Research for Action on Climate Change and Health in the Caribbean:
A Public, Private, People's and Planetary Agenda

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14. MARINE RESOURCES AND HEALTH

14.1. WHAT IS HAPPENING?

The ocean is of vital importance to the health of humanity, and especially to people of the Caribbean, 70% of whom live along coastlines (Gordon-Strachan, 2021; Headley, 2021). The composition and activity of the other components of the Earth system – atmosphere, geosphere, biosphere, cryosphere – are all influenced by the state of the ocean. Evolution and development have proceeded based on oceanic regularity. Climate change is disrupting regular and familiar patterns, with dire consequences for human health and the ecosystems on which health is built (Taylor, 2021). In this chapter, we outline ecosystem services and resources provided by the ocean, highlighting how they mitigate climate change and contribute to health and economic development. We then provide examples of how marine ecological disruption associated with climate change is affecting the conditions for health, and how coastal communities and economies are affected.

Ecosystem services and resources provided by oceans

The ocean covers 71% of the earth's surface, and 97% of the water on the planet is in the ocean (CARPHA, 2018; National Geographic, 2023). It is a complex ecosystem that provides services that are essential to sustain life on Earth. More than 25% of the carbon dioxide (CO_2) emitted into the atmosphere each year as a result of human activity is absorbed by the ocean, and the ocean is also the world's largest net supplier of oxygen. The ocean has been called the planet's main lung (Ocean and Climate Platform, 2022). As a vast "carbon sink", it naturally tends to mitigate the impact of CO_2 emissions on the climate. Coastal plants that surround parts of Caribbean coastlines – mangroves, plants living in salt marshes and seagrasses – store additional large quantities of carbon and protect coastlines from damaging waves (Mycoo et al., 2022; Storlazzi et al., 2021).

The ocean also stores most excess heat due to rising atmospheric greenhouse gas concentrations and provides breeze, making small tropical islands cooler than larger land masses in the tropics (Dubrow, 2021). Thus, the ocean provides a measure of protection from heat-related illness associated with climate change in Caribbean Small Island Developing States (SIDS). Sea bathing provides additional welcome relief from heat on hot days in the Caribbean.

Coral reefs have been referred to as "the rainforests of the sea". Ecosystems of unparalleled biodiversity, they cover less than 1% of the sea floor but are home to over 25% of all marine species. Sea creatures living around coral reefs are a primary source of protein for people in SIDS, and reefs provide a nursery habitat for many commercial species (Storlazzi et al., 2021). Animals living on coral reefs create unique chemicals that are not found on land. These chemicals are used to make important medicines and food supplements (Cousteau, n.d.). Coral reefs are also a major source of attraction for divers and tourists and provide mental health benefits through their beauty. The white and pink sandy beaches that attract tourists to some Caribbean SIDS are mostly composed of coral fragments. Ecosystem services provided by coral reefs are critical to economic livelihoods, well-being and health in SIDS (Storlazzi et al., 2021).

Coral reefs also play a critical role in coastal protection. It has been estimated that they dissipate wave energy coming towards coastlines by around 97% and are therefore especially important in protecting coastal communities and infrastructure from the effect of storms. Degraded, unhealthy coral reefs offer less protection from wave run-off and flooding of coastal areas than healthy coral reefs, whose vertical structures provide "hydrodynamic roughness", forming multiple barriers to waves. Combined with sea level rise, damage to coral reefs constitutes a severe threat to coastlines. Critical infrastructure, agriculture, freshwater supplies and habitats are under threat when corals are damaged, with severe impacts on physical and mental health (Dubrow, 2021; Storlazzi et al., 2021).

Seafood is an important part of a healthy diet. Fish are a major source of protein, and provide valuable dietary components including polyunsaturated fatty acids, iodine, selenium, tocopherols and vitamins A, B, D and K. Consumption of fish has beneficial effects on blood pressure, lipid profile and the inflammatory process. Fish consumption can assist in preventing noncommunicable diseases (NCDs), including cardiovascular diseases, cancer and diabetes (Headley, 2021).

Oceans are important in providing potential alternative sources of energy, contributing to climate change mitigation and improved air quality. Oceanic alternatives to fossil fuel use include offshore wind energy, floating solar energy, sea water air conditioning, ocean thermal energy conversion, tidal energy, wave energy, salt gradient energy and bioenergy (Allen et al., forthcoming; Giebel and Hasager, 2016; Gorjian, 2017). The Caribbean Community (CARICOM) has set a regional target of 47% renewable contribution to total electricity generation by 2027, and ocean energy is at the forefront of CARICOM discussions. A focus on marine renewable energy frees up significant land area for other initiatives, including agriculture and thus enhanced food security (Allen et al., forthcoming; Smith et al., 2013).

Climate change, the ocean and Caribbean health

Disruptions to the oceanic environment caused by climate change are interfering with the services the ocean provides to human health. These disruptions have been accompanied by pollution and overexploitation of marine resources, progressively damaging marine ecosystems (Ocean and Climate Platform, 2022). For example, it has been estimated that more than 80% of untreated wastewater is released into the ocean. This damages marine life and human health and represents a lost opportunity for reuse of water resources, which themselves are increasingly scarce because of climate change (Dubrow, 2021). See Chapter 3, “Water, sanitation and hygiene”.

