Key climate change effects on the coastal and marine environment around the Caribbean and Mid-Atlantic UK Overseas Territories

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EXECUTIVE SUMMARY

- This paper provides a concise high-level scientific review and synthesis of evidence of climate-change impacts in the marine and coastal environments of the UK Overseas Territories (UKOTs) in the Caribbean and Mid-Atlantic; based on available information.
- The UKOTs in the Caribbean and Mid-Atlantic are diverse in size, economic and social development, and systems of governance. They are small territories with populations ranging from approximately 5000 people to approximately 65,000. The collective permanent human population is estimated at 220,000 spread across the islands of Anguilla, Bermuda, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks and Caicos Islands.
- Although these six UKOTs are negligible producers of greenhouse gases in global terms, they are highly vulnerable themselves to the impacts of climate change, because of inherent economic, ecological, and social fragilities associated with the small size of their land masses; this vulnerability is exacerbated by their geographical location that exposes them to Atlantic storms, which have been of increasing intensity since the 1980s, and more-frequent but extreme events, such as droughts.
- Climate change is already impacting communities on populated UKOTs in the region. Sea-level rise, changes in the frequency and/or intensity of extreme weather events constitute the components of

Citation: Murray, P.A., Nichols, K.E., Thomas, A., Lockhart, K., O'Garro, M., McCoy, C., and Austin, T. (2021) Key climate change effects on the coastal and marine environment around the Caribbean and Mid-Atlantic UK Overseas Territories. *MCCIP Science Review 2021*, 27pp.

doi: 10.14465/2021.orc01.car

Submitted: 06 2021
Published online: 21st July 2021.

climate change that are the hazards of greatest concern. In September 2017, the Caribbean was hit by some of the most ferocious Category 5 hurricanes the region has ever seen. Hurricanes Irma and Maria were responsible for widespread devastation across the UKOTs of Anguilla, the British Virgin Islands and the Turks and Caicos Islands. The Climate Studies Group Mona (CSGM) (2020) suggests that the recent warming trend in sea surface temperatures (SSTs) will continue into the future reaching 1.76 ± 0.39°C per century under a 'business-as-usual' scenario.

- In this paper, the three priority areas identified as the focus for consideration are: (1) Impacts on food security, fish, fishing communities; (2) changes in coral reefs and associated communities; and (3) impacts on the provision of natural coastal protection.
- Habitats and ecosystems have already been seriously degraded by climate change resulting in the loss of biodiversity and shrinkage of the habitats. These impacts are exacerbated by anthropogenic activities that diminish the capabilities of ecosystems to build their own resilience to changing environmental conditions.
- As climate change presents significant risks for the six Caribbean and Mid-Atlantic OTs, there is a need for substantial climate action to reduce vulnerability and exposure.
- Examples of regional (nature-based) solutions/initiatives to tackle climate change impacts are highlighted. These range from evidence-based, inter-sectoral approaches to examine vulnerability and adaptive capacities of key sectors to maintain a sustainable tourism industry, development of Climate Change Adaptation Policies, mangrove rehabilitation, building adaptive capacity, and partnership between public and private sector stakeholders.
- Organisational strengthening of key government agencies, adaptive capacity building of fishers, strengthening marine protected areas systems, improving the management, and sharing of data and implementing Integrated Coastal Zone Management plans are among the priorities to address climate-change risks.
- While existing policies and assessments have identified priority measures, an overarching impediment is access to adequate climate financing.
- Addressing climate change in the UKOTs, however, is a global responsibility, not just a matter for policy and decision-makers.

DESCRIPTION OF OVERSEAS TERRITORIES IN THE REGION

The six UKOTs in the Caribbean and Mid-Atlantic are diverse in size, economic and social development, and systems of governance (UK Government, 2012). They are small territories with populations ranging from approximately 5000 people to 65,000 people each, with most of the people living in Bermuda and the Cayman Islands (World Bank Data 2021). The total population is estimated at 220,000 spread across the islands of Anguilla, Bermuda, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks and Caicos (PAHO/WHO 2016, World Bank Data 2021).

Because the UKOTs and small islands are more vulnerable, it is particularly important that the implications of climate change are clearly understood by their governments. The recognition that these islands contribute minimally to global warming is echoed by the UK Government, which submits that "although UKOTs are negligible producers of greenhouse gases in global terms, they are very vulnerable to the impacts of climate change" (UK Government, 2012). The UKOTs support a diverse range of unique ecosystems and habitats which include coral reefs and mangroves.

This paper provides a high-level scientific review and synthesis of climate change impacts on the marine and coastal environments of the UK Overseas Territories (UKOTs) in the Caribbean and Mid-Atlantic. As small islands, these UKOTs are more appropriately considered entire coastal areas, as opposed to having a fixed distance from the land-water interface called the coastal zone. The information emerging from the UKOTs, however, is not sufficient to capture the full impacts of climate change on their marine and coastal resources. Some of the literature pool is outdated, suggesting that much more detailed work needs to be undertaken to inform the current state of these resources.

MAIN CLIMATE CHANGE DRIVERS

Sea-level rise, changes in the frequency and/or intensity of extreme weather events (heatwaves, extreme temperature and heavy precipitation, tropical cyclones, storm surges, and coastal, river and rain-induced flooding) constitute the components of climate change that are the hazards of greatest concern. The UK Government concedes that although UKOTs are negligible producers of greenhouse gases in global terms, they are highly vulnerable to the impacts of climate change, resulting in part from inherent economic, ecological, and social fragilities associated with the small size of their land masses (UK Government, 2012), a vulnerability that is also exacerbated by their exposure to extreme weather events.

Impacts of extreme weather events on the small economies in the Caribbean are of island-wide proportions. Hurricanes Irma and Maria, for example, caused significant infrastructural damage in Anguilla with damage costed at US$55.6 million and British Virgin Islands (US$455 million) (ECLAC, 2018). The economic costs of climate-change inaction in the Caribbean are projected to total US$10.7 billion per year by 2025, including those from hurricane damages, loss of tourism revenue and infrastructure damage (CMEP, 2021). Hurricanes are a major risk, causing loss and damage of boats, fishing gear and fisheries-related facilities. This is particularly worrisome as the records suggest that the region has been experiencing a “significant increase in frequency and duration of Atlantic hurricanes since 1995” (Climate Studies Group Mona, 2020).

Brown (2008) emphasises that climate change poses a challenge for all aspects of human and social development in the UKOTs. The IPCC in its Fifth Assessment Report concludes with high confidence that “many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change.” (IPCC, 2014b). Monnereau and Oxenford (2017) confirm that “pressure on the fish stocks in the Caribbean is being exacerbated by climate change given that it has negatively affected the marine habitats, which are important to support healthy fisheries”.

PRIORITY 1: IMPACTS ON FISH, FISHING COMMUNITIES AND FOOD SECURITY

Climate change is already affecting fisheries and aquaculture in the region through changes to important fish habitats, distribution, growth, and reproduction, which all affect fisheries’ yield (Townhill *et al.*, 2021; see also Oxenford and Monnereau, 2017). Fish distributions are changing, and important habitats, such as coral reefs, are being lost, causing declines in fish numbers. Monnereau and Oxenford (2017) provide a detailed review of the impacts of climate change on fisheries in the region, 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. Fisherfolk and coastal communities are affected by changes to the fish and shellfish populations they depend upon, and directly by the effects of storms.

For ease of comparison with much of the literature on CARICOM fisheries and for informing the review of impacts on the fisheries sector, Oxenford and Monnereau (2017) examined the impacts of climate change on each of the four main groupings of commercially important species generally considered to typify the CARICOM region. These species groups are categorised by the environment (broad habitat types) in which they are found. The ‘reef-associated shallow shelf group’ includes many essentially benthic or site-attached species such as the reef fishes, and is characterised by a reliance on coral reefs and associated ecosystems, which are typical of the shallow, clear-water, shelf areas of the insular Caribbean (and Caribbean coastlines of Belize and other Central American countries).

The 'deep slope group' includes a number of essentially benthic species that live, at least as adults, in deep (>100 m) rocky or rubble areas well below the typical depth of actively growing euphotic coral reefs (i.e. < 50 m) usually along the shelf edge or deep banks. The group includes mostly finfishes, such as deep-water snappers, deep-water groupers and other species groups that are found below the depth of actively growing coral. The 'shrimp and groundfish group' generally refers to a number of benthic species of shellfish, i.e. penaeid shrimps/prawns and finfishes which rely on shallow, muddy or sandy continental shelf areas and associated estuaries and mangroves typical of the Caribbean coastlines of Guyana and other South American countries. The 'oceanic pelagics group' includes the more-offshore, open-water, highly migratory, epipelagic (surface) species and large sub-surface species which occur throughout the Atlantic and Caribbean Sea in offshore, open water.

