Climate Change and Caribbean Coral Reefs

***

Anastasia, a student at the University of Toronto, St. George, is pursuing a Bachelor of Science Double Major in Physics and Caribbean Studies and a Minor in Mathematics. She is a pianist, plays the guitar and steelpan and spends her free time arranging music. Her love for soca music and steelpan in no way takes away from her passion for classical piano and physics. As a person of the Trinidadian Diaspora with many interests, Ana has decided to look at the Caribbean from a different perspective by combining her love for science and the region.

THIS PAPER IS A SYNOPSIS OF THE ORIGINAL

***

Introduction

This paper explores the extent to which climate change is affecting the Caribbean region. In the first part, the importance of coral reefs to the Caribbean will be shown. In the second part, the sensitivity of coral reefs to environmental changes will be examined. Since human activity plays a major role in climate change, the third part will explore several anthropogenic (manmade) forces that affect climate change, with spin off effects that threaten the existence of coral reefs and beaches in the region. The paper concludes with suggested strategies and policies to counteract the effects of climate change in the Caribbean.

Along with its remarkable history and exciting topography, the Caribbean has a complicated political flavour which adds to recent challenges of climate change. Studies provide evidence of dramatic world weather patterns, with temperatures reaching all-time lows, irregular rain fall, hotter summers and terrifying hurricane seasons which appear to be worsening. These changes in climate are directly affecting the Caribbean region. The region's economy, largely dependent on "sun, sea and sand" is gradually being destroyed. More importantly, the livelihood of many who survive on tourism and fishing is being dramatically affected. Increasing carbon dioxide levels have resulted in rising earth temperatures with concomitant high levels of coral reef bleaching. Increases in storm and hurricane activity have caused destruction of coastal systems. Increased rainfall and tremendous flooding have brought havoc to the fishing industry. In short, Caribbean progress is being stifled by changes in climate.

Importance of Coral Reefs to the Caribbean

Coral reefs are among the world's most amazing ecosystems in terms of biodiversity, far surpassing rain forests and other land ecosystems[1]. One merely has to take a trip to Tobago's Buccoo Reef to experience this wonder of nature. There, the opportunity presents itself to enjoy one of the most stunning sites in the world while sitting in a comfortable glass bottom boat in the scorching sun. Millions of organisms live in this coral reef which is also home for hundreds of thousands of varieties of fish.

Coral reefs are really marine systems created from the secretion of calcium carbonate from corals[2]. Corals live in colonies, which grow on the surface of the reef[3]. They extract limestone from the water and with the help of *zooxanthellae*, secrete calcium carbonate to make the hard shells of protection that are left behind when the coral dies, resulting in the formation of coral reefs[4]. Zooxanthellae are single celled plants that live inside larger organisms, mostly corals[5]. They have a mutual relationship with corals and coral reefs[6]. Corals provide protection for zooxanthellae, which in turn provide food and nutrients for the coral via photosynthesis, enabling the secretion of the calcium carbonate needed for the reef[7].

---

[1] (Birkeland) page 4
[2] (Schluter) page 3
[3] Ibid
[4] ibid
[5] (Baker)
[6] ibid
[7] Ibid

Photosynthesis of zooxanthellae is very important for corals and for the calcification (formation of calcium carbonate) of coral reefs. Both processes, i.e. photosynthesis and calcification, take place side by side in these ecosystems. Photosynthesis is the chemical reaction of carbon dioxide and water to produce glucose (a carbohydrate), which is one of the main sources of food for the corals[8]. At the same time that zooxanthellae are carrying out processes of photosynthesis, the coral itself is carrying out processes of respiration (reverse photosynthesis), which produces carbon dioxide that zooxanthellae use[9].

While scientists recognize the importance of these organisms to each other and tourists no doubt visit to enjoy the beauty of the reefs, a more significant aspect of coral reefs is that they present a source of livelihood for many in these countries.

Coral reefs are important to the Caribbean for three (3) main reasons[10].

(1) They provide a substantial amount of food for humans including "gastropods (e.g. queen conch), bivalves (e.g. giant clams, rock oysters, and pearl oysters), octopus, squid, cuttlefish, lobsters, prawns and sea cucumbers"[11]. Aquamarine organisms in coral reefs are an important source of food for coastal communities, entire countries and a wide-range of pelagic or inshore pelagic fishes[12].

(2) They are major contributors to tourism. They are a huge source of income for tropical countries, especially those in the Caribbean, through scuba diving, jewelry, curios and souvenirs from black corals, gorgonaceans, seashells, giant clams and dried fishes[13].

(3) They are vital to the aquamarine trade. In the region, there are over 60,000 small scale fishing operations. In Jamaica alone, over 95,000 tons of fish are harvested for food and business annually[14]. Fish from coral reefs and surrounding seas are

[8] (Jean-Pierre Gattuso) page 4
[9] Ibid page 4
[10] (Birkeland) page 13
[11] Ibid page 56
[12] Ibid page 15
[13] Ibid page 46
[14] Ibid page 46

exported to all corners of the earth, bringing in income to local businesses.