The major physical and biogeochemical oceanic changes arising from rising greenhouse gas emissions and climate change are ocean warming, ocean acidification (caused by CO_2 emissions), deoxygenation and sea level rise (Headley, 2021). These have disastrous consequences, including increased intensity of tropical storms/hurricanes, storm surges, species loss, reduction in biodiversity, coastal flooding and shoreline retreat (Dubrow, 2021). Inland and coastal flooding are worsened by sea level rise, since excess water backs up and takes longer to flow into the ocean.

An estimated 22 million people in the Caribbean live below 6 m elevation; these areas are threatened with inundation, some even with eventual submergence (Mycoo et al., 2022). With much of the population, infrastructure and economic assets of Caribbean SIDS located in the low-elevation coastal zone of below 10 m elevation, oceanic changes will affect most of the Caribbean population quite profoundly (CARPHA, 2018; Gordon-Strachan, 2021; Hassan, 2021; Mycoo et al., 2022; R4ACCHC, 2022a). For instance, it is estimated that the sea levels around Jamaica will, by 2100, have risen between 0.18 m and 1.4 m above current levels, depending on the level of future greenhouse gas emissions (Climate Studies Group, 2012). This will retard coastal development and contribute to population displacement from coastal settlements (Climate Studies Group Mona, 2012). Changes in wave dynamics superimposed on sea level rise are predicted to increase coastal flooding significantly.

Severe coral bleaching, together with declines in coral abundance, have already been observed in Caribbean SIDS. It is projected that, once the temperature rise compared with the pre-industrial period reaches 1.5 °C, 70–90% of reef-building corals will be lost globally across small islands, with this figure rising to 99% with warming of 2 °C or more (Mycoo et al., 2022). Saltwater intrusion from sea level rise compromises both agriculture and water security. Storms can devastate plant and animal agriculture and can also damage fishing boats, equipment and fish stocks (Dubrow, 2021). Table 1 shows how the varied geographical characteristics of Caribbean SIDS are likely to influence specific vulnerabilities.

Table 1: CARICOM member states' geographical vulnerabilities to oceanic climate change

Geophysical setting	Key climate change vulnerabilities	CARICOM members
Coastal plains below 10 m	• Flooding from storms • Inundation from SLR • Saltwater intrusion of ground water • Erosion with loss of mangroves	Belize, Guyana, Suriname
Low-lying islands	• Inundation from SLR • Flooding from storms • Saltwater intrusion of ground water • Erosion with SLR and storms	The Bahamas, Barbuda, the Grenadines
Volcanic island coasts	• Beach erosion from SLR and storms • Landslides (locally) • Localised flooding from storms	Dominica, Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent
Varied geophysical characteristics	• Localised erosion by SLR and storms • Localised inundation from SLR • Localised flooding from storms • Localised saltwater intrusion of ground water	Antigua, the Bahamas, Haiti, Jamaica and Trinidad and Tobago

Note: SLR, sea level rise.
Source: Simpson et al. (2010).

Coastal threats: fisheries, food security, tourism, coral reefs and biodiversity

Fisheries and tourism make major contributions to Caribbean economies, health and wellbeing, and are fundamentally threatened by climate change through its devastating impact on marine environments (Headley, 2021; Oxenford et al., 2021a).

Ocean warming and acidification damage ocean ecosystems and marine life, threatening the food security of island nations and the viability of the fishing industry. In 2018, 3.3% of the working population in member countries of the Caribbean Regional Fisheries Mechanism (CRFM)[1] were employed in the fisheries sector, in

[1]Member states of the CRFM are Anguilla, Antigua and Barbuda, the Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago and Turks and Caicos.

fishing, processing, retailing, boat construction, net repairs or other activities. Fisheries are an important source of export revenue as well as income from sales within the region (Headley, 2021).

Coral reefs and shellfish are especially at risk (Dubrow, 2021). New studies have reported large reductions in the populations of some marine species, and it is predicted that, if warming exceeds 3 °C, some endemic species in insular biodiversity hotspots will become extinct (Mycoo et al., 2022). One of the threats to biodiversity associated with climate change is the incursion of invasive species such as the lionfish, which eats endemic species and has no natural predators (Albins and Hixon, 2013; Green et al., 2012; Norton and Norton, 2021). Species distributions are predicted to shift, with suitable habitats for a range of species projected to decline across most of the Caribbean region, resulting in substantial local loss of species, decline in fisheries catch potential and change in catch composition. Loss and damage from tropical cyclones will exacerbate these challenges. The short time frame over which these impacts are projected to occur poses substantial challenges to adaptation. Caribbean nations are therefore projected to suffer losses in economic well-being and health due to a reduction in the production and consumption of seafood (Headley, 2021).

More than 25% of the world's coral reefs have already been damaged beyond repair. Global stressors include increases in temperature and ocean acidification. Local stressors include land-based pollution, overfishing and mechanical damage. According to the Reefs at Risk Indicator, many of the Caribbean reefs are at very high risk (Burke et al., 2011; World Resources Institute, 2022). Forecasted reef degradation and sea level rise exacerbate the risks of flooding associated with climate change, increasing threats to coastal communities (Storlazzi et al., 2021).

Caribbean reliance on tourism as a major contributor to gross domestic product also underscores the importance of the ocean and coastlines to Caribbean lives and livelihoods (Gordon-Strachan, 2021). Tourism is threatened by destruction caused by hurricanes, by beach erosion due to sea level rise (R4ACCHC, 2022b) and by the ocean ecosystem degradation caused by warming oceans, ocean acidification and harmful algal blooms. Increased ocean temperatures can lead to the seaweed *Sargassum* overgrowing along the shoreline and washing up on beaches, which is likely to have an adverse impact on tourism (R4ACCHC, 2022c). The perception that the Caribbean is unsafe due to increasing potential hazards (e.g. hurricanes, Saharan dust) could make the Caribbean a less attractive tourism destination than other areas (Dubrow, 2021). Yet some tourist establishments contribute to the challenges by polluting the sea water and depleting the resources of coral reefs in an uncontrolled manner (R4ACCHC, 2022d), and marine and other forms of transport associated with tourism continue to be highly reliant on fossil fuels. The adverse effects of climate change on the tourism industry in the Caribbean, and the resulting loss of revenue, could lead to anxiety, depression and other mental health conditions among those affected.

