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Climate Change Impacts on Coral Reefs in the Gulf of Mexico

White Paper

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1.1 Background

Coral reefs are diverse communities that provide habitat to many marine organisms. Losing these systems will affect many species that rely upon them and limit the benefits that they provide to the planet. Although shallow-water coral reefs are not as abundant in the Gulf of Mexico (Gulf) as in other areas, such as the Caribbean, their uniqueness, isolated locations, and the rapid disappearance of certain species make their conservation highly important. Shallow and deep coral reefs are more widely distributed throughout the Gulf than previously thought, providing new avenues of research, but also new challenges for their sustainable management.

Shallow coral reefs in the Gulf occupy about 2,640 km^2 (<0.2%) (Tunnell et al. 2007) while the extent of mesophotic corals, defined as light-dependent corals living at depths between 30–150 m (Hinderstein et al. 2010), and the extend of deep sea corals in the Large Marine Ecosystems (LME) are relatively unknown but recent efforts from the Council and partners are trying to close this gap (Brooke and Schroeder 2007; Ross et al. 2017; GMFMC 2018; Dee et al. 2019) About 85% of shallow-water corals in the Gulf are distributed along the coasts of Florida and Cuba (Tunnell et al. 2007), but the uniqueness and endemic nature of reefs throughout the Gulf makes them particularly important (Figure 1). The coral coverage on reefs within the Gulf is also variable, having both some of the lowest (Florida Keys, just above 10%) and the highest coral cover (Flower Garden Banks, almost 60%) (Schutte et al. 2010) in the Wider Caribbean Region (Gulf and Caribbean) (Tunnell et al. 2007).