A review of available literature published (Nurse, 2011) confirmed a dearth of studies on the impacts of climate change on fishery species specific to this region, perhaps except for coral reef fishes. Oxenford and Monnereau (2017) considered the broad biological and ecological characteristics of each of the four main species groups that may be impacted by one or more aspects of climate change. They considered the information available in the published literature from conspecifics and related taxa and from laboratory and field studies, mostly outside of the Caribbean; together with information on the biophysical characteristics of the Caribbean Sea and knowledge of the broad exploitation status of commercially important stocks, to summarise what is possibly the most significant evaluations of the impacts of climate change on the four main fishery species groups in the region.

Oxenford and Monnereau (2017) suggest that the most obvious impacts of climate change on reef-associated shallow shelf group of fish and shellfish are indirect, and result from the significant impacts (already witnessed in the Caribbean) on their essential benthic habitats, especially coral reefs and, to a lesser extent, mangrove wetlands and seagrass meadows. The impacts of climate change on this group, although species-diverse, are almost undoubtedly the most serious of the four commercially important fishery groups in the region (Oxenford and Monnereau, 2017). The reliance of this group on highly vulnerable and already damaged shallow coastal habitats and the severely overexploited status of many of the nearshore marine fishery stocks puts them at the greatest disadvantage for withstanding climate-change stressors.

Much less is known about the deep-slope group of species and their essential habitats than the shallow reef-associated taxa. As with the reef associated group, these species would be similarly vulnerable to changes in ocean currents and surface water temperatures, potentially affecting the dispersal of their spawn, and ultimately the settlement success and survival of their young recruits (Oxenford and Monnereau, 2017). The impacts of climate change on this group have received little or no specific attention, but considering their biological characteristics and current exploitation status, they are likely to be similar, or perhaps slightly less severe, than those on the shallow reef-associated group. The fact that the species in this group tend to be longer-lived than their shallower relatives, means, however, that the impacts of climate change on stock biomass and abundance will likely be delayed, but any recovery will also take longer (Oxenford and Monnereau, 2017).

The finfish and shellfish (shrimp) species in the shrimp and groundfish group mostly rely on estuarine nursery areas, including mangroves and seagrasses, and offshore deeper soft-bottom areas as adults. Although much less studied in the region than some of the other groups, they too are known to have bi-phasic life cycles with a free-floating pelagic early life stage and a benthic adult stage. This means that they will share the same potential threats posed to early life stages as all the other fishery groups (Oxenford and Monnereau, 2017). The early life stages will also be vulnerable to the myriad of potential effects of high pCO_2, elevated sea surface temperature (SST) and declining carbonate saturation states (the latter likely to impact shrimps), as discussed in detail for the reef-associated shallow shelf group. However, like the deep-slope group, the adult habitats will likely be less impacted by climate change and adults could probably move to deeper offshore soft-bottom habitats.

The oceanic pelagic group comprising large highly migratory species (billfishes, large tunas) as well as smaller more-regionally migrating species (flyingfish, dolphinfish, wahoo, small tunas) is the only group in which the members remain in pelagic environments for their entire life histories as eggs, larvae, juveniles and adults. They also generally have extended spawning periods, being multiple batch spawners, and have relatively broad spawning areas that are not well defined and/or poorly known in the literature (Oxenford and Monnereau, 2017). Of all the groups, Oxenford and Monnereau (2017) suggest that this one will be the least affected, in the short term, by climate change. The early life stages are perhaps less affected by hypercapnia and increasing SST than some of the other species groups and are not reliant on finding and settling in benthic coastal habitats (Oxenford and Monnereau, 2017). Further, the open ocean environment will experience less-extreme ranges in hypoxia, pH and SST than shallow nearshore areas, and will be less affected by additional land-based anthropogenic stressors that exacerbate climate change stressors (*ibid*.). Interestingly, the recent sargassum influxes, if they continue, may support a boost productivity in many of the pelagic species that can benefit from increased shelter opportunity as larvae and small juveniles, and from aggregation of prey species as adults.

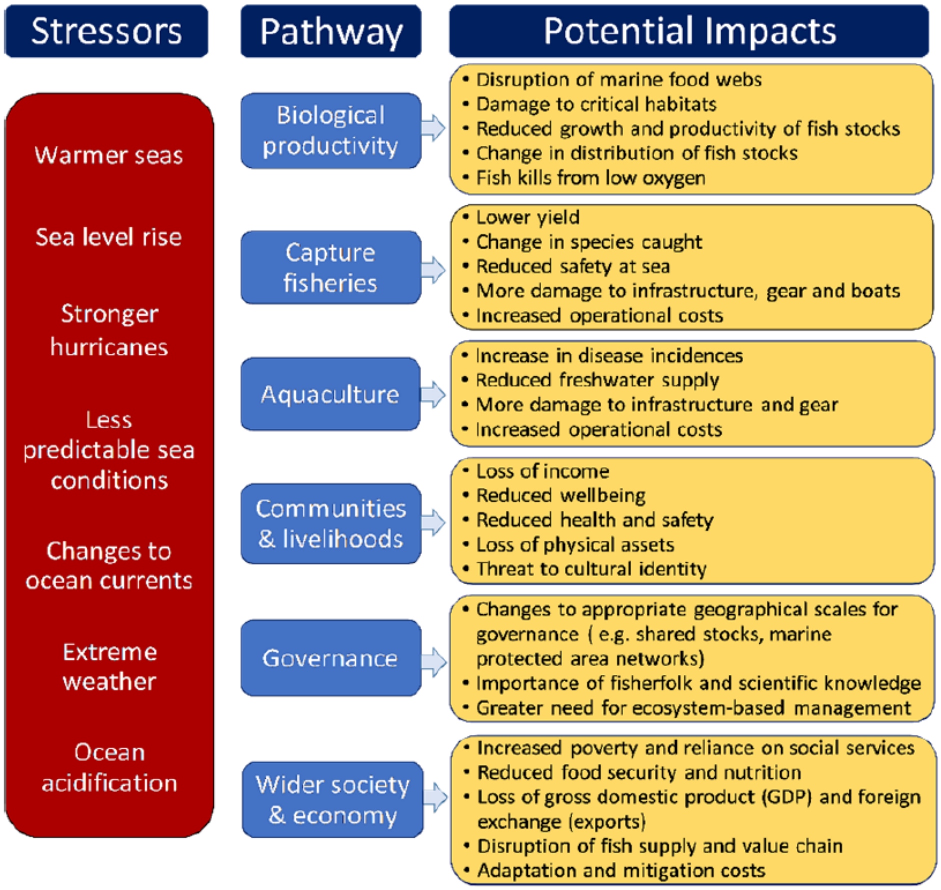


Figure 1. Range of potential impacts of climate change on fisheries. (From Cox et al., 2020).

A report produced by CANARI (2018) found that Montserrat's fisheries are vulnerable to a variety of natural disasters including those induced by climate variability and change. The report reveals that the island's fisheries have been impacted by several major natural disasters which have caused damage to its marine ecosystems and fishing infrastructure. For example, Hurricane Hugo, in 1989, struck Montserrat resulting in eroded shorelines, damaged coral reefs and destruction to the island's fishing fleet resulting in damages of US$2 million to the island's fisheries sector. Several other tropical storms and hurricanes including Luis in 1995, Georges in 1998, Lenny in 1999, Earl in 2010 and Maria in 2017 also contributed to similar losses.

Vulnerability assessments for Anguilla show that climate change has negative biophysical (marine environment) and socio-economic impacts (food security, livelihoods) on the fisheries sector (annex 1 in Fardin *et al*., 2018). Anguilla's fisheries sector is vulnerable to climate-change hazards, including tropical storms and hurricanes passing through or near the island during the hurricane season. Between 1995 and 2010, Anguilla was hit by eight such events causing much damage to coastal resources due to strong winds, wave action and torrential rain. In 1999, Hurricane Lenny impacted the island with torrential rains and major tidal surges. Inland areas were flooded to depths of up to 15 feet, including the capital, The Valley. Many hotels were closed for a year which affected tourism-dependent livelihoods (DFID, 2012, cited in

Fardin *et al*., 2018). Hurricane Irma, in 2017, also impacted Anguilla resulting in destruction to critical infrastructure. In the fishing sector, fisherfolk reported significant losses or damage to fishing vessels and fish traps.

A rise in SST is expected to cause more-frequent and severe coral-bleaching events in the region, damaging and reducing habitats for reef fish. Increase in SST 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 will be impacted further by reduced pH, with major knock-on effects for the biodiversity and fisheries they support.

The impact of elevated temperatures is clearly demonstrated in the Cayman Islands, home to some of the largest remaining spawning aggregations for the culturally and economically important Nassau Grouper (*Epinephelus striatus*). Preliminary research results of laboratory experiments conducted by Grouper Moon Project Scientists on Nassau grouper larvae suggest that rising water temperature will impact larval success (Waterhouse *et al.*, in prep; Waterhouse *et al.*, 2020). Data showed that above the 'ideal' 26ºC–27ºC water temperatures, early life stage mortality increases dramatically. For example, when temperatures increased by 4ºC (to 31ºC), starvation time decreased from 6–7 days to 3–4 days. Grouper larvae do not start feeding until around day four, and this represents a significant problem; if the larvae cannot survive until they are old enough to eat, it is unlikely they will survive at all, which would result in recruitment failure. Increasing water temperatures predicted due to climate change over the next 20 to 50 years, may have devastating consequences for fisheries in the Cayman Islands.