Consequences of marine ecological disruption: harmful algal blooms

The warming ocean and warming freshwater lakes, combined with phosphorus and nitrogen from agricultural run-off (aggravated by extreme precipitation events), increase the risk of harmful algal blooms.

Overgrowth of different species of microalgae can result in excess production of an array of phycotoxins with various effects on the liver, skin and kidney, as well as the gastrointestinal, neurological and respiratory systems. Fish, shellfish and drinking water can become contaminated with phycotoxins, which cause a variety of human diseases including ciguatera fish poisoning, neurotoxic shellfish poisoning, paralytic shellfish poisoning, amnesic shellfish poisoning, diarrhetic shellfish poisoning and azaspiracid shellfish poisoning. Ciguatera fish poisoning, caused by a toxin that is produced by *Gambierdiscus toxicus* (a dinoflagellate) and which bioaccumulates in the large carnivorous fish that inhabit coral reefs, such as barracuda, grouper and mackerel, is the most common. Ocean acidification favours dinoflagellates. Since 2005, ciguatera poisoning resulting from the consumption of contaminated fish has accounted for the second largest number of laboratory-confirmed foodborne disease cases in the Member States of the Caribbean Public Health Association (CARPHA), behind *Salmonella* (CARPHA, 2018; Dubrow, 2021; Gordon-Strachan, 2021).

Fuelled by climate change and ocean enrichment, a new source of *Sargassum* seaweed – a macroalga – began to grow in the Equatorial Atlantic in 2011, and since then vast "golden tides" of the seaweed have been carried to the Lesser Antilles by ocean currents (Sargassum Information Hub, 2021). As a result, Caribbean coastlines have, year after year, been affected by accumulations of *Sargassum* on the seashore (see Figure 1), with major socioeconomic impacts, and *Sargassum* blooms are now considered another form of climate change-related disaster. In some countries, visitor rates have declined by as much as 30%. Additional massive costs are associated with beach clean-ups and at-sea management. Furthermore, *Sargassum* seaweed has a considerable impact on the fishing industry and reduces fish catches: mats of the seaweed impede access to fish, clog boat propellers, damage boats and fishing gear, and force fisherfolk to travel longer distances (Dubrow, 2021). Marine environments have been severely disrupted, with *Sargassum* smothering sea grass and corals, raising water temperature, depleting oxygen and releasing toxic gases. The damage that climate change causes to corals and the sea life they support has been aggravated by the *Sargassum* crisis (Dubrow, 2021; Gordon-Strachan, 2021; Oxenford et al., 2021a).

Figure 1: *Sargassum* on a beach in Barbados

Source: Oxenford et al. (2021a).

When *Sargassum* is trapped in wet environments and decomposes, it releases hydrogen sulphide and ammonia (Dubrow, 2021). Common symptoms of exposure to these toxic gases are respiratory problems, vomiting, rashes, headaches, dizziness, temporary loss of vision and asthma attacks. Medical practitioners in the French Caribbean islands of Guadeloupe and Martinique reported over 11,000 cases of these symptoms arising from *Sargassum* exposure in 2018 (Oxenford et al., 2021a).

Another health challenge is that *Sargassum*, like all ground seaweeds, absorbs heavy metals and pesticides as it passes through the sea. Of special concern is arsenic, one of the most toxic heavy metals, which has been found in most of the samples of *Sargassum* tested in the Caribbean in recent years. This poses significant concerns about potential poisoning, arising via several pathways (Oxenford et al., 2021b):

- Direct consumption of *Sargassum*-based products;
- Consumption of food products containing arsenic if *Sargassum* is used as fertiliser or animal feed;
- Consumption of fish and shellfish that have accumulated toxic leachates released into the nearshore;

- Direct exposure to toxic leachates that have entered the environment as a result of the use of inappropriate disposal methods.

The presence of *Sargassum* in the nearshore also presents a hazard to sea bathers: it may harbour stinging hydroids, which can inflict painful injuries, and it can make it difficult to swim, creating a risk of drowning (Oxenford et al., 2021a).

Research

The University of the West Indies (UWI) has facilities dedicated to marine research and teaching. The Centre for Marine Sciences at the Mona, Jamaica, campus has marine laboratories and conducts marine biological research, ecosystem studies, pollution monitoring and mitigation and coastline management studies. At the Centre for Resource Management and Environmental Studies at the Cave Hill Campus, there is a Coastal and Marine Resources Management team, which has conducted several research projects on climate changes impacts on reefs, fisheries and the *Sargassum* crisis. These institutions have increasingly explored the implications for health of damage to marine ecosystems associated with climate change.

Other institutions and projects focus mainly on the social and economic costs of oceanic changes and on enhancing the well-being of coastal communities. Their work, while not specifically addressing health outcomes and health systems strengthening, assists in understanding critical socioeconomic impacts of changes in the marine environment (see Box 1).