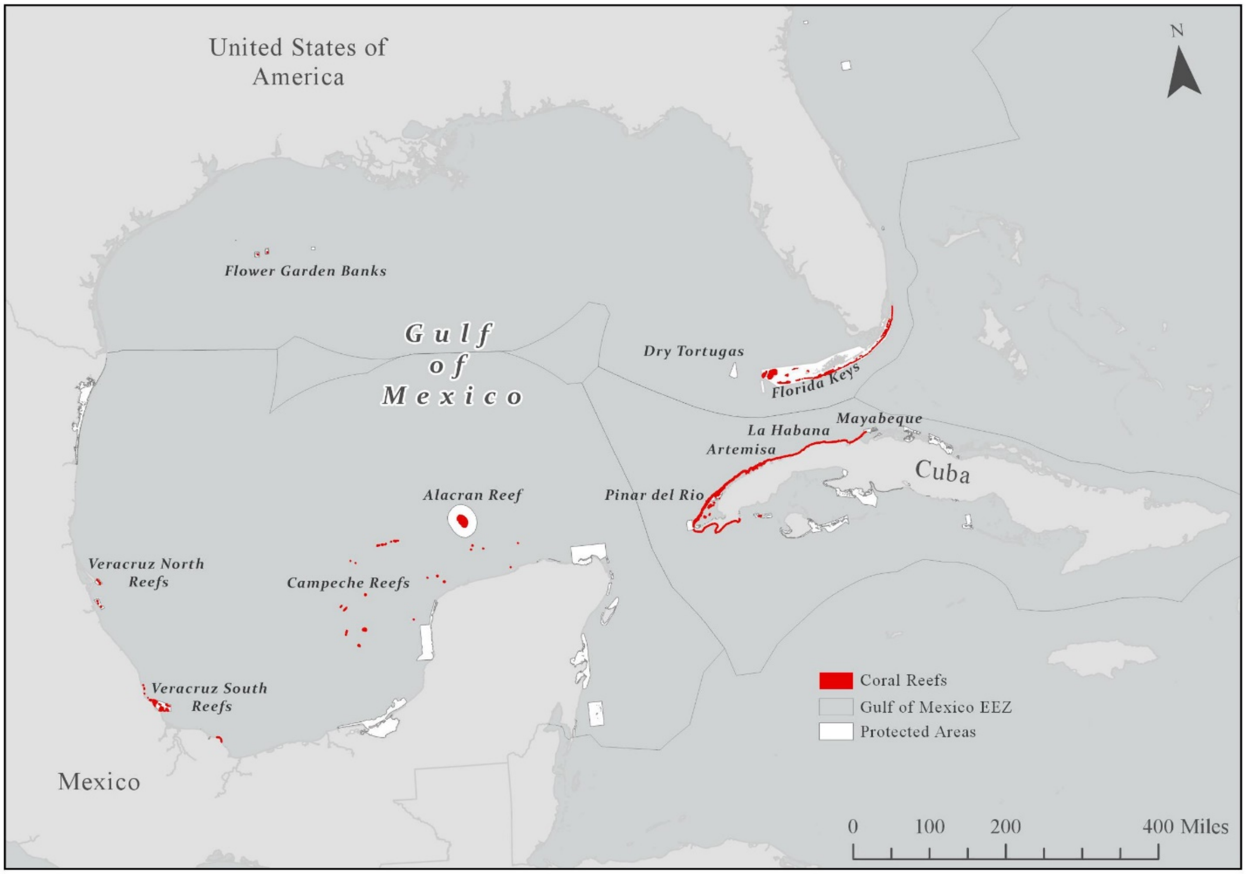

Figure 1. Coral reefs locations in the Gulf of Mexico from Gil-Agudelo et al. (2020)

Similar to other reefs around the world, Gulf reefs are subject to an increased threat from anthropogenic causes, including overfishing, pollution, and climate change. Although some reefs, such as the Flower Garden Banks, have maintained a coral cover over 50%. This is thought to be explained by their distance from the coast which reduces human interactions (Gil-Agudelo et al. 2020). Because of their economic and biological importance, protections through the work of government, and local communities are constantly being developed (Gil-Agudelo et al. 2020).

While corals have been resilient to changing oceans throughout time, the ocean environment is changing at an unprecedented rate and slow-growing corals may not be able to adapt to ensure their future success. Warmer oceans and increased acidification are two principal factors of climate change that threaten the health of coral reefs. This document reviews recent literature on climate change and its effects on Gulf corals.

1.2 Coral Reefs in the Gulf of Mexico

The Gulf has coral reefs located mostly in coastal mesophotic zones (up to ~150 m) around Texas, Louisiana, Florida, and Mexico. A wide array of deep-sea coral species (as well as other reef builders, such as sponges) are also found along the continental shelf and slope (Figure 2). The majority of these coral reefs are located within managed areas including Dry Tortugas National Park, Veracruzano Coral Reef System National Park, Flower Garden Banks, Florida Keys National Marine Sanctuaries, and Florida State Parks. Other coral reefs include Campeche Bank, Tuxpan, Tuxtlas, Yucatan Shelf, Florida Middle Grounds, and Pulley Ridge (Waddell and Clarke 2008; Ortiz-Lozano et al. 2013; Dee et al. 2019).