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 fisheries infrastructure, with recovery of the fishing sector after a hurricane potentially taking a long time. So, improved safety-at sea training and associated equipment are required, as well as early warning systems, which are currently not prominent in small-scale fisheries across the region (Monnereau and Oxenford, 2017).

Negative impacts that are already obvious in this region include coral bleaching (which damages critical fish habitat), increasing intensity of storms together with increased sea-level rise (which damages fish habitats, fishery access and assets), and sargassum influxes (disrupting fishing operations and communities and impacting the sustainability of the resource) (Monnereau and Oxenford, 2017; Oxenford and Monnereau, 2017). Sargassum influxes in the Caribbean continue to affect harvesting and fishing operations and communities by impeding access to fishing vessels in ports, reducing access to fishing grounds, clogging fishing gear, damaging propulsion systems, and affecting the catchability of some pelagic species.

The reduction in the availability of high-value species such as the spiny lobster, conch, and snappers will have significant impacts on the sector as fishers' productivity and catch per unit of effort decrease, with negative knock-on effects on export trade volumes and foreign currency reserves.

Reef-associated fisheries, already severely degraded, and on which the countries are heavily reliant, will be hardest hit by current and near-future climate-change impacts (Monnereau and Oxenford, 2017).

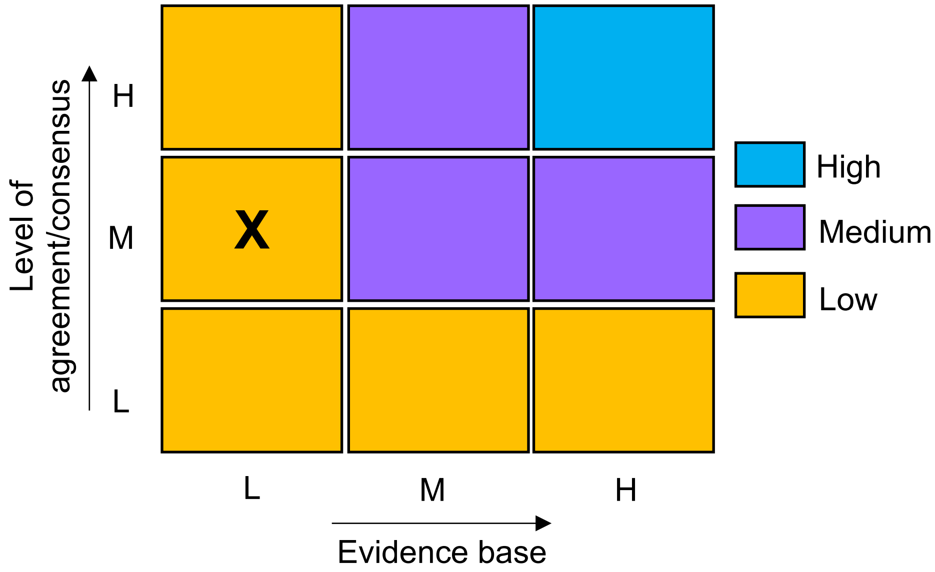
Changes in the productivity and distribution of oceanic pelagic species will force fishers to retool, fish for longer hours, or travel further to maintain catch rates. The relatively newly introduced fish aggregating devices (FADs) will provide some alternative in the short term. These factors combined will have financial consequences for fishers. Smaller catches of pelagic species and associated increased ex-vessel prices will have significant impact on the harvest and the post-harvest sector, especially as these are the species that generally support the greatest value-added processing. Decreases in the profitability of fishing will negatively affect the willingness of investors, and the viability of the harvest and post-harvest processing sectors (Monnereau and Oxenford, 2017).

Over the longer-term, as reef resources become increasingly degraded and over-exploited and pelagic species less available, fisherfolk may have to abandon fishing and look for scarce alternative employment opportunities (Monnereau and Oxenford, 2017). This will likely require government incentives and training programmes to retool fishers. Alternatively, the sector may adapt by switching from small-scale to medium-sized boats, resulting in higher capital investment and maintenance costs as well as higher potential losses in cases of extreme-weather events (*ibid*.).

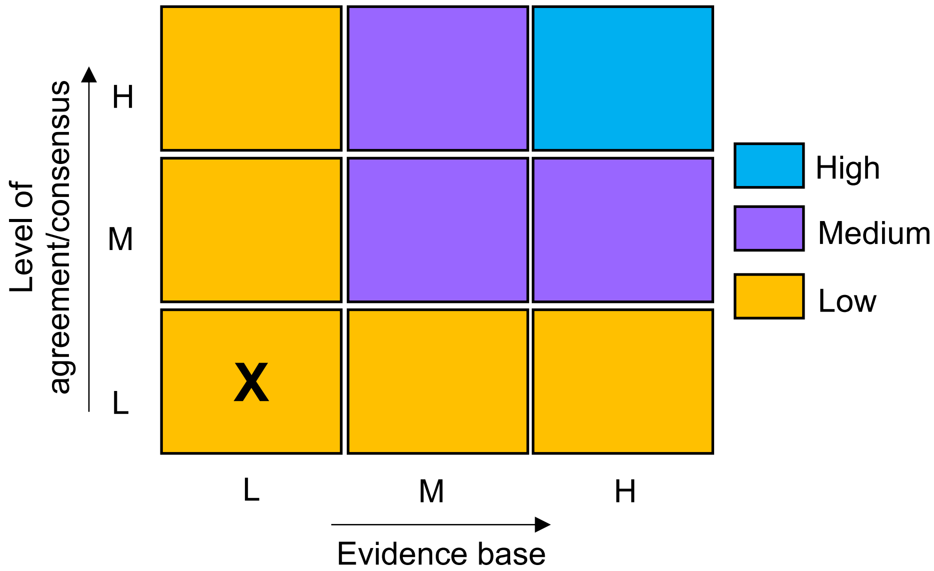
Reducing abundance of fish and shellfish resources may also exacerbate conflict, not only intra-fisheries conflict amongst fishers competing for the same limited resource, but also between the fisheries sector (consumptive users) and other non-consumptive users (e.g. recreational divers). The latter will be especially acute for reef fishes (Monnereau and Oxenford, 2017).

CONFIDENCE ASSESSMENT

WHAT HAS HAPPENED



WHAT MIGHT HAPPEN



Monnereau and Oxenford (2017) have suggested that in terms of what is already happening, there is medium/high level agreement based on the very few studies published for the region supported by impacts reported in other, similar, tropical fisheries. There remain significant difficulties with separating climate-change impacts from other chronic anthropogenic impacts such as the degradation of habitats. Whereas in terms of what could happen in the future, they suggest low level agreement based on the absence of any research in this area and tangible evidence in the region. This, they opine, is coupled with the fact that projections are complicated by an absence of knowledge regarding synergistic effects of the multiple climate-change stressors combined with other anthropogenic stressors and external market forces and demographic changes.

PRIORITY 2: CHANGES IN CORAL REEFS AND ASSOCIATED COMMUNITIES

Climate change is already impacting coral reefs in the region, through coral bleaching, disease outbreaks, ocean acidification and physical damage from stronger hurricanes (IPCC, 2014b). Coral bleaching is the most visible, wide-spread, and iconic manifestation of climate change on reefs, with major events in the Caribbean in 1998, 2010 and 2015/16. The extent of bleaching and associated mortality varies by location and event but has resulted in mortality. Coral disease has already significantly altered the community composition of reefs in the Caribbean and is projected to result in increasing frequency of outbreaks as seas warm. The lack of a centralised database to coordinate reef monitoring information hampers efforts to measure these effects. The NOAA global network of Coral Reef Early Warning Systems (CREWS) stations in collaboration with the Caribbean Community Climate Change Centre (CCCCC) has and is continuing the installation of CREWS stations in select reef areas in the Caribbean. Other portals, though not very well utilised, include the Atlantic and Gulf Rapid Reef Assessment (AGGRA) and the International Coral Reef Initiative (ICRI). The regional UKOTs are working in a Collaborative Coral Reef Working Group with the Joint Nature Conservation Committee (JNCC) towards the development of a cohesive monitoring protocol.

The most-severe bleaching event recorded in the Caribbean is widely considered to have been in 2005, with 80% of coral reefs being affected by bleaching and 40% dying at many locations across 22 countries (Eakin *et al*., 2010). However, for the north-western Caribbean, including Belize, the 1998 event remains the most devastating on record.

In 2019, the Turks and Caicos Islands (TCI) had documented its first case of the Stony Coral Tissue Loss Disease (SCTLD) and have been taking active steps to combat the disease. The first documentation coincided with the TCI Atlantic and Gulf Rapid Reef Assessment (AGRRA) survey in 2019. The TCI has now become part of a Collaborative Coral Reef Working Group with UKOTs, JNCC and Department of Environment and Food and Rural Affairs (Defra). This group is actively discussing what the priorities of the coral reefs of the UKOTs are and how best to address these issues as a region.