Almost all the countries of the region have at least one coral reef. They range in size and diversity. In this section, five (5) reefs will be looked at. These are to be found in the Dominican Republic, Belize, Tobago, St. Lucia, and Cuba. They are all major income sources in their respective countries. In the Dominican Republic, 37% of the country's income comes from the tourism industry with over 500,000 Dominicans employed in the tourism sector[15]. The Parque Jaragua in the Dominican Republic houses coral reefs, mangroves, sea grass beds and beaches[16]. The reefs produce a great deal of the sand for beaches, which are part of the Dominican Republic's Biosphere Reserve. The Reserve brings in over $100 million US dollars from park fees, lodging, gas stations and small businesses[17].

The coral reef off the coast of Belize also contributes to hefty revenue from the tourism industry. Approximately US$175 million to US$262 million in 2007 flowed from coral reef and mangrove associated tourism[18]. According to the World Resources Institute, reef associated tourism and fishing associated with the reef is part of their cultural tradition and provides a safety net for the livelihood of Belizeans[19]. Sport fishing and diving off the coast of Belize alone contributed approximately US$ 30 - US$37 million in 2007[20]. This can be compared to the gross US$11.2 million that Belize collects from the 1.2 million pounds of fish sold in one year[21]. Reef and mangrove associated fishing off the coast of Belize amount to over US$15 million per year for the Belizean economy[22].

Research pertaining to the economic advantages of coral reefs in Tobago and St. Lucia estimate income from visitors' spending money on reef related recreation, accommodation and other activities, to US$43.5 million in Tobago and US$91.6 million in St. Lucia, all in the

[15] (Jeffrey Wielgus) page 2
[16] Ibid page 5
[17] Ibid page 5
[18] (Emily Cooper) page 2, 4
[19] Ibid page 2
[20] Ibid page 4
[21] Ibid page 4
[22] Ibid page 4

year 2006[23]. The resulting combined income from direct and indirectly related reef associated tourism amount to over US$101 million for Trinidad's economy and over US$160 million for St. Lucia's[24]. In these two countries, coral reef fishing has a much smaller economic impact when compared with Belize, ranging from US$0.7 million in Tobago and US$0.4 million in St. Lucia. Coral reef fishing is essential in providing jobs, adding cultural value and a social safety net in both locations[25]. The World Resources Institute (WRI) recognizes the value of coral reefs to the Caribbean and its people in areas of food and public sector jobs. They are also valued as a source of fuel, providing air quality maintenance, climate and water regulation, erosion control, storm protection, cultural diversity, spiritual and religious values, cultural heritage values (e.g. Lucia), recreation, ecotourism and other goods and services for the people of the region[26].

Cuba can be singled out as having one of the largest reefs in the Caribbean, surrounding the island on all four coasts[27]. These reefs stretch virtually along the entire Cuban coastline and for the most part, resemble barrier reefs[28]. Coral reef fishing also plays an important part in the Cuban economy as both a food source and an income generator.[29]. The Cuban fishing industry catches and exports many different marine species from the lane snapper from the Gulf of Batabanó, to the Nassau grouper, the queen conch and shrimp off the southern shelf of the Cuban coast[30]. Chuck Adams explains that despite the fact that economic conditions have not been ideal in Cuba since the "Special Period" (referring to the period of economic crisis after the collapse of the Soviet Union in the 1990's) exports of fish continue to be high for the country[31]. Most recent figures quoted by Adams showed that annual seafood exports in the 1990's were averaging US $107 million, with an increased export value of US $125.4 million in 1996[32].

[23] (Lauretta Burke) page3-4
[24] Ibid page 4
[25] Ibid page 4
[26] (Institute)page 3
[27] (Institute, Cuba)
[28] (UNEP) page 135
[29] Ibid page 136
[30] Ibid page 136
[31] (Chuck Adams) page 6
[32] Ibid page 6

With these figures in mind, there can be no doubt about the importance of corals and coral reefs to the Caribbean region.

Sensitivity of Coral Reefs to Environmental Changes

Corals are highly sensitive organisms that are affected by changes in their environment. They require very strict environmental conditions in order to survive, grow and revive themselves after natural processes.

(1) Rising sea levels is one external factor that may affect coral reefs[33]. At different times of the year there are natural changes in sea levels due to the movement of the sun and earth in relation to one another[34]. These changes in sea levels affect the life and death of corals since reefs that live closer to the sea surface are alternatively exposed or flooded in relation to the sea level[35]. This natural rise and fall of sea levels is exacerbated by global warming and climate change. This results in sea levels remaining elevated, which in turn causes serious flooding problems for coral reefs[36].

(2) Coral reefs are also affected by the changes in sea temperatures. Corals can survive in seas temperatures ranging from 18 ˚C to 36˚ C, but prefer ideal conditions of 26 ˚C to 28 ˚C[37]. Sea temperatures determine the rate of growth of corals and drastic changes in these temperatures outside the regular range could cause total destruction of reefs[38].

(3) Corals are affected by the salinity levels of the water. Corals grow ideally in seas where the salinity levels are between 3.3 to 3.6 %[39]. Salinity levels change due to the dumping of large amounts of fresh water when glaciers melt[40]. Salinity levels are also subject to change due to precipitation, storm activity, fresh water runoff and severe droughts[41].