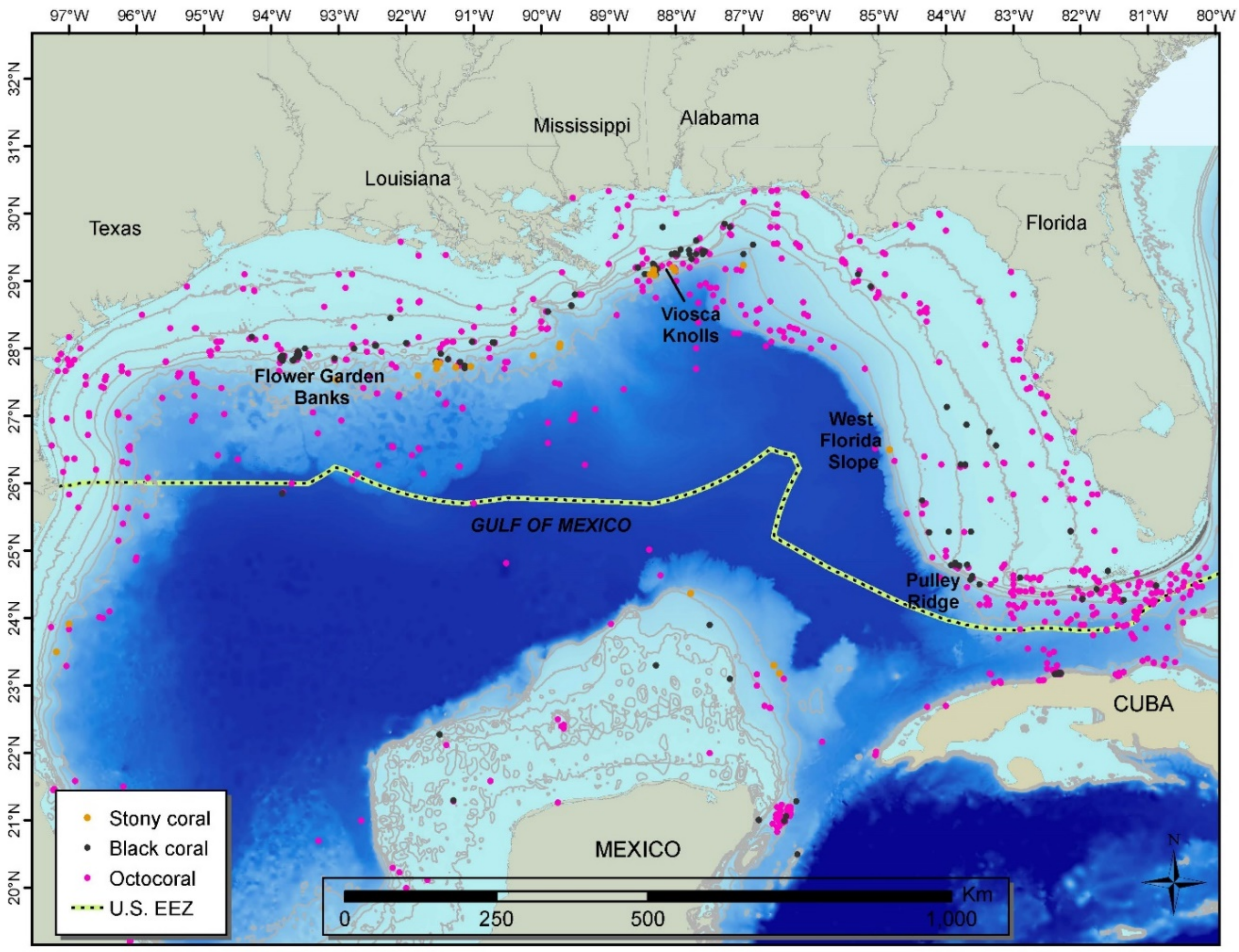

Figure 2. Reported locations of different types of coral in the Gulf of Mexico based on Etnoyer (2009)

1.3 Climate Change Effects on Coral Reefs

Coral reefs are particularly sensitive to rapid climate-induced changes in the physical environment because exposure to maximum ocean temperatures just a few degrees above the long-term average at any location can cause corals to become stressed, bleach and die (Hoegh-Guldberg 1999). Repeated episodes of mass coral bleaching since 1970 have already caused a decline in coral cover at a global scale (Wilkinson 1998; Hughes et al. 2003; Baker et al. 2008) and this trend is expected to continue as ocean temperatures increase further over the coming decades (Hoegh-Guldberg 1999; Donner et al. 2005).

Most of the coral reefs in Gulf are reported to be in degraded condition with the exception of Flower Garden Banks (a protected National Marine Sanctuary) in the northern Gulf and Dry Tortugas National Park in the westernmost side of Florida Keys (Waddell and Clarke 2008; Johnston et al. 2017; Dee et al. 2019). Since the 1970s, studies indicate that dominant branching corals have experienced population declines of more than 90% in some locations (Acropora Biological Review Team 2005). Two of these branching corals *Acropora palmata* and *Acropora cervicornis* are listed as threatened species under the Endangered Species Act of 2006 (National Marine Fisheries Service and Hogarth 2006). The National Marine Fisheries Service found significant evidence in 2010 to list 82 additional coral species as threatened species, including eight Caribbean species (NMFS 2010).