While the TCI does not have specific case studies that speak to changes to coral reefs and associated communities, there has been some work conducted by non-profit organisations and educational facilities. According to Knipp *et al*. (2020), research conducted in South Caicos of the Turks and Caicos Islands documented that corals, historically dominated by *Montastraea* spp., *Siderastrea* spp., *and Porites* spp., have experienced a drop in average coral cover from 32.5% in 1995 to 21.9% in 2004, with signs of increased coral bleaching and disease. It should be noted that until 2012, South Caicos has had a lower density of tourism and minimal anthropogenic drivers of coral stress. The Knipp *et al* (2020) study revealed that significant coral bleaching and restoration of coral colour occurred offshore of South Caicos Island during, and after the 2014–2017 Global Bleaching Event (GBE) for plate-type corals. More specifically, the study found that some corals were more susceptible to temperature fluctuations. For example, the 2014–17 bleaching event occurred as record-breaking SST pushed some TCI corals past their physiological limits (Knipp *et al*., (2020).

A long-term coral reef monitoring programme, established in 1997, at Andes Reef, Grand Cayman, revealed a loss of 55.5% coral cover between 1997 and 2013 (32.8% in 1997 compared to 14.6% in 2013), with a significant proportion of that loss attributed to the devastating 1998 coral bleaching episode (DoE, unpublished data; see also Figure 2). Additionally, a further reduction in absolute coral cover between 2013 and 2016 of 32.3% has since been recorded (14.6 % in 2013 compared to 9.89% in 2016; *ibid*.). These changes can be attributed to elevated water temperatures during the summer months resulting in regular bleaching events and subsequent disease outbreaks (DoE, unpublished data). Observations of the reef system up to 2020 show a similar trend of loss of live coral cover.

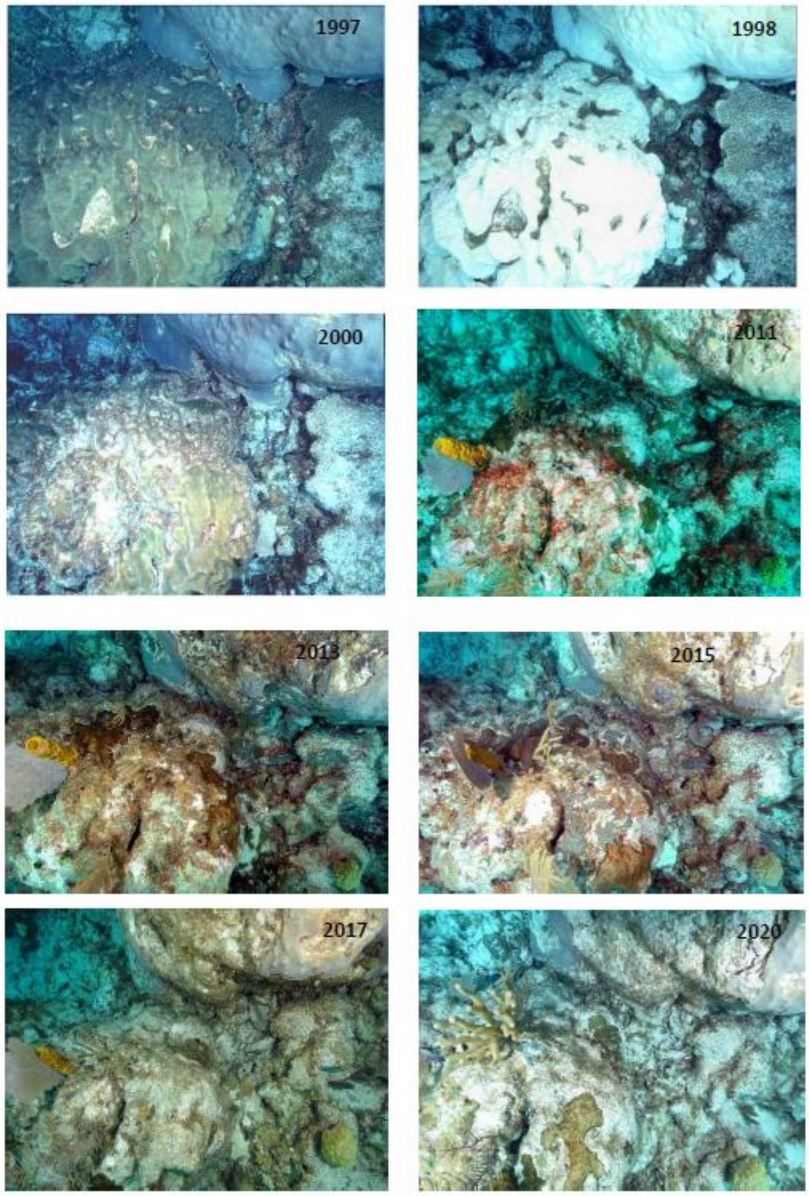


Figure 2. Andes reef, 1997–2020 North coast of Grand Cayman from long-term benthic photo-quadrat project monitoring. (Source: DoE unpublished data.).

In September 2009, the Cayman Islands coral reefs experienced a localised acute mass coral-bleaching event with water temperatures >30ºC for six weeks. This elevated temperature anomaly resulted in >90% of corals bleaching (DoE, unpublished data). Crabbe (2008) noted that bleaching is forecasted to be an annual event by 2040, causing high mortality of coral reefs regionally and globally in the tropic, while adding that this trend is likely to be witnessed sooner in the Caribbean. Hughes *et al*. (2003) predicted that by 2030, >60% of coral reefs globally would disappear.

Increases in sea temperature have already had other more hidden impacts, including declines in coral reproductive success (Baird *et al*., 2009), metabolic rates (Munday *et al*., 2009), and shifts in geographic ranges

(Hughes *et al*., 2003). Results from the Knipp *et al*. (2020) study suggest that there is a change in composition of reefs in the TCI from massive colonies of scleractinian corals to less massive structures (Figure 3). In combination with more localised stresses, such as overfishing and degraded water quality, unprecedented thermal stress impacts could undermine significant investments in protection of coral reefs over recent decades (Game *et al*., 2005). It is therefore reasonable to conclude that the rapid pace of climate warming is likely to increase damage to coral reefs.

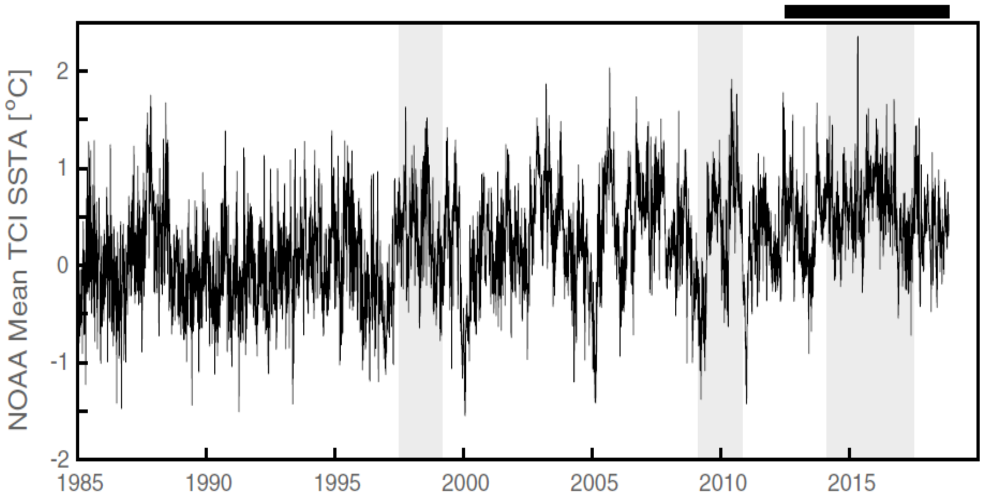
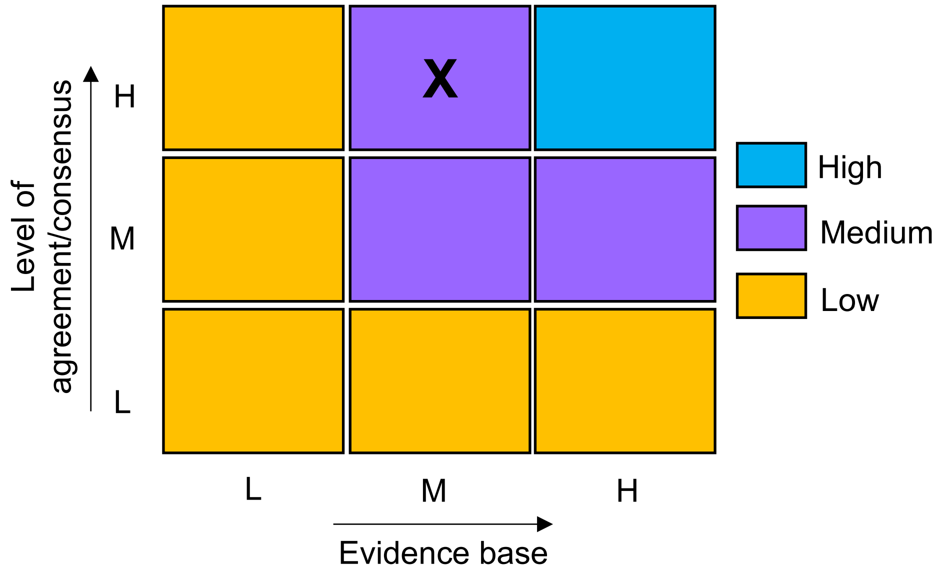


Figure 3. NOAA Sea Surface Temperature Anomalies (SSTAs) averaged over three TCI 5km grid cells, 1985 to 2019. The 1997–1998, 2009–2010 and 2014–2017 mass Global Bleaching Events are shaded in grey. The 2012–2018 study interval used to analyse TCI sensitivity. (From Knipp et al., 2020).