---

[33] (Birkeland) page 46
[34] Ibid page 46
[35] Ibid page 47
[36] Ibid page 5
[37] (Birkeland) page 50
[38] Ibid page 50
[39] Ibid page 52
[40] (Lee Hayes Byron) page 1
[41] Ibid page 1

(4) Light intensity also affects the growth of corals. As depth increases, light intensity decreases exponentially[42]. As a result, photosynthesis and calcium carbonate levels decrease[43].

(5) The upwelling of nutrients could have a number of different effects on coral life[44]. Upwelling is the process by which warm, nutrient rich water rushes in to replace cool, nutrient depleted water[45]. It brings in warm water from closer to the coasts, due mostly to the winds blowing over the sea[46].

While coral reefs are a large source of economic assistance to developing states, especially in the Caribbean, their environmental advantages are equally important. Marine ecosystems such as coral reefs and mangroves protect island coastlines from added erosion and destruction from storms and natural breakwaters[41]. Reefs not only protect the beaches and coastlines from storms and waves but also provide the sand for beaches[47]. Clearly, the destruction of beaches and the coastal systems of developing states is a major concern in light of climate change and rising sea levels.

Climate change is not only affecting the earth's surface temperatures, but is also affecting sea temperatures, sea levels and the intensity and frequency of weather systems, such as storms and hurricanes. The next section of the paper will explore existing evidence of destruction of coral reefs in the region. It will be seen that together with changing weather patterns in the region, specifically hurricanes in the past few years, there has been severe beach erosion which presents challenges to the tourism economy of the Caribbean.

Destruction of Coral Reefs, Intensification of Hurricanes and Effects on Beaches

Coral reefs in the Caribbean are being slowly destroyed, and it will be shown that a primary reason for this destruction is

[42] (Birkeland) page 56
[43] Ibid page 56
[44] Ibid page 56
[45] (Wikipedia)
[46] Ibid
[47] (UNEP) page 55

anthropogenic (manmade)[48]. While human activity is not the only reason for the depletion of coral reefs, over the last few years such activity has only exacerbated the situation. Human impact on reefs can be separated into 4 categories: pollution; sedimentation; over fishing and climate change[49].

(1) Pollution in the form of nutrient upwelling is a type of reef pollution and is linked very closely to human waste and agricultural runoff[50].
(2) Sedimentation has been linked to coastal development such as dredging, land reclamation, deforestation and poor agricultural practices throughout the islands[51].
(3) Unsustainable fishing is more so related to marine life in the reefs rather than the physical reef itself. Over fishing is extracting marine life from the system at a rate which is faster than it could be naturally replenished[52].
(4) Human activity causes climate change. Industrialization increases levels of carbon dioxide in the atmosphere which in turn increases global temperature. Increases in temperature cause sea levels to rise due to melting glaciers and polar ice caps. Increased sea temperatures cause coral bleaching[53]. Coral reefs in the Caribbean prefer to grow in the upper levels of the temperature range of 18°C to 36°C. Coral bleaching is the loss of color by coral polyps due to them expelling their zooxanthellae or by the zooxanthellae expelling their chlorophyll which is used in photosynthesis[54]. Temperature increases of 1-2° C above the maximum temperature range for just a few weeks are enough to cause mass coral bleaching and the destruction of reefs[55]. Coral bleaching events have increased since 1979 and has been correlated to occurrences of the El Niño Southern Oscillation (ENSO)[56] (explained later).

[48] (Hance)
[49] (UNEP) page 56
[50] Ibid page 57
[51]Ibid page57; (Nicholls) page319
[52] Ibid page 58
[53] Ibid page 59
[54] Ibid page 59
[55] Ibid page 59
[56] Ibid page 62

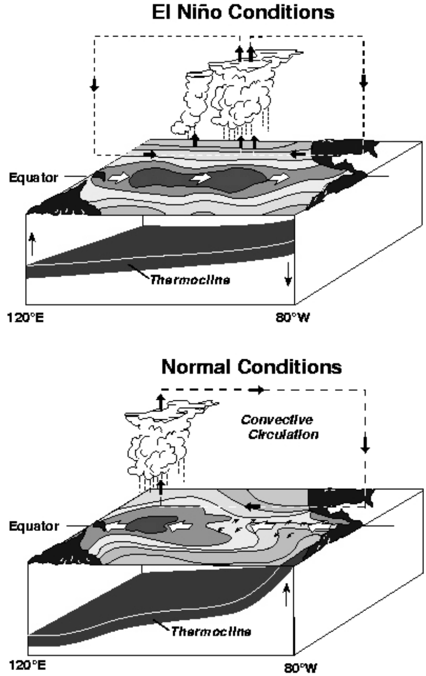
The World Resources Institute confirms that reefs are being greatly affected by human activity and have faced serious depletion over the years. As much as 80% of the coral reefs in the Dominican Republic are at threat from over fishing and sedimentation due to increased unemployment and coastal development[57]. The coral reefs around the coasts of Trinidad and Tobago are all under threat from over fishing and coastal development since fishing is very important for coastal villages[58]. 85% of the reefs are at threat of destruction from water pollution from poorly treated sewage, agricultural runoff, fertilizers, pesticides and chemicals[59]. Despite the fact that the Buccoo Reef in Tobago has been declared a restricted area, coastal development and the tourism industry has done very little to preserve this ecosystem[60]. 90 sq km of the coral reefs surrounding the St. Lucian coast are being threatened by coastal development and over fishing, but the main source of damage to the reef has been from regional hurricanes and storms[61]. In Belize, 63% of the reef is directly affected by over fishing, coastal development, and agricultural runoff from sugar and banana plantations and from natural weather systems[62]. For the first time in 1995, severe coral bleaching occurred off the coast of Belize although it had already occurred in different reefs in the region[63]. In Cuba, 70% of the country's reefs are being affected by over fishing, pollution and hurricane activity[64].

