whereby the Fisheries Division and Caribbean Network of Fisherfolk Organisation (CNFO) collaborated to educate fishers on the FAO Code of Conduct for Responsible Fisheries (CCRF) (Horsford and Lay, 2012). This highlights the importance of sector champions and the need for participatory governance in the sector.

There are a number of ongoing projects and initiatives aimed at overcoming governance and institutional barriers (Oxenford et al., 2020). These include improvements to national and sub-regional policies, such as the Organisation of Eastern Caribbean States' (OECS) ocean policy, and the inclusion of the Climate Change Adaptation and Disaster Risk Management Protocol in the Caribbean Community Common Fisheries Policy (CCCFP) developed under the CC4FSH project (FAO-CRFM, forthcoming). It is important that policies are flexible enough to adapt to rapid changes in fisheries, such as changing distributions and migrations of target species, and changes in fishery yield and productivity. Examples where efficacy can be improved is by having access arrangements that respond quickly to stock abundance and distribution between countries, and legislation allowing for changes in gear used, species harvested and spawning season or location changes.

Financial barriers are difficult to overcome in the short term. National budgets and official development assistance are likely to continue to be the main sources of adaptation funding (FAO, 2017). The Green Climate Fund is one of the main providers of funding for climate adaptation projects, with several projects underway in the Caribbean. Country and regional wide policies and plans, such as National Adaptation Plans and Nationally Determined Contributions, provide the links with policy that are used to leverage financing (FAO, 2017). There are other financial mechanisms that could be used such as the Caribbean Biodiversity Fund – Blue Finance, or other conservation funds (CRFM, 2020a). Some of the financial barriers for individual fishers can be overcome by having loans available on terms that fit with their income (i.e. not a fixed monthly income), and having access to insurance for their livelihoods and assets.

9. Research needs to support action

To support all stages in the adaptation process, identifying research priorities is critical. Climate change and fisheries research has evolved considerably in the past 20 years. Many States now have habitat maps, risk mapping and stock assessments, but not all States are covered and there are still many areas where more research is needed. The following key needs have been identified throughout this report, also by Monnereau and Oxenford (2017) and the CRFM Fisheries and Aquaculture Activity and Research Agenda (CRFM, 2019c). Research is urgently needed on:

- Vulnerability and risk assessments for individual States
- Undertaking risk assessment and risk mapping of climate change hazards that impact the fisheries and aquaculture sectors
- Improved data collection and statistics on fish resources and the fisheries they support
- Ecosystem and stock status assessments for the key fisheries, the post-harvest sectors, and on the relative contribution of climate change and other stressors
- Downscaled modelling to assess climate change impacts on key species in the region
- Economic valuations of fisheries and aquaculture resources

- Economic data and analysis on the financial consequences of climate induced changes, particularly to the post-harvest value chain
- Economic assessments of the costs of action and inaction in the Caribbean, to help determine ‘quick wins’
- Social data on the fisheries sector to understand the social consequences of climate induced changes
- Identifying new fishing gears and platforms to help fisherfolk adapt and diversify
- Identifying and developing sustainable and equitable alternatives and/or diverse livelihood opportunities, in collaboration with a range of sector agencies
- Research to identify the most sustainable aquaculture for the region, that is resilient to climate change
- Mapping and valuation of coastal habitats
- The link between Sargassum influxes and the distribution and abundance of key pelagic species
- How to take advantage of fishing opportunities presented by Sargassum mats, whilst not depleting fish stocks

10. Taking Action

Overall strategy for fisheries and aquaculture adaptation in the Caribbean region

In 2020, CRFM published a regional strategy and action plan for climate change adaptation and disaster risk management in fisheries and aquaculture in the CARICOM region for 2020-2030 (CRFM, 2020a). The underlying vision is for a “regional society and economy that is resilient to a changing climate and enhanced through comprehensive disaster management and sustainable use of aquatic resources.” Its guiding principles are for an effective enabling environment, collaboration, integration, subsidiarity, precaution, transparency, participation and gender equality and equity. It highlights the need to bring discussions on the future of the fisheries and aquaculture sectors to the fore at a national and regional level, given its social and economic importance.