The IPCC in its 2014 synthesis report expresses confidence that many marine species face extinction risk or will face redistribution away from more-affected regions. This will undoubtedly affect the viability of fisheries productivity and other ecosystem services. It is also with high confidence that coral reefs will be impacted by lowering of ocean pH. The UK Government also concedes that climate change is also increasing pressure on the rich biodiversity resources of the UKOTs and could lead to a decline in the populations of some species (Brown, 2008). In an examination of the climate change impacts coastal and marine resilience, it is suggested that the tourism and fisheries sectors, key contributors to employment, food security and the GDP will continue to be affected by the changes in the ecosystem environments (CANARI, 2020).

CONFIDENCE ASSESSMENT

WHAT HAS HAPPENED



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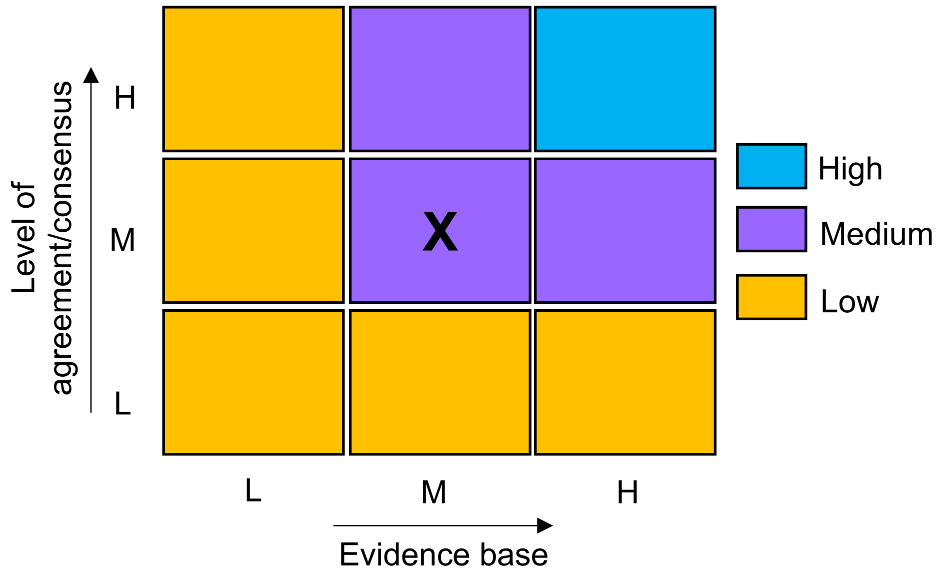


McField (2017) has proposed that there is reasonably high confidence in what is already happening, such as measuring the extent of acidification at any location, but because different species respond differently to these stressors, it becomes more difficult to understand the ecological implications of these changes. The fundamental physiological and ecological processes are generally understood, but the precise response to any disturbance depends on many internal and external factors, and needs further research, suggesting a medium score for the amount of evidence. For future impacts there is more uncertainty. A minority of scientists have more expectations for coral adaptation to temperature (through symbiont shuffling or their temperature adaptation). With ocean acidification, the results are highly variable by species, so predicting ecological outcomes is extremely difficult. However, a few key functional groups, like coralline algae (which provide the mortar for the reef framework construction) seem clearly impacted across species, hence a score of medium. The Maynard *et al*. (2015, cited in McField, 2017) models showed a high level of concordance using different approaches. Ocean acidification studies do empirically test different levels and so are sound evidence of impact and future CO_2 levels, resulting in a medium/low score.

PRIORITY 3: IMPACTS ON THE PROVISION OF NATURAL COASTAL PROTECTION

Coastlines are dynamic and are constantly changing due to factors such as wave size, wind speed, water depth, the strength of tides and the rates of relative sea-level change, as well as rainfall and the frequency and intensity of storm events. Coastal ecosystems, particularly intertidal wetlands, and reefs (coral and shellfish) can play a critical role in reducing the vulnerability of coastal communities to rising seas and coastal hazards, through their multiple roles in wave attenuation, sediment capture, vertical accretion, erosion reduction and the mitigation of storm surge and debris movement (Spalding *et al*., 2014). There is some evidence that climate change affects the severity of coastal erosion, flooding, and landslide events, but the contribution of anthropogenic activities such as sand mining, changing land use patters and other pressures cannot be discounted. (IPCC 2014 a, b). A report by Moore (2015) report points to increasing evidence that climate change puts increasing pressure on certain coastal frontages as well as necessitating changes in approach to managing risks arising from sea-level rise, changing weather patterns, and resulting coastal erosion, flooding, and land slippages.

IPCC climate projections suggest increases in SST will result in a corresponding increase in hurricane activity. Other impacts of climate change, in particular sea-level rise, will accelerate coastal erosion. All these stressors have the potential to seriously impact settlements and infrastructure. For example, climate change is already impacting energy generation, distribution and transmission infrastructure as hurricanes damage lines and poles and power generation stations located on or near the coast which are highly vulnerable to flooding from storm surges and sea-level rise and wind damage (Lincoln, 2017). Road networks, air and seaports of the islands are particularly vulnerable and under threat of inundation. Many of the air and seaports in these islands are located on the coast and are under threat and at risk of inundation under scenarios of 1m sea-level rise (CARIBSAVE, 2011c cited in Lincoln, 2017). These experiences are already commonplace in the region.

Natural processes such as coastal erosion have resulted in losses and damage to shoreline properties in recent years whilst the market values of others have been affected because development has taken place at inappropriate locations

(EUrosion, 2004). Some of the more-serious risks that are evident around coastlines have resulted from a lack of co-ordination between land-use planning and development proposals (cf. McInnes, 2006). Improved understanding and application of knowledge related to the array of factors that affect the strength or efficacy of coral ecosystem services in different locations, as well as management interventions which may restore or enhance such values will form a critical part of coastal adaptation planning, likely reducing the need for expensive engineering options in some locations and providing a complementary tool in engineering design (Spalding *et al*., 2014).

There is clear evidence of how erosion has impacted beaches, coastal infrastructure, livelihoods, and economies, exposing the vagaries of ill-informed or ill-planned developments. A UNESCO (2003) report on beach erosion chronicles the damages to coastal Cove Bay in Anguilla, when in 1995 Hurricane Luis eroded the seaward face of sand dunes that separated a salt pond from the sea. Similar damage from Hurricane Luis was evident on Mead's Bay. In 1999, the waves generated by Hurricane Lenny breached the dune on Cove Bay allowing seawater to flow into what was a contained salt pond.

The dramatic impact of Hurricane Lenny on the high-end resort of Cap Juluca on Maunday's Bay in Anguilla is again a demonstration of what we should expect from similar type events in the future. The wide beach on the resort's frontage totally disappeared during the storm leaving most of the villas that were built on the top of the dune, teetering cantilevered over open space after most of the beach sediment on which the villas were built had vanished into the sea. What was more dramatic were the images of staircases that once facilitated beach access from the villas left standing as isolated monoliths on what was left of the beach –'stairways to nowhere' (UNESCO, 2003). These images play throughout the UKOTs following similar extreme weather events in the past resulting in serious damage to private and public properties.

Like the rest of the UKOTs, the Cayman Islands has experienced considerable environmental, social and economic costs associated with coastal erosion and wave inundation. While many of these impacts could have been mitigated or avoided through adequate coastal setbacks and appropriate planning decisions the evidence suggests that climate change will continue to exacerbate these impacts with increased storm frequency and intensity predicted sea-level rise.

During October and November 2020, Hurricanes Delta and Eta, which passed through the Cayman Islands as Tropical Storms, resulted in severe beach erosion and coastal retreat to the southern end of Seven Mile Beach, a key tourism section and local recreational area. By June 2021, the start of the next Hurricane Season, no significant beach recovery had occurred.