Climate change is put forward as the greatest anthropogenic (man-made) contributor to adversity facing coral reefs in the Caribbean. Reefs are being damaged due to rising sea levels, rising sea temperatures and by increased weather phenomenon associated with occurrences of ENSO and increased and intensified hurricane activity[65]. The El Niño is the five month period when the mean sea surface temperature anomaly in the region of the central equatorial Pacific Ocean exceeds a threshold value of 0.5° C for a minimum of six months

[57] (Institute, Dominican Republic)
[58] (Institute, Trinidad and Tobago)
[59] Ibid
[60] Ibid
[61] (Institute, St. Lucia)
[62] (Institute, Belize)
[63] Ibid
[64] (Institute, Cuba)
[65] (Mimura)

including October, November and December. A cold phase or La Niña occurs when sea surface temperatures in the region are less than -0.5°C for the same six month time period[66]. The Southern Oscillation is the atmospheric counterpart to the El Niño. It is described as the oscillation of the air pressure between the tropical eastern and western Pacific Ocean waters[67]. Waters on the west of the Pacific Ocean tend to be warmer, resulting in cooler temperatures on the coast of Peru (east Pacific Ocean).

FIG. 2 – Characteristics of an ENSO event under normal conditions and during an El Niño[68]. Under normal climate conditions, there are only warm sea temperature conditions off the coast of South America and there is upwelling of the cool water (thermocline) from below that contributes to the success of the fishing industry off the Peruvian coast. During an El Niño, the warm water spreads across the equator and warm weather conditions are experienced across the equator. When this happens, there is a reduction in the upwelling of the thermocline which affects the fishing industry.



El Niño and the Southern Oscillation work hand in hand to give the El Niño/Southern Oscillation (ENSO) which affects the entire world in some way. ENSO can occur in different phases; the warm phase or El Niño; the neutral phase (neither defined as warm nor cold) and the cold phase or La Niña[69]. According to Tartaglione et al., during warm ENSOs (El Niño) when there is a decrease in atmospheric pressure,

[66] (WMO); (Tartaglione)
[67] Ibid
[68] (Rhode Island)
[69] (Tartaglione)

there is a decrease in hurricane activity in the Caribbean and a decrease in the probability of a hurricane hitting land[70]. It is during the La Niña phase of an ENSO that there is increased hurricane activity in the region[71]. In the last 20 years, there have been many major El Niño events in 1991-92, 1994-95, 1997-98, 2002-03, 2004-05 and 2009-10[72]. All of these occurrences were synonymous with decreased hurricane activity.

Table 1 – Table showing the number of tropical storms/ hurricanes during an El Niño phase in the Caribbean

Year	Tropical Storm/ Hurricanes
1991 – 1992	7
1994 – 1995	7
1997 – 1998	8
2002 – 2003	14
2004 – 2005	16
2009 – 2010	11

Table 2 – Table showing the number of tropical storms/hurricanes during a La Niña phase in the Caribbean

Year	Tropical Storm/ Hurricanes
1992 – 1993	5
1995 – 1996	21
1998 – 1999	14
2003 – 2004	21
2005 – 2006	31
2010-2011	21

It is during the La Niña years that hurricane activity increases and research has shown that since 1995 the occurrence of hurricanes reaching category 3 has almost doubled[73] (Table 1).

Looking at the results in the previous tables, we see that with time there was a general trend of decreased hurricane activity over the

[70] Ibid
[71] Ibid
[72] (T. F. Wikipedia)
[73] (Centre)

last 20 years compared to the average hurricane activity of 10–15 tropical storms/ hurricanes during normal conditions. After every El Niño event, there is a La Niña phase which is categorized by increased hurricane activity, seen in Table 2. It can also be seen that over the last 20 years there has been increased hurricane activity over time, in correlation with the strength of the previous year's El Niño. For example in 2005, one of the strongest El Niño's occurred, seeing very little tropical storms reaching hurricane status even though there were a greater number of storms on the whole. After this El Niño, one of the strongest La Niña's occurred with a record of 31 tropical storms/ hurricanes that year.