There are nine stated strategic elements. These include enabling actions (climate change and sustainable development; climate finance access); management, including adaptation and mitigation support (adaptation implementation; fossil fuel independence; sustainable ecosystems (including mangroves and wetlands); societal capacity; loss and damage management) and emerging issues (ocean governance; security integration).

To support these strategic elements and their associated goals, this section highlights the value of adaptation frameworks, and describes a set of achievable short, and long-term actions, as well as essential cross-cutting actions.

A framework for adaptation in the Caribbean fisheries and aquaculture sectors

The Caribbean already has excellent examples of where climate change adaptation and resilience is being implemented for the fisheries sector. To progress this further and increase the speed, coverage, and effectiveness of adaptation, it is recommended that the following five steps are followed by Caribbean States (Figure 14) (US Aid, 2019), which will help educate, facilitate and legislate for climate change action. At all steps, creating channels through which local and traditional knowledge and culture can be included in policy and be used to inform action in fisheries and aquaculture will be important, including addressing information gaps in fisheries data.

Figure 14. Five steps for sustainable adaptation (Taken from US Aid, 2009)

Step 1. Climate risk or vulnerability assessments are vital to understand the specific source of vulnerability for a country, island, area, community, or fishery. Exposure and sensitivities vary geographically for different species and demographics, and as such, vulnerability assessments can really delve into where adaptation action needs to be targeted. Assessments have been carried out for each Caribbean country by Monnereau et al. (2017), and more detailed assessments for certain countries or areas (e.g. Dominica by Pinnegar et al., 2019, and Grenville Bay, Grenada by the Nature Conservancy, 2018).

Step 2. Selecting a course of action includes identifying a range of specific interventions which address the specific vulnerabilities and risks in the target community or fishery (Poulain et al., 2018). The most at-risk groups can be identified so that limited funding has the most effect and needs for building adaptive capacity can be fulfilled alongside physical adaptation interventions. Local stakeholders must be fully included when identifying and choosing the most appropriate course of action. The list of adaptation options included in Table 2 can be used to inform action.

Step 3. The chosen actions can be used to develop a climate adaptation strategy or plan, linked to national policies and legislation, and with support from fisheries departments, cooperatives, and communities. Adaptation priorities for fisheries and aquaculture should be included in Nationally Determined Contributions to the UNFCCC and National Adaptation Plans. Relevant guidance and best practice documents should be followed to prevent maladaptation, and lessons learnt from similar initiatives in other parts of the region. Mainstreaming adaptation must consider the broader community, with due consideration given to gender equality, youth, and marginalised groups inclusion as an integral part of fisheries and aquaculture adaptation and disaster risk management at all levels. This would include expanding extension and support services for fisherfolk and aquaculturists to facilitate holistic climate change adaptation planning and implementation, integrating gender equality and youth inclusion.

Step 4. The adaptation measures are implemented with community participation at every stage. There is a need to increase the capacities of fishers and coastal communities to participate and engage in planning processes that use ecosystem-based management and other integrated approaches, either as individuals or community-based groups. More broadly, it will be important to adopt a livelihoods and rights-based approach to fisheries and aquaculture policies and plans within climate change adaptation, and the design and implementation of programmes for disaster prevention, preparedness, response and recovery.

Step 5. Continued evaluation and monitoring of the adaptation measures, and their effectiveness, to ensure that the measures are achieving their aims. With continued monitoring, measures can be adapted and changed as necessary, if more climate risks come to light, or if the measures are not meeting the desired aims. For example, if reef fish populations are not increasing as expected in a marine protected area, monitoring may reveal other pressures on the area such as pollution or illegal fishing, and other management measures may be needed. Biological as well as socio-ecological monitoring and evaluation is needed to ensure that the needs of local communities are met, as well as the environment (Poulain et al., 2018). From a social perspective, analysing, and improving, the effectiveness of social protection programmes in reducing vulnerability of fisherfolk and aquaculturists to climate hazards impacts in the Caribbean will be important.