The damaging effects of human activity on coastal capital denies these ecosystems their role in providing protection to shorelines and adjacent property. The practice of removing sand from beaches and dunes for construction purposes not only destroys the integrity of the beach but also negatively impacts tourism, a significant economic activity in the UKOTs (UNESCO, 2003). That report also very accurately speaks to the impacts of other seriously detrimental anthropogenic activities such as building too close or on the beach, the installation of badly planned or engineered sea/coastal defences, pollution, building on sand dunes and interfering with coastal vegetation.

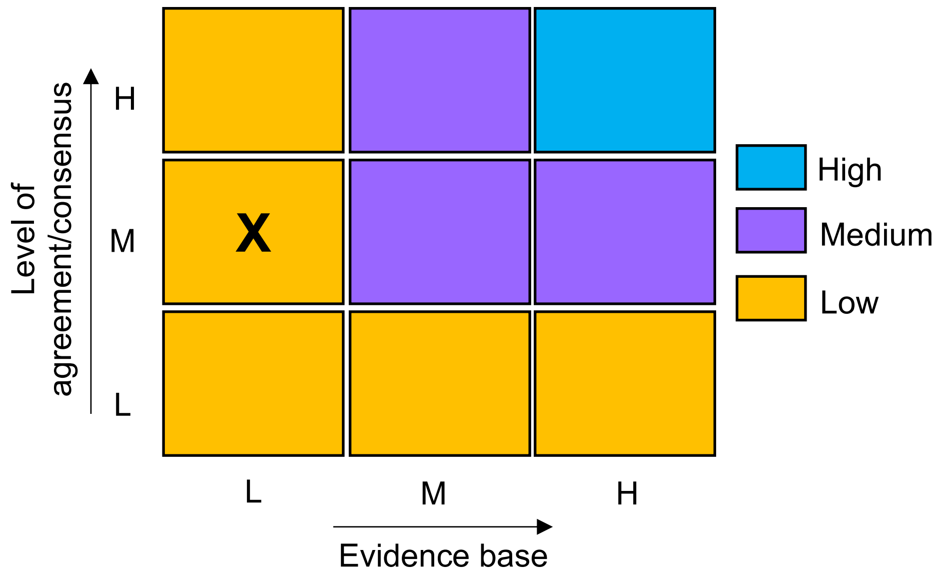
In addition, several of the ecosystems found in the territories, such as mangroves and coral reefs in the Caribbean that provide protection to the shoreline, are among those that the IPCC has identified as "most vulnerable" and "virtually certain to experience the most severe ecological impacts" of climate change (IPCC, 2014b). Brown (2008) adds that coastal erosion linked to climate change is causing the loss of turtle nesting sites in the territories. This implies that beaches, a major attraction to visitors, are disappearing, suggesting that tourism, a major revenue earner in the UKOTs, will also be impacted.

While it may be impossible and, indeed, undesirable to defend all parts of the coastline, the development of risk management strategies to address coastal issues must be based on a thorough understanding of coastal evolution and natural processes. The costs of emergency action, remediation and prevention can represent a significant burden on affected communities with a proportion of the costs often falling on regional or local authorities with limited resources (McInnes, 2006). Sea-level rise poses a particular risk to coastal communities from increased marine erosion, flooding from storm surges, and slope failures. A hazard map and linked responses would help as a planning tool.

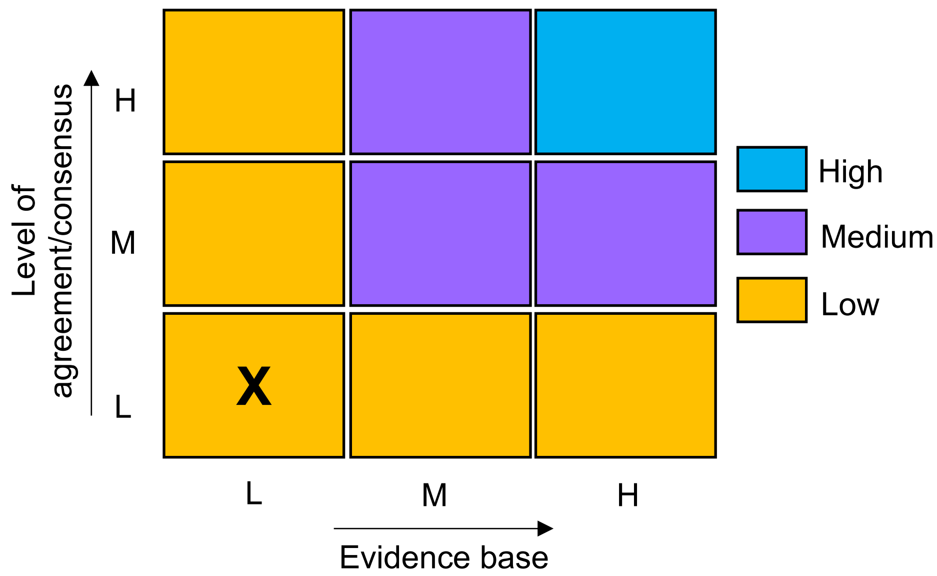
In the region, valuation could shed light on important policy questions related to the protection, restoration, and sustainable use of coastal ecosystems – including questions related to tourism, fisheries, coastal erosion, and climate change (Waite *et al*., 2014). Most valuation studies focus on the impact of extreme events, such as hurricanes or droughts, on the agricultural, tourism and fisheries sectors, based on the market value of infrastructure, hardware or produce (Bueno *et al*., 2008). There is an urgent need however to project estimations of the cost of climate-change impacts on the environmental services of marine and coastal habitats across the region like coral reefs, mangroves, beaches, and seagrass beds. Examples of coastal ecosystem goods and services include provisioning services (food, water, raw materials, medicines); regulating services (flood/storm/erosion protection, climate regulation); cultural services (tourism and recreation, history, culture, traditions, science, education, knowledge); supporting services (primary production, nutrient cycling, species and ecosystem protection) (Waite *et al*., 2014).

CONFIDENCE ASSESSMENT

WHAT HAS HAPPENED



WHAT MIGHT HAPPEN



For the 'What is already happening' assessment, Cashman and Nagdee (2017) are of the opinion that notwithstanding there is a better understanding of the science and better confidence in science and amount of available evidence, there are (still) many gaps and uncertainties.

REGIONAL NATURE-BASED SOLUTIONS: CASE STUDIES

From 2000, the region has invested in major projects aimed at building resilience to climate change. These included the *Caribbean Planning for Adaptation to Climate Change* (CPACC 1997–2001); *Adaptation to Climate Change in the Caribbean* (ACCC, 2001–2004); *Mainstreaming Adaptation to Climate Change* (MACC, 2004–2009); and the *Special Program on Adaptation to Climate Change: Implementation of Adaptation Measures in Coastal Zones* (SPACC, 2007–2011) projects. These were designed to understand the region's vulnerability to climate change, build capacity, develop, and implement adaptation plans and mainstream adaptation throughout different sectors. In fact, these projects served as the genesis for the establishment of the Caribbean Community Climate Change Centre (CCCCC) in 2002 and its operationalisation in 2005 (www.caribbeanclimate.bz/history). Since its inception the CCCCC has adopted, planned, or implemented 56 projects across various sectors in the Caribbean at an estimated value of approximately US$200 million.

Today, regional and national initiatives are guided by the CARICOM *Regional Framework for Achieving Development Resilient to Climate Change* (the Regional Framework 2009–2015 and its revision in 2021), which was endorsed by CARICOM Heads of Government in 2009 to chart the region's path towards building resilience to the impacts of climate change and which embeds nature-based solutions as actions to be pursued. Although there is much more work to be done, there have been several initiatives all aimed at building resilience that also incorporate nature-based solutions.

One example is that of the CARIBSAVE Climate Change Risk Atlas (CCRA) project. The CCRA project employed an evidence-based, inter-sectoral approach to examine vulnerability and adaptive capacities of key sectors with the aim of maintaining a sustainable tourism industry in the face of a changing climate, tourism being a fundamental part of the economy of Caribbean nations. There are also national examples of emerging adaptation initiatives. Some of the governments of the region have developed national climate-change policies and plans, low-carbon development strategies, trust funds such as that of the BVI[1], and tools aimed at evaluating the climate influences on development activities such as the CCCCC-developed Caribbean Climate On-line Risk and Adaptation tooL (CCORAL).

Other development partners such as the USAID with its Climate Change Adaptation Programme (CCAP), the EU Global Climate Change Alliance programme (EU GCCA and EU GCCA+), as well as other bilateral and multilateral programmes supported by Australia, Germany, the UK Government, Italy, Japan, the Pilot Programme on Climate Resilience (PPCR) supported by the Inter-American Development Bank (IDB), the

[1] The Virgin Islands Climate Change Trust Fund was legally established in March 2015 by passage of the Virgin Islands Climate Change Trust Fund Act. The Trust Fund is an independent entity dedicated to raising, managing and disbursing funds to qualified applicants to build resilience to climate-change impacts and to reduce carbon emissions. The Trust Fund can support actions by Government, the private sector and civil society.