Box 1: Projects analysing the social and economic impacts for Caribbean people of changes in ocean environments associated with climate

As part of the Caribbean Regional Track of the Pilot Programme for Climate Resilience (PPCR), the Caribbean Regional Fisheries Mechanisms and the Mona Office for Research and Innovation have collaborated to conduct assessments of the impacts of climate change on fisheries. They have also worked to develop a monitoring system to track these impacts. Between January 2018 and April 2020, they worked with stakeholders in Dominica, Grenada, Haiti, Jamaica, Saint Lucia and Saint Vincent and the Grenadines to conduct the assessments. Impacts on the number and distribution of species were assessed. Economic assessments looked at impacts on communities and effects along the fisheries value chain. A data portal and a monitoring and evaluation framework were established, with adaptation planning guidance to assist in the response. Results were fed into a Fisheries Early Warning and Emergency Response (FEWER) system, which included access to information on fisheries-related threats and sources of support accessible on a web-based dashboard and via mobile phone. A poster series, educational slide deck and documentary video were developed to inform fisherfolk. Among other things, FEWER provides access to local ecological knowledge, weather alerts, emergency contacts and procedures, damage reporting and notifications of missing persons. These serve to reduce fishers' vulnerability and inform management decision-making (Headley, 2021).

The Climate Change Adaptation of the Eastern Caribbean Fisheries Sector Project (CC4FISH) of the Food and Agriculture Organization of the United Nations is a USD 5.5 million project in seven Eastern Caribbean countries with five regional partners. The project covers improving the fisheries sector, capacity building of fisherfolk, aquaculture and fisherfolk organisations, mainstreaming of climate change into fisheries plans, policies and legislation, and post-disaster needs assessments of the fisheries sector. The Centre for Marine Sciences, UWI, carries out studies of Caribbean marine environments, without an explicit health focus. Several Caribbean governments have established units responsible for coastal zone management (Allen, 2021; CARPHA, 2018).

The US Geological Service uses a combination of oceanographic, coastal engineering, ecological, geospatial, social and economic models in an **estimated damage function** to assess how coral reef degradation will impact coastal communities. There are three main components:

- Offshore hazards – waves and how they come to the shoreline;
- Ecosystem – how reefs, in current and predicted future scenarios, affect levels of flooding;
- Consequences – impacts on people, built infrastructure and associated costs.

The estimated damage function has been applied in the United States of America to estimate the numbers of people in different geographic areas who will be affected under predicted scenarios of damage to coral reefs arising from climate change, and the associated economic value of damage to public and private property and infrastructure. It was found that the numbers of people in vulnerable communities at risk (children, the elderly and low-income and minority people) are especially high in the United States island territories in the Caribbean (Puerto Rico and the United States Virgin Islands), as are the estimated values of damage to residential commercial, industrial, government and agricultural property and infrastructure. It was concluded that coastal communities in SIDS are at relatively high risk of increased flooding resulting from projected coral reef degradation due to climate change, especially the young, the old and those on low incomes or from minority groups (Storlazzi et al., 2021).

14.2. WHAT SHOULD BE DONE?

Individual and community actions and how to support them

Collaborate to protect marine and coastal environments

Education of the general population and coastal communities about the importance of marine conservation is needed to assist in motivating individual and community action. Local universities and other educational establishments can play important roles in providing the expertise and raising awareness. A wide range of communication and outreach methods may be needed (R4ACCHC, 2023). Chapter 13, "Awareness and skills-building", provides details of strategies that may be used, and Chapter 9, "Distribution, equity and justice in climate change and health", provides details of ways in which the resilience of vulnerable communities can be built in collaboration with these communities.

Stakeholders who are affected by damage to coastlines and reefs should come together with experts to develop solutions. For instance, to facilitate the protection of reefs and coastlines, affected communities, such as coastal residents, schoolchildren, fisherfolk, hotel owners and water sports operators, can collaborate with medical and other experts, such as professional divers, marine biologists, oceanographers and coastal zone management experts, to develop plans to protect ecosystems and reduce damage (Storlazzi et al., 2021).

Solutions include simple actions such as beach clean-ups (already popular among schools and community groups in the Caribbean) as well as strategies that require longer-term commitment and enforcement. These include strategies to reduce pollution flowing into the sea from both households and industry, including tourism and agriculture. Solid and liquid waste management should be a focus of particular concern (R4ACCHC, 2023). Government agencies need to be involved in supporting and enforcing the longer-term solutions and to collaborate with communities (Gordon-Strachan, 2021). These types of action do not themselves mitigate climate change, but they do reduce additional sources of damage to marine ecosystems and the coastal protection and resources they provide. Community involvement, however minor, can assist in increasing activism and participation in the larger struggles to protect marine environments and reduce the damaging effects of climate change on health.

Involve communities in developing strategies to mitigate climate change impacts on marine environments

Individuals and communities can contribute in small but important ways to mitigation by reducing fossil fuel use and choosing transport solutions with zero or reduced emissions, such as cycling and use of electric and hybrid vehicles. Although active transport methods, such as cycling or walking, have health co-benefits, it may be challenging to implement these methods on a mass scale, as exercising in conditions of high temperature, which already prevail, can cause heat-related illness. The use of low-carbon forms of energy for air and sea transport should also be supported. Planting and maintaining mangroves and seagrass around coastlines and increasing the number of plants and trees on land is another solution to increase absorption of emitted CO_2. Mangroves and seagrass can also help to mitigate effects of coastal storms and flooding.