Individual and local scale actions

Actions to create climate-smart fisheries and build resilience at the local-level can reinforce each other to create greater resilience on a broader scale. Building resilience to climate change therefore needs a strong focus on action at the individual and community level. Individuals or communities can drive development of climate-smart fishing practices themselves by learning best practice approaches from other individuals and communities via direct comparison approaches (FAO, 2013). Many actions can be no-regret actions, which improve efficiency, income, or safety within the sector, regardless of climate change. Fishing cooperatives can have a big part to play in coordinating, supporting, and providing training in these actions, particularly where groups of fishers can adapt together, such as moving to moored FAD fishing or adding value to fish products. Some of these actions may require additional funding or technical support. Actions which can be prioritised at the local scale include:

• Developing local fisheries sector pre- and post-disaster plans

• Improving safety at sea, using radios and FEWER mobile app

• Stopping destructive fishing practices that catch juveniles or damage habitats

• Moving to sustainable pelagic fishing to take pressure of overfished reefs

• Switching to more sustainable fish species or areas (and reverting to a different gear if necessary)

• Providing catch data to fisheries managers

• Marking gear, disposing of damaged gear correctly and removing lost fishing gear to prevent ghost fishing

• Involving fisherfolk in data collection and real time data collection

• Improving traceability throughout the fish chain

• Adding value to fish products by drying, salting, packaging, and improve shelf life

• Diversifying livelihoods, such as into aquaculture or eco-tourism

• Providing training in business skills and personal finance (e.g via cooperatives if applicable)

• Minimising fuel consumption and replacing inefficient engines

• Reducing carbon footprint of aquaculture facilities

Short-term actions and longer-term goals

From the adaptation options identified in this report for the fisheries and aquaculture sectors, there are some which are already in place in some states, and could be replicated elsewhere with a low level of resources. There are also some which require investment in research or policy change, so may take longer to implement. A few important areas for further development that build on existing activities in the Caribbean are listed below.

Short-term actions

Actions identified in this report that could be implemented on a short timeframe (<2 years) and achieved within current resources, or with minimal investment, include:

• Sector-specific disaster preparedness plans

• Sector-specific national adaptation planning

• Expand livelihood diversification projects

• Continued improvements in safety at sea

• Improved awareness about climate change and adaptation to build adaptive capacity

• Wider social inclusion and access to participatory processes

• Reduced human pressures to marine ecosystems

• Wider uptake of existing decision support tools and physical, biological, and socio-economic data

• Access to high value markets, locally and overseas

Disaster preparedness plans. To support adaptation and risk management, the CRFM has developed a Protocol on Climate Change Adaptation and Disaster Risk Management in Fisheries and Aquaculture under the Caribbean Community Common Fisheries Policy (FAO-CRFM, forthcoming), funded by the FAO-CC4FISH Project, and CRFM's Model Disaster Preparedness and Risk Management Plan for the Fisheries and Aquaculture Sector outlines plans for 2020-2030 (CRFM, 2019b).

Developing national plans. There are a number of examples of guidance documents being used to develop national plans. For example, a Model Disaster Preparedness and Risk Management Plan for the Fisheries and Aquaculture Sector has already been adapted by Belize and Saint Vincent and the Grenadines (CRFM, 2019b). Some countries already have fisheries and aquaculture included in their National Adaptation Strategies, with specific aspects to target and address. In Saint Lucia, the revised 10-year National Adaptation Plan (NAP), released in 2018, recognises the threats posed by climate change to fisheries and aquaculture. The NAP identifies several adaptation measures which should be the target of future projects and investment. These documents could be used by other countries as the basis for their NAPs, or to give examples of adaptation measures to be implemented. Also, readily available are several climate-smart and adaptive fisheries management guidance documents that can be implemented by national governments, such as the guidance on adaptive management in the flying fish fishery (Blue Earth, 2019).