Data on thermal stress on Gulf coral reefs go back to 1878 (Kuffner et al. 2015) with the most recent bleaching event in 2016-2017 when 1 to 29% of the coral cover found bleached at Flower Garden Banks Sanctuary (Johnston et al. 2019a). Field observations of sea surface temperature (SST) records show a temperature increase 0.8°C over the last century in the Florida Keys (Kuffner et al. 2015), where corals have declined, especially at the end of the twentieth century. Observed rates of SST warming are spatially and temporally variable throughout the Gulf (Figure 3), but the highest warming rates tend to occur in summer months (June, July, and August); most recently, the highest heating rates have been observed in the central Gulf in the region where loop current is prevalent (Figure 4) (Chollett et al. 2012; Allard et al. 2016).

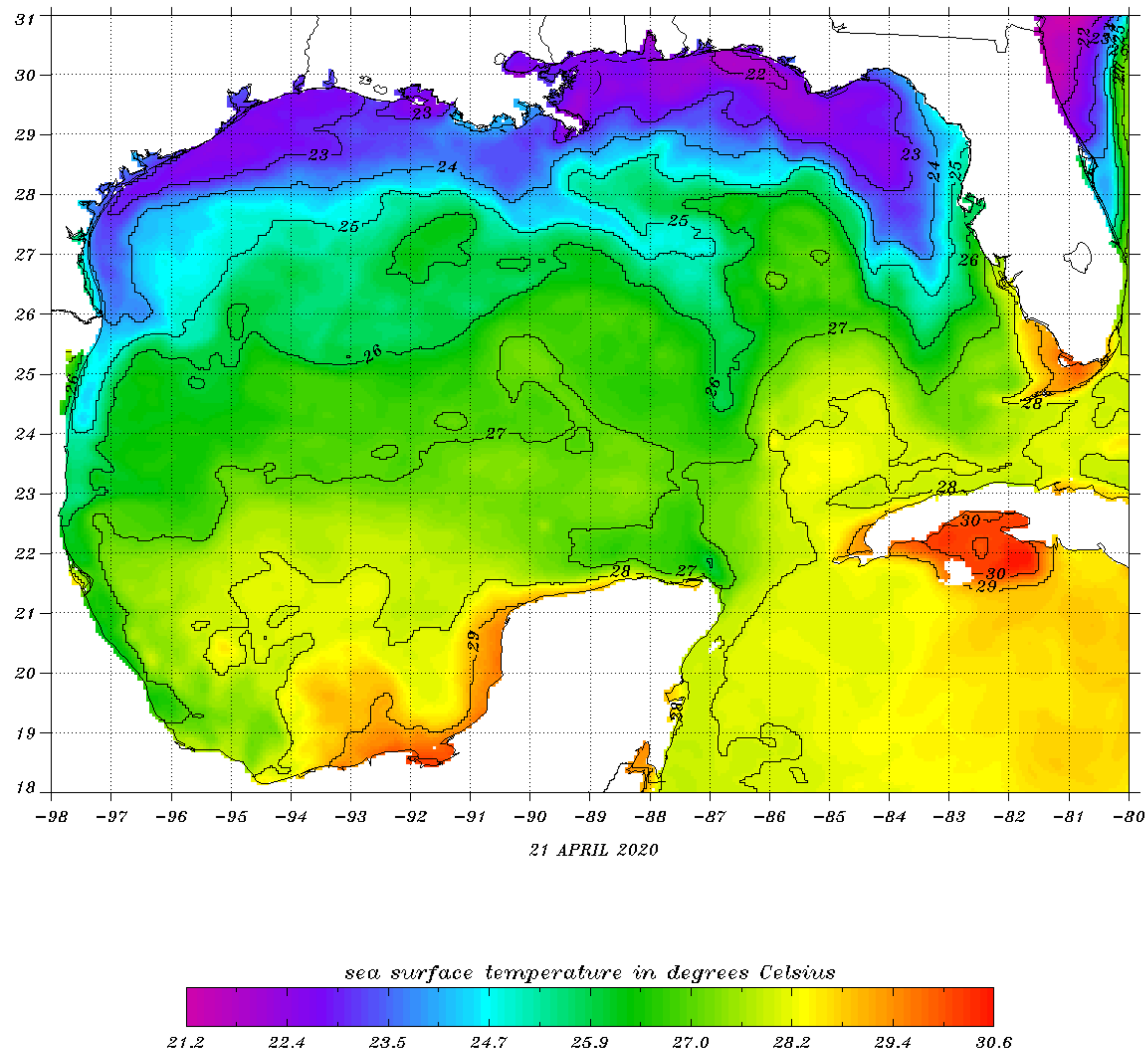