To encourage individual and community action, children and adult communities should be educated about the gravity of the impacts of climate change on oceanic environments and therefore on Caribbean health (Ocean and Climate Platform, 2022; R4ACCHC, 2023). Campaigns should be conducted to increase popular support for mitigation action, also including sustainable oceanic energy development (Allen et al., forthcoming).

Involve communities in oceanic disaster preparedness strategies, including simulation exercises

Coastal protection is an important aspect of disaster prevention. It is increasingly important that measures to protect the coast be accompanied by preparedness activities to enable communities to prevent and respond to destruction of property, injury, illness and death resulting from massive waves and flooding from hurricanes and sea level rise (Harewood, 2021). It is important to focus especially on disadvantaged coastal communities such as people on low incomes and ethnic minorities with poor housing. Capacity-building among healthcare workers is an important complementary and supportive activity. Box 2 provides an example from the Caribbean coast of Nicaragua of how academic institutions collaborated with coastal populations to conduct disaster simulations and ensure access to health care (Mitchell et al., 2021).

Box 2: Collaboration between disadvantaged coastal communities and academic institutions to improve disaster preparedness and climate resilience on the Caribbean coast of Nicaragua

The Caribbean coast of Nicaragua is populated by several ethnic minority populations and is vulnerable to the impacts of climate change, especially hurricanes and flooding. Most economic activities are marine based.

The Bluefields Indian and Caribbean University (the only school of nursing on the Caribbean coast of Nicaragua) and the University of Virginia School of Nursing worked to develop faculty and student capacity for disaster preparedness specific to the health impacts of climate change. Through iterative case study development, faculty members in Nicaragua and in the United States of America collaboratively created simulations aimed at increasing student knowledge and community preparedness.

Beginning with case studies of historical natural disasters (Hurricane Joan in 1988, Hurricane Mitch in 1998, etc.), the academic team worked with local leaders to support and facilitate the integration of trained nurses into the disaster response team. They also developed locally responsive collaborations to build capacity in the coastal communities through (1) a series of workshops for 60 young Afro-descendant leaders on sexual and reproductive health, incorporating models of empowerment and history of the Caribbean coast; and (2) a community-based capacity-building response to climate change programme focused on the experiences and empowerment of Afro-descendant youth in the context of ongoing political autonomy initiatives. Simulations provided hands-on experiences for nurses and showed them how they would help community members during a disaster. The simulations were iteratively adapted to become more appropriate to local scenarios.

The collaborations strengthened the capacity of health systems, and the resilience and preparedness of professionals and laypersons, to respond to both the immediate and delayed consequences of climate change for coastal communities. The team concluded that the role of nurses is especially important in these systems.

Source: Mitchell et al. (2021).

Structural/governmental and private sector actions

Advocate at global and regional level for resources and measures to protect SIDS' marine environments and support implementation

Protection of marine resources in SIDS is an important dimension of global climate justice. The marine environments surrounding SIDS are profoundly affected by greenhouse gas emissions, the vast majority of which are from outside SIDS themselves. The impacts are compounded by various forms of pollution that are often beyond the control of Caribbean people. Politicians and civil society activists should draw attention to marine-related impacts on health and development. For example, they should highlight the commitment of countries who are major emitters and polluters to numerous global environmental conventions, including agreements pertinent to marine environments (R4ACCHC, 2023). These include:

UN environment agreements

- Convention on Biological Diversity;
- Convention on Migratory Species;
- Ramsar Convention on Wetlands;
- Convention on International Trade in Endangered Species;
- Stockholm Convention on Chemicals Management;
- Basel Convention on Hazardous Waste.

International Maritime Organization agreements

- International Convention for the Prevention of Pollution from ships (MARPOL);
- Ballast Water Convention;
- London Convention.

Global agreements and commitments

- Agenda 21;
- Barbados Small Island Developing States (SIDS) Programme of Action;
- Johannesburg Plan of Implementation;
- Rio+20;
- Samoa Outcome for Small Island Developing States;
- Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities;
- The United Nations Sustainable Development Goals (SDGs), especially SGD 14: "Life Below Water".

Caribbean leaders should also become involved in the Sustainable Oceans Initiative, which is associated with the Convention on Biological Diversity (Sustainable Ocean Initiative [www.cbd.int/soi]).

In 1986, Caribbean governments signed the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, or the Cartagena Convention, the first and only regional legally binding treaty of its kind. This treaty promotes the protection and development of the marine environment of the region and provides the legal framework for the Caribbean Environment Programme. It is supported by three technical agreements or protocols, on oil spills, specially protected areas and land-based sources of marine pollution. Implementation of the convention is supported by regional activity centres in Cuba, Curacao, Guadeloupe and Trinidad and Tobago. Governments should continue to uphold and support the implementation of the convention (Caribbean Environment Programme, n.d.).

The convention should also be collectively reviewed and updated at the regional level in view of the accelerating impact of climate change since it was first signed. Currently, its focus is largely limited to pollution. Contracting parties to the convention are also required to protect and preserve rare or fragile ecosystems and the habitats of depleted, threatened or endangered species. They must also develop technical and other guidelines for planning and carrying out environmental impact assessments for important development projects. The focus of legislation and activity should shift towards protection and preservation of biodiversity in the context of climate change, and addressing the causes and impact of threats such as hurricanes of increased intensity, storm surges, ocean acidification, sea level rise, sea surface temperature rise, coastal erosion, invasive species, and harmful algal blooms. It is especially critical to address issues of ocean governance in the context of development of blue economy initiatives,[2] which may be harmful unless environmental standards are imposed (R4ACCHC, 2023).