Livelihood diversification projects. There are a range of projects which have worked on diversifying livelihoods, which could be expanded to, or replicated in, other States. Communities which have benefitted from these projects could share knowledge with others, helping to expand the areas that these projects can reach, with lessons learnt incorporated along the way. The CC4Fish project is an example where small projects have been implemented in a number of places, and could be replicated in other areas, given funding or time available. Knowledge from successful aquaculture businesses could be shared with other States to show how to start up and manage a facility. Fishers that have started to use FADs could share this knowledge with others, again with lessons learnt along the way, as under the CARIFCO project.

Mitigating the risk of climate hazards at sea. Reducing physical risk from climate change impacts needs to be a key goal. There are already tools available that are used by some countries to reduce risk at sea for fishers. The FEWER app is available and can be installed by fishers to receive alerts about bad weather. In Dominica, fishers must undertake a training course on safe and sustainable fishing when they become licensed (Norris and Theophille, 2016). This course is accompanied by a training manual containing information on staying safe at sea, as well as guidance on sustainable fishing and fisheries management. The manual is available online to any fisher, regardless of State, and a similar training course could be rolled out in other countries to improve safety and raise awareness.

Building adaptive capacity within fishing communities. There are resources available to improve knowledge and understanding amongst fishers, helping to build adaptive capacity. The CME Programme produced a Caribbean Marine Climate Change Impacts Report Card (CMEP, 2017a) which describes the different impacts of climate change on the marine environment in the Caribbean. The Pilot Program for Climate Resilience (PPCR, 2019) has produced information for fishers to understand climate change impacts on their livelihoods and promote adaptation options they can undertake. Approaches need to be socially inclusive, including on gender, youth, and marginalised groups, and provide access to participatory processes.

Improving the health of the marine environment. Much is already known about the importance of improving the health of the marine environment to improve resilience to climate change. There are many projects that have been carried out or are underway which can be replicated, and many legislation and fisheries policies already written. Improving the marine environment by reducing anthropogenic pressures and rehabilitating degraded ecosystems is a top priority in terms of climate change, but also sustainable fishing in general. The knowledge is already there with regard to how this can be done, and projects carried out elsewhere can be replicated with skills shared. Funding should be sought for such projects as an immediate priority. Some of these projects may be longer term, but there are some that can be implemented in the short term, and beginning this process is a top priority if ecosystems that support fisheries are to be prevented from further deterioration.

Decision support tools and data. While further data collection and research are needed, there is already a lot of climate research and data available that is not always fully used. Decision support tools are available, such the Caribbean Climate Online Risk and Adaptation TooL (CCORAL), which contains a wealth of information on the climate influences on the sector, and how to use this to make decisions. There are also a lot of fisheries data that countries hold, but which may not be digitised or freely available. Such data and tools can be used in conducting vulnerability assessments, prioritising adaptation actions and is invaluable for informing resilience building.

High value markets. Fishers need access to higher-value markets so they can receive greater benefits from fisheries and aquaculture production, compensating for reduced yields due to climate change. This can include promoting certification and eco-labelling schemes and assisting fisheries with obtaining certification. Such schemes require the fisheries to be sustainable, and to provide evidence to show this. For example, Guyana and Jamaica have recently been seeking Marine Stewardship Council certification of their industrial and semi-industrial fisheries, with aims to increase their market opportunities and increase value. Some fisherfolk have already added value to their fish products by producing packaged tuna steaks, or other high value products. These, and other examples of eco-labelling or certification schemes more suitable for artisanal or small-scale fisheries can be replicated elsewhere.

Longer-term goals

There are other adaptation actions which require more funding to implement, or which first require supporting research or legislation. These will have a large impact on the sector and its ability to withstand the effects of climate change, but may take longer to implement.