Figure 3. Sea surface temperature at Gulf of Mexico from NOAA GEOS-15 Satellite (Available from: https://www.ospo.noaa.gov/Products/ocean/sst/contour/)

A recent study comparing field-based coral reef data from multiple sites suggest mid-latitude reefs (15–20° of latitude) have higher probabilities of bleaching despite similar levels of thermal stress compared to equatorial reefs (Sully et al. 2019). Coral growth rates need to keep up with the current rate of sea-level rise for these ecosystems to sustain (Toth et al. 2015). Studies in the reef systems found sea-level rise also threatens reefs from the Florida Keys reefs and other Gulf regions as the growth of corals in the region falls behind the rate of die-off (Shinn 1976).

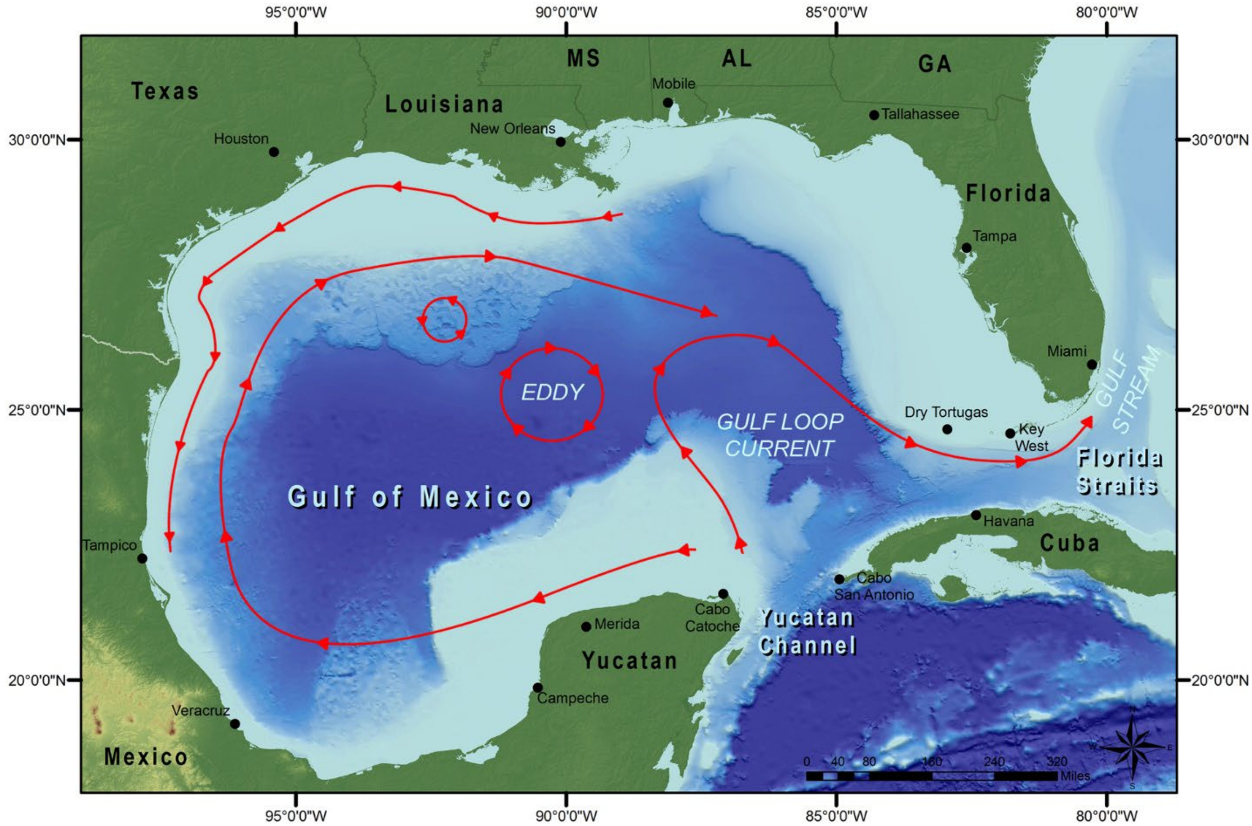

Figure 4. Current pattern in the Gulf of Mexico, including the loop current (Image Courtesy, NOAA)