Global Environment Facility (GEF), the Green Climate Fund (GCF)[2] and others have all helped pave the path towards greater resilience.

Belize, for example, with the largest barrier reef in the northern hemisphere, has embarked on the development of the Aquatic Living Resources Act as an alternative to the fisheries laws in Belize and a means of ensuring the long-term sustainability of its aquatic resources. There are a growing number of Marine Protected Areas (MPAs) in Belize, covering approximately 250,000 ha of marine area (Cooper *et al*., 2009 cited in Lincoln, 2017). Belize has a strong history of environmental research and monitoring compared to other Caribbean countries with support provided by the Coastal Zone Management Authority and Institute (CZMAI). That capacity is gradually being built primarily through partnerships with the University of Belize and other civil society organisations in the country (CZMAI, 2016 cited in Lincoln, 2017). Belize also benefits from hosting several regional agencies under official CARICOM mandates, including the CCCCC ('5Cs') and the Caribbean Regional Fisheries Mechanism (CRFM).

NEXT STEPS

As climate change presents significant risks for OTs, there is a need for substantial climate action to reduce vulnerability and exposure. All the OTs have either begun development of or approved climate change policies with the aim of achieving low-carbon, climate resilient development (Hodge *et al*., 2011; Ministry of Natural Resources and Labour, 2012; National Climate Change Committee, 2011). Across these policies, the importance of integrating climate change into all government strategies, spending and investment decisions is highlighted.

There have been few sector-specific policies or assessments focused on needed climate action in the OTs. In Anguilla and Montserrat, a fishery-focused vulnerability assessment identified the need for a multi-hazard approach that considers multiple climate change impacts along with other pressures that stem from coastal development, resource overuse, pollution, and invasive species fisheries (Granderson *et al*., 2018).

Organisational strengthening of key government agencies, adaptive capacity building of fisherfolk, strengthening marine protected areas systems, improving the management, and sharing of data and implementing Integrated Coastal Zone Management plans were all identified as priorities to address climate change risks in fisheries (Granderson *et al*., 2018).

Whereas some adaptation actions have been identified and prioritised in various fisheries and fisheries-related planning documents for the fisheries sectors in Anguilla and Montserrat, implementation of these actions has been limited (Fardin *et al*., 2018). Recommended actions to improve the institutional environment for climate adaptation, include development of a

[2] The CCCCC and the Caribbean Development Bank (CDB) are both accredited to the GCF as Regional Implementation Entities (RIEs) enjoying access of up to US$50 million per project.

policy, legal framework and management plan for the fisheries sector, and easing pressure on the reef fishery by supporting the development of a pelagic fishery and/or aquaculture.

Fardin *et al* (2018) note that in Montserrat, while catch and effort data are collected by the Fisheries and Ocean Resources Unit and stored in an electronic database, there is limited collection of other fisheries relevant data, including socioeconomic data on the sector. Data collected by the Unit is also not readily accessible and shared via any information sharing platform, though it can be made available to stakeholders upon request. In Anguilla, basic data on fishing and fisher and vessel registration are collected and stored in a database (*ibid*.). Sharing of information (reports, project information and relevant news) is facilitated through different platforms, including websites and social media. However, there is no focus on climate change and adaptation actions and sharing of related information to relevant stakeholders is not done (*ibid*.).

For Anguilla and Montserrat, mainstreaming of climate change adaptation in fisheries policies would help to improve the integration of adaptation actions (Fardin *et al*., 2018). Effective integration of climate change adaptation and disaster risk management in Montserrat's fisheries sector is limited by the absence of a fisheries policy and a national fisheries management plan into which climate adaptation actions can be mainstreamed. Adaptation efforts for the sector are therefore primarily *ad hoc*. Actions to cope with climate change (guiding principles, policy measures and directives) are mainstreamed in Anguilla's Climate Change Policy, which is aimed at promoting the development of a climate resilient society.

The development and implementation of a sustainable fisheries management policy and a supportive legal framework are among the policy directives set out to increase the OT's resilience to climate change as well as the preservation of its marine habitats (Fardin *et al*., 2018). Also, education of key stakeholders about climate risk to coastal marine resources is another policy measure to be undertaken.

CMEP (2021) has noted that fishers and communities must be involved at every step of the adaptation process. It is important that**:**

- Particular attention should be paid to gender equality, inclusion of youth and marginalised groups, and the role that adaptation plays in reducing poverty.
- Fisherfolk and coastal communities can engage meaningfully in policy development and planning, giving them the 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.
- Gender equality, poverty and youth inclusion are integrated into adaptation and disaster risk management.

- Access to financing has been made more challenging by complex institutional mandates and arrangements in the OT and the UK related to climate change.

(Defra, 2012, UK Overseas Territories Conservation Forum (UKOTCF), 2020).

The UK Government (2012) has quite appropriately asserted that “addressing climate change in UKOTs is everyone’s business, not just a matter for policy and decision-makers to deal with.” This however must be reflected not only in policies and action plans and placing the responsibility for climate action in the Ministry with the influence to advance resilience building, but ensuring access to appropriate financing to give effect to national action.

It is worth noting that the Turks and Caicos Islands has made attempts to prioritise the research surrounding coral reef health and the effects found from Climate Change; however, the department responsible for the management of the environment is restricted in capacity and has had difficulty in obtaining resources for the ongoing monitoring of the coral reefs.

The paucity or unavailability of data demands greater action on research into the impacts of climate change in the UKOTs and the generation of data and information to support evidence-based decision-making. Research however in the OTs is often conducted by persons external to these islands. If the outputs of this research are not published in mainstream journals, accessibility and utility for the UKOTs is almost non-existent. Consideration might worth be given to having a repository at a ministry or institution in the OT that keeps a record of research. This could be facilitated by a ‘research permit’ system, whereby issuance of such a permit would ensure the creation of a list or database on all research.

Ultimately, however, the dearth of research data and information is a major cause for concern in the UKOTs as in the rest of the Caribbean. Research findings suggest that estimated costs of not adapting to climate change ranges from 18% of GDP to 75% in the more exposed UKOT in the Caribbean. The average cost, however, is estimated at 50% of GDP raising serious concerns about the threat to the sustainable development of the islands. It must be emphasised that a whole of society approach must be deployed, coupled with the necessary climate financing from external resources – national budgets cannot accommodate the cost of adaptation – if countries are to effectively attain resilience building goals.

ACKNOWLEDGEMENTS

MCCIP wishes to acknowledge the contributions of Ajhermae White, Stephen Mendes (Montserrat Government) and Hannah Jallouli-White (FCDO) who participanted in the regional workshop to identify the priority climate change issues.

MCCIP would also like to thank the two anonymous reviewers whose constructuve comments helped to improve this work.

REFERENCES

Brown, N. (2008). *Climate change in the UK Overseas Territories: An Overview of the Science, Policy and You*. Peterborough, UK: Joint Nature Conservation Committee, ISBN-13:978 1 86107 609 0.

Bueno, Ramon & Herzfeld, Cornelia & Stanton, Elizebeth & Ackerman, Frank. (2008). The Caribbean and climate change: The costs of inaction.

CANARI (2018). *Institutional Assessment of Climate Change Adaptation Readiness of the Fisheries Sector in Montserrat.* Prepared by M. Andrews and T. Phillips September 11, 2018. Barataria, Trinidad: Caribbean Natural Resources Institute (CANARI).

CANARI (2020). Rising to the Climate Challenge: Coastal and Marine Resilience in the Caribbean. CANARI Issue Paper No. 2, Barataria, Trinidad: Caribbean Natural Resources Institute (CANARI).

Cashman A and Nagdee, M.R. (2017). Impacts of climate change on settlements and infrastructure in the coastal and marine environment of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card Science Review* 2017, pp. 155-173.

Climate Studies Group Mona (Eds.). 2020. "The State of the Caribbean Climate". Produced for the Caribbean Development Bank.

CMEP (2017). *Caribbean Marine Climate Change Report Card 2017*, (eds. P. Buckley, B. Townhill, U. Trotz, K. Nichols, P.A. Murray, C. Clarke-Samuels, A. Gordon, M. Taylor). Commonwealth Marine Economies Programme, 12 pp. Available on: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604876/Caribbean_Report_Card.pdf

CMEP (2021). *Climate Change Adaptation for Caribbean Fisheries*, (eds. B. Townhill, P. Buckley, P.A. Murray, K. Nichols and I. Monnereau). Commonwealth Marine Economies Programme, 12 pp. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/974010/Climate_Change_Adaptation_for_Caribbean_Fisheries.pdf

Cox, S.A, Oxenford, H. and Monnereau, I. (2020). Climate change and fisheries. FAO CC4FISH Policy Brief: May 2020, Issue 1, 4 pp. Available at: http://www.fao.org/3/cb1471en.pdf

Crabbe, M.J.C. (2008). Climate change, global warming and coral reefs: Modelling the effects of temperature. *Computational Biology and Chemistry*, 32, 311-314.