These include:

• Fisheries monitoring and ecosystem-based management

• Increased adaptive capacity and social protection

• Adaptive and responsive legislation

• Climate-proofing infrastructure

• Network of marine protected areas

• Resilient ecosystems

• Developing and adapting the aquaculture sector

Fisheries monitoring and ecosystem-based management. Ecosystem-based management of fisheries, including spatial management, is needed across the Caribbean, in line with the Caribbean Community Common Fisheries Policy (CCCFP). It would greatly improve the sustainability of stocks in the Caribbean, providing healthy fish populations and food for the long term. To achieve this, fisheries must be monitored regularly, and the data used in stock assessments nationally and across boundaries for pelagic stocks. Management measures should be put in place and enforced. Community involvement in co-management should also be the aim in the longer term.

Adaptive capacity and social protection. There are insufficient and inadequate social security and protection systems in many Caribbean States. The effectiveness of social protection programmes in reducing fisherfolk and aquaculturists' vulnerability to climate change and strengthening programmes should be analysed, and then developed accordingly. Having adequate social protection in place enables fishers and communities to be proactive and develop autonomous, planned adaptation. Extension and support services for fisherfolk and aquaculturists should be expanded to facilitate holistic climate change adaptation planning and implementation, integrating gender equality, youth, and marginalised groups inclusion in service design and implementation.

Adaptive and responsive legislation. Changing legislation can be a lengthy process, but it must be flexible to allow fishers to respond to changes in spawning seasons, quotas, target species and fishing gear or techniques. This extends beyond direct fisheries legislation, for instance to planning and environmental legislation, allowing for facilities to be relocated if necessary, or to ensure that marine habitats are protected from other human pressures as climate change pressures develop over time.

Climate-proofing infrastructure. Natural sea defences, such as healthy reefs, seagrass beds and mangroves will increase coastal protection in areas where these habitats are currently degraded. Coastal inundation modelling can show where these natural habitats can have the most benefit. In many cases, additional engineering solutions are required, and such hard infrastructure projects require a lot of capital investment and time to implement. For infrastructure that requires rebuilding after storm damage, planning laws and building regulations must ensure that new buildings are built to withstand storms and hurricanes, and these must be enforced, and if necessary, building could be subsidised to ensure that communities can build back better.

Network of effectively implemented marine protected areas. There are examples across the Caribbean of successful MPAs that benefit local communities as well as the environment. However, to increase the benefits that these provide, networks of protected areas are required which allow for movement of organisms between sites, and genetic exchange. Networks of protected areas can be included in integrated coastal zone, and marine spatial planning and modelling can help to identify suitable locations that ensure genetic exchange. A network of marine protected areas could have huge benefits for biodiversity, the tourism industry, as well as for fish populations, therefore bringing in income in the future.

Resilient ecosystems. Small changes can be made in the short term, but larger interventions are required in some areas to achieve fully resilient ecosystems. Compounding pressures need reducing, such as improving water quality by large-scale sewage treatment, and reducing damaging activities such as sand mining. Restoration of seagrasses, mangroves and corals has been shown to be effective, and may be necessary on a larger scale where reducing pressures is not sufficient. This requires long-term monitoring and rehabilitation while they establish, but could be done incrementally in large areas.

Developing and adapting the aquaculture sector. The focus of climate change adaptation and disaster risk management to date has largely been on the fisheries sector. At the regional level, there is considerable scope for aquaculture development, but aquaculture development in the CARICOM/CARIFORUM region has been slow compared to other areas in the world (CRFM, 2014). Furthermore, in many Caribbean countries, aquaculture is often under the mandate of the fisheries department, which is also responsible for managing and implementing climate resilient strategies in the larger fisheries sector. Consequently, implementing adaptation measures the fisheries sector often take precedence over aquaculture in a resource limited environment.