Laws against pollution of the ocean, to guard against the infringement of marine protected areas and to prevent overfishing must be put in place and enforced. To support this, the seriousness of the threat to human health and well-being posed by damage to marine environments must be communicated and included in the training and appraisal procedures for law enforcement agents. Action against those who violate these laws must be taken without fear or favour.

Address mental health impacts of damage to marine environments

People in SIDS, and especially those living along coastlines, are profoundly affected emotionally as well as physically by their oceanic environments. The ocean also has spiritual significance for some people (Gibson et al., 2020; Tiatia-Seath et al., 2018). Awareness of the impact of damage to marine environments should be addressed in training of mental health professionals and skills-building for community-based counsellors. Faith leaders should also be engaged in dialogue so that they understand and can respond to marine environmental issues with their congregations (R4ACCHC, 2023) (see Chapter 7, "Mental health", and Chapter 13, "Awareness and skills-building").

Engage in management of terrestrial, coastal and marine ecosystems

In SIDS, terrestrial, coastal and marine ecosystems are highly interconnected and interdependent, with each ecosystem contributing towards maintaining the health of the others. These ecosystems collectively provide protection from natural hazards to human populations living in SIDS. Reef-to-ridge ecosystem management involves improved land use as a driver of ecosystem health, including better management of forests, nutrients and wastewater upland catchments (Mycoo et al., 2022). Adaptation and mitigation actions by governments, civil society and the private sector can protect and restore ecosystems, with benefits for health. Table 2 provides examples of actions that can be taken in each type of ecosystem, with benefits for all three ecosystems and for human health.

[2]The blue economy is defined as comprising the range of economic sectors and related policies that together determine whether the use of oceanic resources is sustainable (World Bank, 2017).

Table 2: Examples of ecological and health benefits of ecosystem adaptation and mitigation actions in SIDS

Type of ecosystem	Mitigation or adaptation action	Ecological benefits	Human health benefits
Terrestrial	Reforestation and planting of plants and trees, including on coastlines and beaches	• Reduction in erosion and landslides • Reduction in ocean run-off of pollutants • Preservation of biodiversity • Increased absorption of CO_2	• Reduction in infrastructure and building damage, injuries and deaths, including in coastal communities • Protection of coastal communities and food security through retention of biodiversity and coral reefs • Protection of food and water security through stabilisation of air, soil and water quality • Slowing of climate change impacts on health
	Reduction in the use of the ocean to deposit organic and inorganic waste	• Reduction in toxic algal blooms • Reduction in the global proliferation of *Sargassum* seaweed • Preservation of marine species • Protection of coral reefs and their ecosystems	• Reduction in poisoning from contaminated fish • Reduction in the risk of toxic fumes from rotting seaweed and arsenic poisoning from the unsafe use of *Sargassum* products • Protection of the livelihoods of those working in fishing and tourism • Protection of coastal communities and food security through retention of biodiversity and coral reefs • Preservation of opportunities to develop pharmaceutical and other products
Coastal	Mangrove, seagrass and beach vegetation planting	• Increased CO_2 absorption • Protection of coastlines	• Slowing of climate change impacts on health • Protection of coastal communities and food security through retention of biodiversity and coral reefs
Marine	Marine Protected Areas	• Reduces ecosystem exposure to human disturbance, increasing their resistance and resilience to climate events	• Protection of coastal communities and food security through retention of biodiversity and coral reefs • Enhances food security and assists sustainability of the fishing industry through replenishment of fish stocks

Sources: adapted from Headley (2021), Mycoo et al. (2022), Oxenford et al. (2021a) and Storlazzi et al. (2021).

Manage the consequences of sea level rise on human settlements and displacement

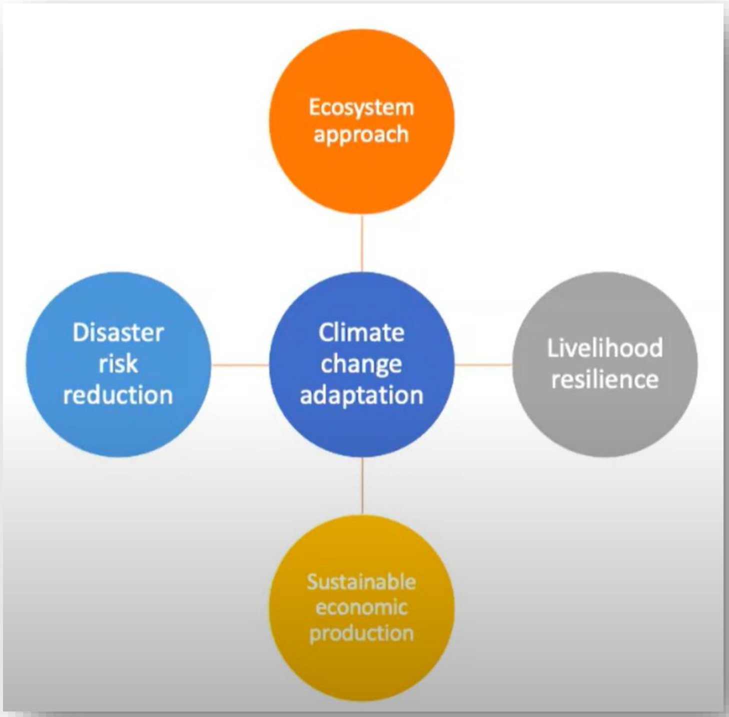
Caribbean coastal communities are under severe threat from sea level rise, with massive potential damage to housing, infrastructure, economic livelihoods, and physical and mental health. Without careful management, potential consequences include climate-induced displacement, migration and depopulation of Caribbean countries. *In situ* adaptation options include further coastal protection measures such as mangrove planting, ever-higher hard barriers such as sea walls and raising dwellings (e.g. on stilts). In the medium and longer term within countries, relocation inland or to other islands is likely to be necessary. Without management, this is likely to favour people with more resources to enable relocation, leaving poorer and marginalised communities to suffer more of the consequences of sea level rise. Governments can help support the relocation of households, with a focus on vulnerable populations. Wholesale relocation of communities is likely to be too expensive for Caribbean governments and will require some external support (Mycoo et al., 2022).