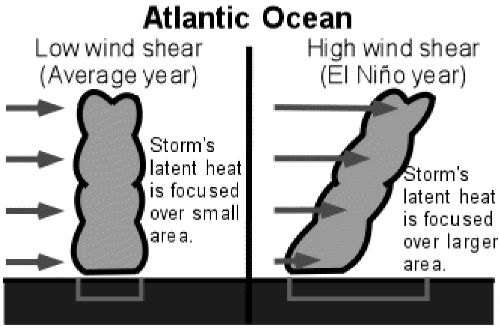
During an El Niño (warm phase) there is an increase in sea surface temperatures and a decrease in the strength of westward blowing trade winds[74]. There is also an increase in vertical wind shear (change in wind speed with height) and El Niño's tend to dry out and warm the atmospheric temperature above the sea[75]. Wind shears cause tropical storms to tilt. Therefore, when there is an increase in vertical wind shear, tropical storms tilt and this is what causes a reduction in hurricane activity during an El Niño. During a La Niña there is a cooling of the sea surface temperatures and an intensification of westward blowing trade winds[76]. There is a decrease in vertical wind shear and cooler atmospheric temperatures[77]. This decrease in vertical wind shear does not force tropical storms to tilt and does not prevent their formation.

With climate change being very apparent in the past few decades, it has become very obvious that the atmosphere and oceans have risen in temperature. ENSO events have increased and intensified and have caused tremendous coral bleaching whenever they occurred[78].

---

[74] (Rhode Island)
[75] Ibid
[76] Ibid
[77] Ibid
[78] (Buddemeier, Kleypas and Aronson)

FIG. 4 – Effects of wind shear to hurricanes during an El Niño[79]



During the 1991-92 ENSO events, the Caribbean saw tremendous coral bleaching in countries such as Jamaica and the Bahamas[80]. For the first time in the 1990's Belize experienced coral bleaching[81]. During the 1997-98 ENSO events, high levels of coral bleaching were recorded throughout the world, including the Caribbean[82]. After a major bleaching event in 1997-98, there were also recorded bleaching events across the Caribbean in 2005, due to higher than normal sea surface temperature, with the occurrence of an ENSO during that time period. The thermal stress caused by this event resulted in mass coral bleaching across the entire Caribbean Sea from Panama to Nicaragua, the Bahamas, the Lesser Antilles, Cuba, Hispaniola, Puerto Rico and the Windward and Leeward islands[83]. Scientists studying Virgin Island coral reefs predicted similar levels of coral bleaching in 2010 as in 2005 where the territory lost about 60% of its reefs[84].

The rise in sea temperatures over the last few decades has caused high levels of coral bleaching in the region. However, the rise in sea surface temperatures has not been the only cause for the destruction of reefs in the region. Coral bleaching by high sea temperatures has only exacerbated the damage caused by natural weather phenomenon such as storms and hurricanes. There is one thing to keep in mind however, that with climate change becoming an issue, hurricane activity

[79] (Byrnes)
[80] (Brown) page 1
[81] Ibid page 1
[82] (UNEP) page 59
[83] (Eakin, Morgan and Heron)
[84] (lisaparavisini)

has increased over the last few decades, as mentioned earlier with an average of 10 - 15 tropical storms/ hurricanes during non-El Niño years. With sea temperatures increasing, waters become more favorable for the formation of hurricanes and an increase in frequency and intensity of hurricane activity in the region is expected[85]. This can be seen in hurricane data collected by the National Hurricane Centre over the past few decades.

The table below shows an average of over 50% of tropical storms becoming hurricanes over the last 20 years. It is very clear that not only has the frequency of hurricane activity been increasing in the region, but the intensity of hurricanes is sky-rocketing beyond belief. An example is the damage caused by Category 2 Hurricane Tomas to St. Lucia[86]. Compared with other hurricanes at that stage, Hurricane Tomas caused tremendous damage. Thus, it is evident that increased hurricane intensity is a cause for great concern.

Table 3 – Table showing percentages of tropical storms that became hurricanes during La Niña phases in the last 20 years[87]

Year	# of Tropical Storms	# Hurricanes	%
1996	13	8	61.5
1998	14	10	71.4
2004	16	8	50
2005	31	15	48
2010	17	8	47

The nexus between hurricane frequency and intensity due to climate change and damage to coral reefs will now be examined. In a research paper done on the effects of hurricanes on reefs in the region,

[85] (Reid)
[86] Ibid
[87] (Centre)

the results showed that after major hurricanes over the last 20 years, there was a 17% decrease in coral cover across the region, with no sign of re-growth or recovery up to 8 years after[88]. The research indicates, the more intense the hurricane, the more coral reef loss is expected. The paper concluded that with increased hurricane intensity and no reef recovery after a hurricane, the effects on reef mortality in the region was devastating. This research was carried out for hurricanes up until 2001. Subsequently, the next major hurricanes occurred in 2005.

Following 15 hurricanes and 15 tropical storms that passed through the Caribbean region in 2005, scientists recorded that coral bleaching in the region was never higher. Coral reefs in the US Virgin Islands decreased by over 50% in that year and the same thing happened in Puerto Rico, the Cayman Islands, St. Marteen, Saba, St. Eustatius, Guadeloupe, Martinique, Barbados, Jamaica and Cuba[89]. Coral mortality in the Lesser Antilles was just as severe, with 73% damage to certain coral species in Trinidad Tobago[90]. The hurricanes of 2005 caused tremendous damage to coral reefs in the region causing mass flooding, bringing in muddy water and sediments from land run off, and increased wave activity[91].