CRFM's five-year plan on aquaculture (CRFM, 2019a) details actions to develop aquaculture in the region, including ensuring that facilities are resilient to climate change, and that a sector-specific disaster preparedness plan is prepared. It is recognised within the region that most national fisheries agencies have expertise in fisheries management, rather than aquaculture (CRFM, 2020b). Therefore, further specific experience or private investment and expertise may be needed to develop the sector further, particularly for farming high value species such as shrimp. Improved access to environmentally sustainable and climate-resilient solutions (e.g. technologies, equipment, processes) is needed to overcome existing challenges in the aquaculture and mariculture sectors. There is also a need to generate disaster preparedness plans for the aquaculture sub-sector, especially in the context of increased hazard risks with climate change.

In terms of locating new aquaculture facilities, considerations must be made beforehand regarding available space. For the insular Eastern Caribbean island chain, many near shore environments on east coasts may be too high energy due to the exposure to the Atlantic Ocean. On west coasts, with high coastal populations and land use pressures, and sharp marine drop-offs, scope for developments, other than cages might be limited. There are some locations with more available land and freshwater, or more extensive coastlines for land-based or near-shore aquaculture (CRFM, 2020b). More support is also needed to identify and select appropriate species for polyculture, integrated multitrophic aquaculture (IMTA) and mariculture. IMTA combines, in the appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. molluscs and macroalgae). The use of waste from the fed species acts as 'feed' for another system. This can increase profits and reduce risks (through diversification of species cultured). The perceived environmental benefits of using excess nutrients and organic matter as feed can improve buy-in to, and sustainability of, aquaculture practices, compared to providing wild-caught food for carnivorous fish.

Cross-cutting actions

For all short- and long-term adaptation actions, including research and capacity building, it is vital that the communities are involved at every stage. Particular attention should be paid to gender equality, inclusion of youth, marginalised groups or minorities, and the role that adaptation plays in reducing poverty. It is important that:

• Fishers and coastal communities can engage meaningfully in policy development and planning, giving them skills to be involved in ecosystem-based management and co-management.

• Channels are created through which local and traditional knowledge and culture is included in policy and used to inform action in fisheries and aquaculture.

• Gender equality, youth and marginalised group inclusion are included in adaptation and disaster risk management.

• Gender, poverty and youth inclusion lenses are used to design and expand extension and support services for fisherfolk and aquaculturists, which can encourage and enable autonomous and planned adaptation.

Monitoring progress and success

The CRFMs regional strategy and action plan (2020a) recognises the fundamental requirement for monitoring, evaluation, and learning to help identify systematic gaps, revise the nine strategic elements, and provide updated guidance to Member States. Evaluation of national and regional programmes will be required to track progress and identify areas for further action. To be effective, this will require clear ownership from relevant bodies, with set timescales for review.

In the Caribbean region, fish are essential, both for food and as part of the culture. It is imperative that the fisheries and aquaculture sectors can adapt to climate change, so that the substantial benefits they bring to the region are ensured into the future. Therefore monitoring, evaluation and learning should be embedded in the institutional mechanisms for tracking progress. This includes identifying the roles and responsibilities of the range of stakeholder institutions, guided by Fisheries Departments. Not all adaptation actions listed here are the responsibility of Fisheries Departments or management institutions, and they are cut across government ministries and agencies.

Adaptation planning in the fishing and aquaculture industry should be included in national planning and development, and recognised for its importance nationally and internationally.