The reefs located at the Florida Keys have probably been one of the systems most affected by health degradation in the region, with a decrease in coral cover, and a reduction of species numbers, particularly after the bleaching event of 1997–1998, and these reefs are showing little to no recovery (Somerfield et al. 2008). In contrast, reefs of the Flower Gardens Banks National Marine Sanctuary in the US have been historically relatively unaffected by coral diseases. Although coral bleaching occurred at the Flower Garden Banks every summer during 1989–1991 it was always minor (<5%), and yielded negligible mortality (Schmahl et al. 2008), until 2016 when they were affected by a possible decrease in dissolved oxygen (DO) concentration affecting an estimated 2.6% of corals in East Flower Garden Bank, and up to 82% of corals in the area suffered partial or total mortality (Johnston et al. 2019b). Although shallow coral reefs are by far the most affected by raising temperatures, mesophotic and deep-sea corals have not been exempted from damages. White et al. (White et al. 2012) found evidence of coral stress (i.e., varying degrees of tissue loss, mucous production, bleached commensal ophiuroids, etc.) up to 86% of the coral colonies surveyed among 11 sites spread across the Gulf visited after the Deepwater Horizon oil spill in 2010.

1.4 Physiological Changes in Corals Induced by Climate Change

Bleaching

Most reef-building shallow-water corals have a symbiotic, or mutually beneficial, relationship with zooxanthellae. Through photosynthesis, these algae provide close to 90% of the coral's energetic requirements. Coral bleaching is the whitening of the coral due to the loss of the symbiotic algae or the loss of their photosynthetic pigment (Glynn 1984; Brown 1997; Figure 5).