It is important to be reminded of the importance of reefs in protecting the coastlines and beaches of Caribbean islands. With the major decline of reefs and the loss of protection to coasts, hurricanes have caused more damage than imaginable. In 1995, Tropical Storm Iris and Hurricanes Luis and Marilyn devastated the coastlines of Anguilla, Antigua and Barbuda, Nevis, Montserrat and Dominica causing severe coastal erosion[92]. The distance of coastline retreat in the islands varied from 2.5 m in Dominica to up to 17.5 m in Barbuda (coastal retreat refers to the average retreat of land from its original location)[93]. This coastal retreat brought with it damage to infrastructure and coastal vegetation[94].

---

[88] (Gardner, Cote and Gill) page 8
[89] (Wilkinson and Souter) page 1
[90] Ibid
[91] Ibid
[92] (Cambers)
[93] Ibid
[94] Ibid

FIG. 5 – Barnes Bay, Antigua before and after Hurricane Luis[95]

FIG. 6 – Coconut Beach, Dominica before and after the 1995 hurricane season[96]

Regular monitoring of Caribbean beaches over the years has shown that coastlines have been retreating and eroding at a rate of 0.3 m per year[97]. In 1998, beach erosion caused by storms and hurricanes resulted in Cuba having to refill its beaches with over 1million m^3 of sand after the effects of Hurricane Lili[98]. In 2001 after Hurricane Michelle, there was a net loss of over 140 million m^3 of sand from just one of Cuba's beaches[99]. In 2004, when Hurricane Ivan passed over the Cayman Islands, there was serious damage to the coastline beaches, especially to the Seven Mile Beach on the western peninsula. Although no quantitative data was given for the amount of damage caused, the reason suggested for such damage was the lack of reef protection along that part of the coast along with very strong wave surges.[100]. In Jamaica, damage to beach and housing has also occurred due to hurricanes and storms undermining housing foundations along coastlines of St. Margaret's Bay and Orange Bay[101]. Hurricane forces have also caused

95 Ibid
96 Ibid
97 (Cambers, Impact of Climate Change on the Beaches of the Caribbean)
98 (UNEP/GPA) page 56
99 Ibid page 57
100 (Young) page 48
101 (Robinson, Rowe and Khan)

breaking and erosion of limestone cliffs in Jamaica. This occurred with Hurricane Wilma[102].

Clearly, damage to coral reefs by hurricanes and storms is being aggravated by the anthropogenic factors of pollution, sedimentation, overfishing and climate change. Reduction of coral reefs in the Caribbean portends even further damage to land and coasts of Caribbean islands.

Mitigation and Adaptation Strategies & Policies for the Region

Dr. Ulric Trotz defines mitigation as "anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.[103]" He refers to adaptation as the "adjustment in natural or human systems to a new or changing environment.[104]" In relation to climate change and global warming, adaptation refers to the adjustment of natural and human systems[105]. In this context, mitigation and adaptation strategies are looked at in an effort to alleviate the strain on the environment being caused by climate change. Different strategies need to be adopted for each Caribbean island depending on levels of damage and the economic and political climate. The Intergovernmental Panel on Climate Change (IPCC) and the Caribbean Community Climate Change Centre (CCCCC) advocate mitigation (through reduction of carbon emissions) and adaptation strategies, in relation to the Caribbean and other Small Island Developing States (the latter are low-lying coastal countries that have small, growing populations, limited resources, susceptibility to natural disasters and dependence on international trade). Some broad adaptation strategies that are plausible are:

(1) Early action to avoid the more disastrous effects of climate change, such as setting effective carbon prices[106]

(2) Increasing government funding for research, development and demonstration of carbon-free energy sources[107]

---

102 Ibid
103 (Trotz) page 3
104 Ibid page 2
105 Ibid page 2
106 Ibid page 11
107 Ibid page 11

(3) Preventing development close to coasts[108]
(4) Modification of land use and building codes[109]
(5) Defence structures such as dikes, levees, sea walls, flood gates and tidal barriers[110]
(6) Afforestation measures along with wetland recreation[111]

A few mitigation strategies include:

(1) Finding more efficient ways of using fossil fuels[112]
(2) Suppression of greenhouse gases, e.g. suppression of carbon dioxide from oil and gas wells[113]
(3) Switching to renewable sources of energy like biomass, wind energy or solar energy[114]
(4) Waste minimization –reuse, reduce, recycle[115]

Strategies and policies are not easy to put in place without cooperation from all sectors in the respective states. The Caribbean islands have dynamic governmental structures, with varying policy goals and economic priorities. For example, the Haitian government when it takes up office may prioritize the rebuilding of its infrastructure and a steady supply of food and provision for its people. On the other hand, Trinidad and Tobago has no immediate concern with rebuilding infrastructure and can therefore utilize brain and manpower to implement sustainable policies.