11. Conclusion

It is clear that climate change is already having negative effects on fisheries in the Caribbean, and is expected to bring profound changes in years and decades to come. Action needs to be taken now, and everyone in fisheries and aquaculture can play a part, from fisherfolk and managers to ministers. There is already a lot of work underway to improve fisheries management, for example in the areas of fisheries governance, safety at sea and improving the health of the marine environment, but further action is needed to secure people's livelihoods in the long term. Here, we have provided an overview of the action that can be taken in the short term, by fisherfolk, aquaculturalists, cooperatives, managers and policy makers. Individuals and communities can drive the development of climate-smart fisheries through no-regret actions that save money, increase income or improve safety, regardless of climate change. Longer term goals are described which require further investment or policy changes, but which will bring about huge shifts in how fisheries and the marine environment are managed, in food security and in the sustainability of livelihoods. Local communities must be involved at every stage, including marginalised groups and youth, making the most of local knowledge and skills, and involving people in co-management. To inform successful adaptation, and ensure continuous improvement, targeted research is needed that can help policy makers and managers to facilitate on-the-ground change.

Citation

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Annex 1.

Further information on vulnerability and risk assessments

Table A1. The key components of two approaches for quantifying climate risk in fisheries: the climate vulnerability assessment (CVA) and climate risk assessment (CRA). Components that are similar between the two approaches are shown side-by-side. Variations on both frameworks exist, as both CVAs and CRAs can be flexibly adapted to accommodate specific case studies. Note that usage of the term 'exposure' differs between CVA (more akin to 'hazard') and CRA (more akin to 'sensitivity' in CVA), and likewise usage of 'vulnerability' (more akin to 'overall risk' in CVA, and as the reverse of 'adaptive capacity' when used in CRA).

Approach	**Climate Vulnerability Assessment (CVA)**	**Climate Risk Assessment (CRA)**
Key source, or example studies	IPCC, 2001; Allison et al., 2009; Monnereau et al., 2015, 2017; Barange et al., 2014; Pinnegar et al., 2019	IPCC, 2014b; Payne et al., 2020; Pinnegar et al., 2020
Physical drivers	**Exposure (E):** considers the physical effects of climate change that a system or area is exposed to (including temperature change, extreme events, sea level rise and flooding)	**Hazard (H):** considers the physical effects of climate change that comprise a hazard to a system or area (including temperature change, extreme events, sea level rise and flooding)
Ecological and socio-economic effects	**Sensitivity (S):** describing the degree to which a system is affected by a given climate stressor, i.e. is either sensitive or robust to climate change. A distinction may be made between: • ***Species sensitivity***, or ecological sensitivity, based on the temperature preferences of fish and shellfish species, their specific habitat requirements and/or their potential to recover from disturbances • ***Fisheries sensitivity***, or socio-economic sensitivity, which considers the dependence of a community on fisheries to provide employment, income or food security	**Exposure (E):** describing the extent to which a system or community is exposed to – i.e. likely to be affected by – a given climate hazard. A distinction may be made between: • ***Species sensitivity,*** or ecological sensitivity, based on the temperature preferences of fish and shellfish species, their specific habitat requirements and/or their potential to recover from disturbances • ***Fisheries exposure,*** which considers the diversity of species caught by a fishery, i.e. their reliance on either very specific resources or a broad 'portfolio' of species
Capacity to adapt – or lack thereof	**Adaptive Capacity (AC):** reflects the ***ability*** to anticipate and respond to changes and to minimise, cope with, and recover from the consequences	**Socioeconomic Vulnerability (V):** reflecting the ***challenges*** within a community to anticipate or respond to changes and to minimise, cope with, and recover from the consequences
Combined assessment	**Overall Vulnerability (V):** the overall vulnerability of a community or area, defined as E + S + (reverse) AC	**Overall Climate Risk (R):** the combined risk within a system or community to climate change, based on the combination of H, E, and V

Further information on Climate Exposure (CVA) or Hazard (CRA)

Rising sea temperature. Caribbean-wide, sea surface temperatures are rising (on average by +2°C between the present and 2050-2099), but this rise is not even across the region; areas with particularly warm sea surface temperature include the waters between Cuba and Jamaica, and off north-eastern Colombia (Nurse and Charlery, 2016). At shorter time-scales, heatwaves are becoming increasingly common – periods lasting weeks to months where sea temperatures far exceed those normally experienced, and which can lead to coral bleaching. Both long-term warming and heatwaves can have a plethora of effects on fish and other marine life that Caribbean fisheries depend upon (Oxenford and Monnereau, 2017).