Climate-induced displacement and migration are likely outcomes of sea level rise. Options for management of these movements and for health systems responses are presented in Chapter 8, "Population displacement and migration".

Implement sustainable and resilient fisheries strategies

Adaptation to climate change must be undertaken within the multifaceted context of fisheries. Relatedly, measures or actions to address climate change should complement overall governance for sustainable use of fisheries resources. Figure 2 shows various elements of climate change adaptation in fisheries. The ecosystem approach is integrated across coastal and marine areas and promotes conservation and the sustainable use of the ecosystem. Examples include the use of Marine Protected Areas, regulation and enforcement of regulations on fishing specific species and sizes of fish, coral reef conservation and selective breeding of fish and shellfish. Building livelihood resilience means addressing the human, physical, social and financial risks arising from both short-term events and long-term climate change. For example, climate change can alter fish stock distribution, while hurricanes can damage boats, equipment and other infrastructure necessary for fisheries. Sustainable economic production involves optimising fishing effort and improving fisheries management. Disaster risk reduction means adaptation to improve the sustainability of fisheries as part of food systems in the face of disasters, including severe weather events and oceanic events such as massive coastal incursions of *Sargassum* seaweed (Headley, 2021).

Figure 2: Elements of climate change adaptation in fisheries



Source: Caribbean Regional Fisheries Mechanism.

Assist in the transition to alternative livelihoods of people in traditional ocean-based occupations

As climate change advances, fisherfolk and others dependent for their livelihoods on the ocean will need to be provided with new skills and possibly helped to transition to alternative ways of making a living. Skills-building should include them in various aspects of marine conservation and development of the "blue economy", reaping benefits from the use and promotion of oceanic resources in sustainable ways. It may also be necessary to help some of those affected to transition to land-based occupations (R4ACCHC, 2023).

Act to reduce destruction of Caribbean reefs

Coral reefs must be preserved if the multiple services they provide are to be protected from further destruction. Although overall responsibility for climate change-related destruction lies with global producers of greenhouse gases, Caribbean governments and the private sector have critical roles to play. Risks to key economic sectors (tourism, fisheries), to biodiversity and to coastal communities must be reduced by focused attention on reef conservation (Storlazzi et al., 2021). Useful initiatives would include those aimed at the reduction of waste disposal and agricultural fertiliser run-off into the sea, the creation of Marine Protected Areas, the removal of *Sargassum* seaweed and the enforcement of regulations to prevent damage by overfishing, fishing boats, tourist vessels and commercial divers, as well as schemes to reproduce corals under laboratory conditions, to repopulate depleted reefs and to establish new coral colonies. Shifting to renewable marine and other energy sources helps make a macro-level contribution to coral reef conservation.

Research gaps and how to address them

Critically examine the legal framework on ocean conservation

Legal experts should critically examine the regional and international agreements and legislation in the light of the current and evolving threats from climate change. They should identify what regional treaties and agreements need to be developed and which existing ones need to be amended to identify and support the actions needed. Specific identification of relevant clauses is necessary for strategic enforcement (R4ACCHC, 2023).

Conduct research on opportunities for sustainable development of the blue economy

Research should be conducted with communities and government and private sector agencies on the potential for economic development based on alternative and sustainable use of the ocean environment. The level of understanding of the concept of the "blue economy" should be explored, along with ideas from stakeholders regarding how they can be involved in developing and implementing projects and entrepreneurship in environmentally sustainable ways with a view to conserving ocean environments. Technical experts on sustainable practices should be involved in this research and developing recommendations (R4ACCHC, 2023).

Conduct research on repurposing Sargassum

Attention is being paid by researchers and the private sector across the Caribbean regarding how to use the *Sargassum* crisis for the region's economic and social benefit as part of blue economy initiatives. Some of the options could directly benefit human health. The biosorption properties of living *Sargassum* can be used to clean contaminants from polluted water. *Sargassum* can be converted to activated carbon, which can be used in water and air purification systems. *Sargassum* also contains bioactive compounds with benefits for human health, including compounds with antiviral, anti-cancer and antioxidant properties (Dubrow, 2021; Oxenford et al., 2021a,b).

There is also potential for *Sargassum* to contribute to climate change mitigation, as it can be used in the manufacture of carbon-neutral biofuels and bioplastics. It can contribute to mitigation by carbon sequestration when it sinks to the ocean floor or is used on land in the form of activated carbon. Further research could identify opportunities for businesses in the region to develop and market new products, increasing economic livelihoods and thus mental well-being (Oxenford et al., 2021a).

Key challenges must be addressed to enable such research and associated economic and social benefits (Oxenford et al., 2021b):

- Better forecasting of *Sargassum* supply is needed.
- The chemical composition of *Sargassum* must be better understood, focusing on its arsenic content.
- Equipment must be improved and expanded for adequate harvesting, transport and storage.
- Safety standards should be developed to regulate *Sargassum* use.
- More funding and greater support for innovation are needed.