The ultimate success for implementation of these policies and strategies rests in the hands of the local population and the government, with the help of the private sector. The adaptation strategies outlined above are very wide ranging but require a great deal of deliberation and funding from governmental and private enterprises. The reason for specifying private enterprise is because the economic situation in some countries of the region is so dire that they would not be able to fully

[108] (IPCC) page 313
[109] Ibid page 313
[110] Ibid page 313
[111] Ibid page 313
[112] Ibid page 591
[113] Ibid page 597
[114] Ibid pages 603 - 614
[115] (Bogner)

fund these projects, like intensive research into energy sources. The Caribbean is a region with a lot of potential for other energy sources, but the economies of the individual islands cannot meet the demand of these projects. This is where integration should play a larger role, with each country helping each other for the betterment of the *entire* region.

Smaller scale adaptation strategies could be adopted as outlined above, such as the modification of land use and building codes and the construction of defense structures. These are steps that could be taken even though they are small. These small changes do add up and can have big effects. The simple construction of defense structures could help eradicate much of the beach erosion along the coasts of our islands. The simple modification of land, better agricultural practices, drainage modifications and afforestation (replanting of forests) could prevent top soil erosion on land during hurricanes and storms.

Improved strategies and policies need to be taken on by the governments of the region. However, smaller projects like construction of defense structures and everyday practices of recycling are the people's responsibility.

Conclusion

The Caribbean region's delicate ecosystems are clearly vulnerable to continuing changing climate. To combat the problem, the region's massive potential for utilizing other energy sources must be tapped into. Although some islands are hugely dependent on the importation of fossil fuels and gas, an immediate and concerted shift to other sources of renewable, sustainable energy is imperative. Solar, biomass, wind and hydropower are undemanding and natural modifications for islands surrounded by water. Further research into these energy sources and their application to the region must be encouraged and funded both by individual islands and regional alliances. Caribbean governments must band together for effective mitigation and adaptation strategies. The main focus must be the prevention of further damage to the region from the effects of climate change. Immediate reduction of carbon dioxide levels in the atmosphere will enormously impact rising sea and earth temperatures. Ultimate success in implementation must begin with the local population working side by side with the government and the private sector. Private sector resources can greatly assist with the funding of projects like intensive research into alternative energy sources. Meanwhile, interim measures such as the construction of simple defense structures can help eradicate beach erosion along the island coasts. The 3R`s – reuse, reduce, and recycle – should be adopted by every household in the Caribbean to help reduce the effects of climate change on their own country. Individual concern such as careful recycling practices will demonstrate that we are all becoming aware of our environment at this most crucial juncture in global development.

Bibliography

Baker, Dr. Andrew. Coral Reefs: A Reef Resilience Toolkit Module. 2007. 20 11 2010 <http://www.reefresilience.org/Toolkit_Coral/C2a1_Zooxanthellae.html>.

Birkeland, Charles. "Life and Death of Coral Reefs." Birkeland, Charles. New York: Chapman and Hall, 1997.

Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang. Waste Management, In Climate Change 2007: Mitigation. United Kingdom and New York: University Press, Cambridge, 2007.

Brown, B.E. "Coral Bleaching: causes and consequences." Coral Reefs (1996): 129 - 138.

Buddemeier, Robert W., Joan A. Kleypas and Richard B. Aronson. "Coral Reefs." 02 2004. PEW Centre on Global Climate Change. 28 11 2010 <http://www.pewclimate.org/docUploads/Coral_Reefs.pdf>.

Byrnes, Kristen. "Facts and Fictions of Al Gore's "An Inconvenient Truth"." 13 06 2007. Global Warming Hoax. 10 12 2010 <http://www.globalwarminghoax.com/news.php?extend.11>.

Cambers, Gillian. Hurricane Impact on Beaches in the Easter Caribbean Islands 1989-1995. 12 2996. 28 11 2010 <http://www.unesco.org/csi/act/cosalc/hur1.htm>.

—. "Impact of Climate Change on the Beaches of the Caribbean." Commonwealth Association of Planners Regional Conference, 24-27 06 2007.

Centre, National Hurricane. Archives. n.d. 27 11 2010 <http://www.nhc.noaa.gov/pastall.shtml>.

Chuck Adams, Placido Sanchez Vega, Anicia Garcia Alvarez. An Overview of the Cuban Commercial Fishing Industry and Recent Changes in Management Structure and Objectives. Gainseville, 2000.

Diaz, Henry F., and Markgraf Vera. El Nino and the Southern Oscillation: Multiscale Variability and Global and Regional Impacts. Cambridge: Cambridge University Press, 2000.

Eakin, C.M., et al. "Caribbean Corals in Crisis: Record Thermal Stress, Bleaching,and Mortality in 2005." PLoS ONE (2010): 1 - 9.

Emily Cooper, Lauretta Burke, Nadia Bood. "World Resources Institute." November 2008. World Resources Institute. 20 11 2010 <http://pdf.wri.org/coastal_capital_belize_brochure.pdf>.

Gardner, Toby A., et al. "Hurricanes and Caribbean Coral Reefs: Impact, Recovery Patterns, and Role in Long-Term Decline." Ecology (2005): 174 - 184.

Hance, Jeremy. Human activity is killing coral reefs in the Caribbean. 8 1 2008. 27 11 2010 <http://news.mongabay.com/2008/0108-hance_coral.html>.