Extreme weather events. Both the frequency and intensity of extreme weather events have increased, a trend that is set to continue into the future (Stephenson and Jones, 2017). All Atlantic hurricane seasons from 2016 to 2020 have had at least one category 5 hurricane (i.e., at the maximum level), and the 2017 season stood out as particularly devastating with hurricanes Irma and Maria. Eastern Caribbean countries are particularly exposed to extreme weather due to their geographical position. However, hurricanes may impact the entire Caribbean region as demonstrated in 2020 by hurricanes Eta and Iota making landfall in Nicaragua. Extreme weather events can have devastating effects not only on fisheries but also on housing, infrastructure, agriculture and other critical sectors, sometimes with country-wide impacts including direct loss of life.

Ocean acidification. In the Caribbean region, a decrease in pH has followed the global trend of ocean acidification due to rising carbon dioxide levels (Gledhill et al., 2008). In turn this represents a key threat to coral reefs by reducing the calcification rate of framework builders (Anthony et al., 2008) causing bleaching and productivity loss of reef-dependent fish stocks. Ocean acidification can also negatively impact shell-building molluscs and crustaceans, which are crucial to shellfish fisheries in the region. Moreover, ocean acidification may impact many other types of organisms, which might not be directly fishable but are key to the health of the marine ecosystem.

Sea level rise and flooding. Sea level rise (SLR) can cause flooding, coastal erosion and the loss of coastal regions. It reduces the return period for extreme water levels (storm surges) and threatens existing coastal ecosystems. Within the Caribbean region, mean SLR was 2-3 mm annually averaged over 1950–2000 and has been greatest around Antigua and south to Grenada, less in the central Caribbean Sea (Palanisamy et al., 2012). Future impacts from SLR will be felt most keenly on low-lying coastlines with high population densities and relatively small tidal ranges, where the impacts from flooding and storm surges will be greatest.

Further information on Species Sensitivity (CVA) or Ecological Exposure (CRA)

Thermal tolerance. In the Caribbean Sea, temperature conditions are such that most species are already close to their maximum thermal tolerance ranges; as a result, there will be few "winners" under future climate change with regard to commercially important fish species, which are expected to suffer population declines and reduced productivity in the region (Oxenford and Monnereau, 2018). The thermal preferences of species, linked with their tolerance to high temperature, are closely associated with their responses to warming, with some species better able to withstand high temperatures than others (Pinnegar et al., 2019).

Habitat specificity. This metric distinguishes between highly specialised species and those that can thrive in a broad range of habitat conditions; for example, reef-associated fishes are typically directly dependent on their vulnerable coral habitats to survive, whereas many pelagic fishes roam widely and are able to follow changing water masses – influencing their sensitivity to climate change.

Recovery potential or population resilience. This metric distinguishes between species characterised by slow or fast reproductive turnover rates, and hence their resilience to fishing and the rate by which their populations may recover from any potential disturbances – whether or not these are associated with climate change.

Further information on Fisheries Sensitivity (CVA) or Fisheries Exposure (CRA)

Jobs in fisheries. In some communities a high proportion of people earn their living as fishermen whereas in other communities, many alternative job opportunities options are available. In the Caribbean, many people also work part-time as fishermen; where fishing provides important income at times when little other work is available.

Jobs indirectly linked with fisheries. Many jobs depend on fisheries – including fish processors and vendors, as well as those working as boat builders or providers of equipment. Other jobs may be more indirectly linked; including those catering for fishers, and jobs in tourism associated with recreational fishing.

Diversity of catches. Some fisheries are entirely dependent on only a small number of species, and are therefore highly exposed if one of these is impacted by climate change; other fisheries catch a broad portfolio of fish species and are less exposed, because if some species go down, this is more than likely to be compensated by increases in catches of others (Payne et al., 2020).