There are roles for research in addressing these challenges. For instance, meteorological and oceanographic researchers can contribute to better forecasting and development of *Sargassum* early warning systems.

Conduct research on responses of marine ecosystems to climate change

Food and water security, and security of other marine resources such as components of pharmaceuticals, are affected by marine ecosystem damage resulting from climate change. Research must be conducted to establish and monitor key ecosystem changes, including the effect of changes in ocean temperature, salinity and acidity on marine life, and differential effects of ocean warming and acidification on stocks and movement of various commercially important fish species by geographical area (Dubrow, 2021).

Conduct research to preserve marine food security and quality

The health benefits of eating fish and other seafood of various kinds available in the Caribbean context of climate change should be assessed. It is important to consider the health benefits by age group. Research should also be conducted into the feasibility and value of using aquaculture to counteract the loss of natural fisheries. Research is important to develop innovative fish products with improved nutritional value. The results can form the basis of nutrition-sensitive fisheries policies and nutrition education and awareness programmes (Dubrow, 2021).

Surveillance gaps and how to address them

Monitor key oceanic climate change drivers of ill-health and their consequences

Ocean warming, acidification, decreasing salinity, deoxygenation and rising sea levels must be continually monitored for the sake of the health of the ocean and Caribbean populations. The disastrous consequences of these climate-change-driven changes to the ocean, including increased intensity of tropical storms/hurricanes and storm surges, fish species loss, reduction in biodiversity, coastal flooding and shoreline retreat, should be monitored as well (Headley, 2021; Taylor, 2021). The health of coral reefs also should be monitored, and early warning systems for coral bleaching events developed (R4ACCHC, 2023).

Monitor the status of fisheries and marine ecosystems

To bolster sustainable fisheries strategies, data must be generated and monitoring systems established on the status of Caribbean fish stocks, marine ecosystems and the economic status of fisheries. Suitable approaches are exemplified by the joint project of the Caribbean Regional Track of the PPCR, the Caribbean Regional Fisheries Mechanisms and the Mona Office for Research and Innovation. These organisations together developed a monitoring system and collaborated with local communities to track the number and distribution of species and conducted economic assessments looking at impacts on communities and effects along the fisheries value chain. A data portal and a monitoring and evaluation framework were established.

Surveillance data can be used in early warning systems, such as the FEWER system under the same project, which included access to information on fisheries-related threats and sources of support accessible on a web-based dashboard and via mobile phone. The results can be presented to a variety of audiences, and using a range of communications products, to inform decision-making (see Box 1 in Section 14.1, “What is happening?”).

Monitor harmful algal blooms

Research is needed to track harmful microalgal blooms, as well as *Sargassum* seaweed infestations, over time and space and to identify their climate and other determinants. Such research could inform harmful algal bloom and *Sargassum* seaweed early warning systems that ultimately could facilitate prevention microalgal bloom and prevention of *Sargassum* infestation occurrences (Dubrow, 2021; R4ACCHC, 2023).

Research and surveillance capacity-strengthening needs

A number of institutions in the Caribbean conduct research on and surveillance of oceanic environments and how they are impacted by climate change. These include several departments within the University of the West Indies, notably the Climate Studies Group, the Centre for Marine Sciences, the Centre for Resource Management and Environmental Studies and the Caribbean Institute for Meteorology and Hydrology, as well as other CARICOM institutions, such as the Caribbean Regional Fisheries Mechanism. The Instituto de Meteorología de la Republica de Cuba has compiled Caribbean data on sea level rise and sea surface temperatures (Climate

Studies Group Mona (editor), 2020), and has conducted important climate and health research (Linares-Vega and Ortiz-Bulto, 2021; Linares-Vega et al., 2020; Ortiz, 2021; Ortiz et al., 2015), although it is not clear whether this has included research into the connections between oceanic climate change phenomena and health. The Food and Agriculture Organization of the United Nations (FAO) has an ongoing project on Climate Change Adaptation in the Eastern Caribbean Fisheries Sector, which has included capacity-building in fisheries statistics, damage and loss assessment and vulnerability and capacity assessment (FAO, 2020).

Institutions with research capacity should collaborate with technical agencies concerned with ocean conservation and health, such as (R4ACCHC, 2023):

- The Institute of Marine Affairs, which is the only multidisciplinary coastal, marine and environmental organisation in the CARICOM region, and whose mandate is to collect, analyse and disseminate information relating to the economic, technological, environmental, social and legal developments in marine affairs and to formulate and implement specific programmes/projects;
- The Commonwealth Secretariat, which is in the process of developing strategic approaches to deal with ocean governance and the blue economy;
- Global organisations such as the United Nations Environment Programme (UNEP) and the United States National Oceanic and Atmospheric Administration;
- The UNEP Caribbean Regional Coordinating Unit and the secretariat to the Cartagena Convention and its protocols;
- The European Union–CARIFORUM Climate Change and Health Project;
- The Caribbean Public Health Agency;
- The Pan American Health Organization/World Health Organization.

Some of these institutions have begun to explore, but should deepen their focus on, the health outcomes of ocean-related climate change and research on suitable mitigation and adaptation strategies to strengthen marine ecosystems/resources and the resilience of coastal communities. More human resources and equipment for marine biology, oceanography, remote sensing and coastal resource management research are needed (R4ACCHC, 2023). Medical and nursing research must be conducted on health risks associated with marine environmental damage and how to treat associated health conditions. To build these resources, and especially to obtain the equipment needed for marine research, collaboration with external academic institutions and sponsors will be necessary.

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