Defra (2012). *The Environment in the United Kingdom's Overseas Territories: UK Government and Civil Society Support*. Department for Environment, Food & Rural Affairs, Government of the United Kingdom

Department of Environment (DoE) (unpublished data). *Cayman Islands Long-term Coral Reef Monitoring Project*. Department of Environment, Cayman Islands Government.

ECLAC (2018). Irma and Maria by the numbers. *Focus Magazine of the Caribbean Development and cooperation Committee* (CDCC) January–March, 2018, Issue 1. Available at: https://www.cepal.org/en/publications/43446irma-and-maria-numbers

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, Alvarez-Filip L, et al. (2010) Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005. PLoS ONE 5(11): e13969. https://doi.org/10.1371/journal.pone.0013969Fanning, L., Mahon, R. and McConney, P. (2011). *Towards Marine Ecosystem-Based Management in the Wider Caribbean*. The Netherlands: Amsterdam University Press.

Eurosion (2004). Living with coastal erosion in Europe: Sediment and Space for Sustainability PART I - Major findings and Policy Recommendations of the EUROSION project. www.eurosion.org

Fardin, F., Andrews, M. and Phillips, T. (2018). *Summary Report: Institutional Assessments of Climate Change Adaptation Readiness in the Anguilla and Montserrat Fisheries Sectors*. Port of Spain: CANARI

FAO (2014). *Securing Fish for the Caribbean*. Subregional Office for the Caribbean Issue Brief #10, October 2014. Available at: http://www.fao.org/3/a-ax904e.pdf

FAO (2016). *Summary of the Recommendations of the Regional Technical Commissions*. FAO Regional Conference for Latin America and the Caribbean. Thirty-fourth Session. Mexico City (Mexico), 29 February–3 March 2016. Bridgetown, Barbados: FAO.

FAO (2017). Climate smart fisheries and aquaculture. In *Climate Smart Agriculture Sourcebook*. Available at: http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b4-fisheries/b4-overview/en/

Granderson, A., Ramkissoon, C., Jehu, A. and Phillips, T. (2018). *Report on the Assessment of Vulnerability to Climate Change in the Anguilla and Montserrat Fisheries Sectors*. Port of Spain. CANARI. 82p. Available at: https://canari.org/wp-content/uploads/2018/10/vulnerability-assessment-of-anguilla-montserrat-fisheries-sep2018.pdf

Government of Montserrat (2018). Climate change adaptation in the fisheries of Anguilla and Montserrat: Climate change adaptation of the fisheries sector in Montserrat, Institutional Assessment. *Contribution to the report on Climate Change adaptation in the fisheries of Anguilla and Montserrat*.

Government of the Virgin Islands (2019). *Climate Change*: The Virgin Islands Climate Change Trust Fund.

Hodge, K.V.D., Rhon, A.C. and George de Berdt, R. (2011). Transforming to a Climate-Resilient, Energy Efficient and Low Carbon Economy–Anguilla's Climate Change Policy Draft. Technical Report 5C/ECACC-11-01-1. CCCCC Digital Edition (2011). http://www.caribbeanclimate.bz

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C. *et al*. (2003). Climate change, human impacts and the resilience of coral reefs. *Science* **301**, 929-933.

IPCC (2014a). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds Core writing team, R.K. Pachauri and L.A. Meyer). Geneva, Switzerland: IPCC, 151 pp

IPCC (2014b). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. V.R, Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir *et al.*]. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press, p. 688.

IPCC (2020). Special Report on Climate Change and Land. Chapter-5_3 Climate Change and food security. Available at: https://www.ipcc.ch/srccl/chapter/chapter-5/

Knipp, A.L., Pettijohn, J.C., Jadot, C. and Hertler, H. (2020). Contrasting color loss and restoration in survivors of the 2014–2017 coral bleaching event in the Turks and Caicos Islands. *Springer Nature Applied Science*, 2, 331. https://doi.org/10.1007/s42452-020-2132-6

Lincoln, S. (2017). Impacts of Climate Change on Society in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS), *Caribbean Marine Climate Change Report Card: Science Review 2017*, pp. 115–123.

McField, M. (2017). Impacts of Climate Change on Coral in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS) *Caribbean Marine Climate Change Report Card Science Review 2017*, pp. 52–59.

McInnes, R. (2006). *Responding to the Risks from Climate Change in Coastal Zones – A good practice guide*. Centre for the Coastal Environment, Isle of Wight Council, 88 pp

Ministry of Natural Resources and Labour (2012). *The Virgin Islands Climate Change Adaptation Policy, Achieving Low-Carbon, Climate-Resilient Development.* Conservation and Fisheries Department, Ministry of Natural Resources and Labour, British Virgin Islands. 39p. Available at:

http://www.bvi.gov.vg/pub/Climate%20Change%20Policy%20Paper%20(Final).pdf

Monnereau, I. and Oxenford, H.A. (2017). Impacts of Climate Change on Fisheries in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review* 2017, pp. 124-154

Moore, R., Davis, G. (2015) Cliff instability and erosion management in England and Wales. *J Coast Conserv* **19,** 771–784. https://doi.org/10.1007/s11852-014-0359-3

Munday, P.L., Leis, J.M., Lough, J.M. *et al.* (2009) Climate change and coral reef connectivity. *Coral Reefs* **28,** 379–395. https://doi.org/10.1007/s00338-008-0461-9

National Climate Change Committee (2011). *Achieving a Low-Carbon Climate-Resilient Economy: Cayman Islands' Climate Change Policy*. *Available at: https://doe.ky/wp-content/uploads/2015/01/Executive-Summary-Cayman-Islands-Climate-Change-Policy-30-Sep-2011.pdf*

Nurse, Leonard A. (2011). The implications of global climate change for fisheries management in the Caribbean. Climate and Development. Climate and Development 3(3):228-241

Oxenford, H.A. and Monnereau, I. (2017). Impacts of Climate Change on Fish and Shellfish in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review* 2017, pp. 83-114.

PAHO/WHO (2016). Strategy for Technical Cooperation with the United Kingdom Overseas Territories (UKOTs) in the Caribbean, 2016-2022. Available from https://www.paho.org/en/file/50169

Spalding M.D., Ruffo, S. Lacambra, C. Meliane, I. Hale, L.Z. Shepard C.C. and Beck, M.W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management,* 90, 50-57.

Townhill, B.L., Birchenough, S.N.R., Engelhard, G.H., Harrod, O., McHarg, E., Monnereau, I., and Buckley, P.J. (2021) Responding to climate change in fisheries and aquaculture through adaptation, pp 1-57. Available at: https://www.gov.uk/government/publications/commonwealth-marine-economies-cme-programme

UK Government (2012). The Environment in the United Kingdom Overseas Territories: UK Government and Civil Society Support. Available at http://www.DEFRA.gov.uk/publications. PB 13686

UK Overseas Territories Conservation Forum (UKOTCF) (2020). Written evidence submitted by the UKOTCF. AGG0008. UK Parliament. https://committees.parliament.uk/writtenevidence/16752/pdf/

UNEP (2017). Coral Bleaching Futures - Downscaled projections of bleaching conditions for the world's coral reefs, implications of climate policy and management responses. United Nations Environment Programme, Nairobi, Kenya. https://wedocs.unep.org/bitstream/handle/20.500.11822/22048/Coral_Bleaching_Futures.pdf?sequence=1&isAllowed=y

UNESCO (2003). Wise Practices for coping with Beach Erosion. Anguilla. Department of Fisheries and Marine Resources, Department of Physical Planning, University of

Puerto Rico, Sea Grant College Program, Caribbean Development Bank, UNESCO Environment and Development in Coastal Regional and in Small Islands. SC-2003/WS/63. www.unesco.org/csi/act/cosalc/brochang.htm

Waite, R., Burke, L., Gray, E., van Beukering, P., Brander, L., Mackenzie, E., Pendleton, L., Schuhmann, P. and Tompkins, E.L. (2014) *Coastal capital: ecosystem valuation for decision making in the Caribbean*. World Resources Institute 78pp.

Waterhouse, L., Heppell, S. A. Pattengill-Semmens, C.V. McCoy, C. Bush, P. Johnson, B.C. and Semmens, B.X. (2020). Recovery of critically endangered Nassau grouper (*Epinephelus striatus*) in the Cayman Islands following targeted conservation actions. *Proceedings of the National Academy of Science of the United States of America* (*PNAS*), 117 (3) 1587-1595. Available at: https://www.pnas.org/content/117/3/1587?iss=3

Waterhouse, L, Candelmo, A. Stock, B.C., Stewart, J.D., Heppell, S.A., Pattengill-Semmens, C.V., McCoy, C.M., Johnson, B.C. and Semmens, B.X. (*in prep*). Fertilization and Survival Rates of Nassau Grouper (*Epinephelus striatus*) and Tiger Grouper (*Mycteroperca tigris*) Offspring: investigating temperature effects.

The World Bank Group (2021). Data. Countries and Economies. www.worldbank.org