Institute, World Resources. Belize. n.d. 27 11 2010 <http://www.wri.org/publication/content/7877>.

—. Cuba. n.d. 27 11 2010 <http://www.wri.org/publication/content/7883>.

—. Dominican Republic. n.d. 27 11 2010 <http://www.wri.org/publication/content/7885>.

—. St. Lucia. n.d. 27 11 2010 <http://www.wri.org/publication/content/7901>.

—. Trinidad and Tobago. n.d. 27 11 2010 <http://www.wri.org/publication/content/7903 >.

—. "World Resources Institute." 20 September 2006. World Resources Institute. 20 11 2010 <http://pdf.wri.org/methodology_with_appendix_jul06.pdf>.

IPCC. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis. New York: Cambridge University Press, 1996.

Jean-Pierre Gattuso, Denis Allemand and Michel Frankignoulle. "Photosynthesis and Calcification at Cellular, Organismal and Community Levels in Coral Reefs." American Zoology (1999): 160 - 183.

Jeffrey Wielgus, Emily Cooper, Ruben Torres, and Lauretta Burke. "World Resources Institute." Aprile 2010. World Resources Institute. 20 11 2010 <http://pdf.wri.org/working_papers/coastal_capital_dominican_republic_summary.pdf>.

Lauretta Burke, Suzie Greenhalgh, Daniel Prager, Emily Cooper. "World Resources Institute." June 2008. World Resources Institute. 20 11 2010 <http://pdf.wri.org/coastal_capital_summary.pdf>.

Lee Hayes Byron, July Kunz, Chrisitina Shumate. Sea Level Rise & Ocean Warming. n.d. 20 11 2010 <http://www.biology.duke.edu/bio217/2001/sealevel/index.html>.

lisaparavisini. Repeating Island. 20 09 2010. 28 11 2010 <http://repeatingislands.com/2010/09/20/scientists-watching-v-i-coral-bleaching/>.

Lohmann, Kyger C. "The Reef Environment and Biological Constituents ." Course Outline. Michigan: Department of Geological Sciences, University of Michigan, 8 7 2001.

Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet and G. Sem. Small islands. Climate Change 2007. Research. Cambridge, UK: Cambridge University Press, 2007.

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe. Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Research. Cambridge, UK: Cambridge University Press, 2007.

Reid, Sean. "Climate Change in the Caribbean..." 01 2010. CMMB. 28 11 2010 <http://www.mycmmb.com/docs/EMW/2010/EMW2%20-%20Climate%20Change%20in%20the%20Caribbean.pdf>.

Rhode Island, University of. "Variability of Hurricane Activity." 2010. Hurricanes: Science and Society. 10 12 2010 <http://www.hurricanescience.org/science/science/activity/>.

Robinson, Edward, Deborah-Ann C. Rowe and Shakira A. Khan. "Beach Erosion: A response to rising sea level." Newspaper article. Kingston: The Gleaner, 27 01 2006.

Schluter, Lorelle. "Great Barrier Reef and Marine Park Authority." 2006. Australian Government: Great Barrier Reef and Marine Park Authority. 15 10 2010 <http://www.gbrmpa.gov.au/__data/assets/pdf_file/0017/12437/Reef-Facts-01.pdf>.

Stacey Combes, Micheal L. Prentice, Lara Hansen, Lynn Rosentrater. Going, going, gone! Climate Change and Global Glacier Decline. Berlin, 1996.

Tartaglione, C.A., et. al. "ENSO Impact on Hurricane Landfall Probabilities for the Caribbean." America Meteorological Society (2003): 2925-2931.

Trotz, Dr. Ulric. "Building Climate Resilient Economies." Lecture. 11 2010.

UNEP, WCMC. World Atlas of Coral Reefs. Los Angeles: The University of California Press, 2001.

UNEP/GPA. "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches." Environmental Agency, Ministry of Science, Technology and Environment, Government of Cuba, 03 2003.

Unknown. "Buccoo Reef Trust." 01 March 2010. Buccoo Reef Trust: research education conservation. 28 11 2010 < 2. http://www.buccooreeftrust.org/multimedia/wallpapers/picture/wallpapers/5-buccooreefaerial1024>.

Wikipedia. Surface runoff. 6 11 2010. 20 11 2010 <http://en.wikipedia.org/wiki/Surface_runoff>.

—. Upwelling. 3 11 2010. 20 11 2010 <http://en.wikipedia.org/wiki/Upwelling>.

Wikipedia, The Free Encyclopedia. El Niño-Southern Oscillation. 09 12 2010. 27 11 2010 <http://en.wikipedia.org/wiki/El_Ni%C3%B1o-Southern_Oscillation#Recent_occurrences>.

Wilkinson, Clive and David Souter. "State of Caribbean Coral Reefs after Bleaching and Hurricanes in 2005." n.d.

WMO, UNESCO, UNEP, ICSU. The 1997 - 1998 El Nino Event: A Scientific And Technical Retrospective. London: World Meteorological Organization, 1999.

Young, Dr. Simon R. "Impact of Hurricane Ivan in Grand Cayman." Grand Turk: UK Department of International Development, 21 12 2004.