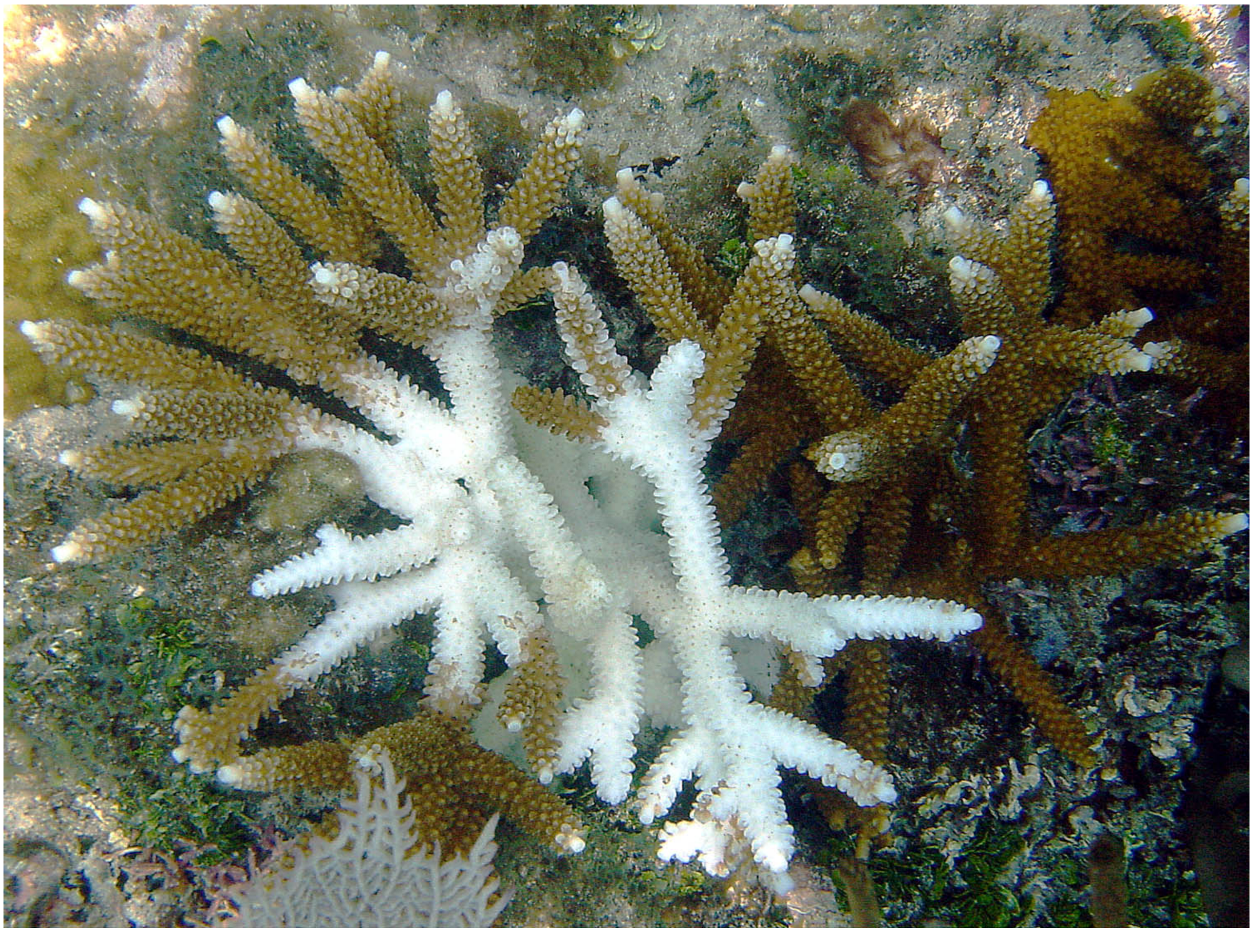

Figure 5. Bleached staghorn coral (*Acropora cervicornis)* in the Gulf of Mexico (Image Courtesy: NOAA)

Usually, corals can withstand and adapt to normal environmental changes, such as hurricanes and changes with temperatures that come with annual seasons. The problem arises when temperatures fall outside their tolerance threshold for a prolonged period of time or during recurring events. These events can stress the corals and zooxanthellae enough to disrupt their symbiosis. Coral bleaching provides a visual cue that the corals are under stress. Corals bleach by expelling their zooxanthellae, revealing their white calcium carbonate skeleton. A bleached coral is not benefiting from the energy provided by their symbiotic algae. If the stress is not prolonged, corals can repopulate their symbiotic algae and recover from bleaching. If the bleaching event lasts too long, the corals do not have enough energy to survive and can eventually die. Although there are many studies on coral bleaching, the mechanism is not fully understood (Guest et al. 2016). Things become more complicated when considering the effects of compounding stressors (e.g., temperature, light, nutrient concentrations) and the fact that not all corals respond to stress the same way. For example, following a mass bleaching event in Florida in 2005, there were no reports of bleaching of rough cactus coral colonies (Wagner et al. 2010). At least six mass (1990, 1998-99, 2006, 2012, 2014) bleaching events related to the increase in water temperature have affected the reefs of the Florida Keys since 1987 (Manzello 2015), in some cases affecting >40% of coral colonies (van Woesik and McCaffrey 2017; Gil-Agudelo et al. 2020). In the bleaching event of 1997–1998, surface water temperatures were recorded peaking at 32°C compared to below 30°C average, causing extensive bleaching to scleractinian corals, milleporids, and octocorals (Jaap et al. 2008).

Bleaching events can also affect coral reproduction, as corals do not have sufficient energy to produce sperm and eggs during period of extreme thermal stress. *Orbicella* species are one of the major reef builders in the Gulf (Figure 6). A long-term study on the reproduction of the *Orbicella* species complex (*O. annularis, O. faveolata*, and *O. franksi*) reported a reduction in the probability of reproduction lasting for years after the bleaching event (Levitan et al. 2014).

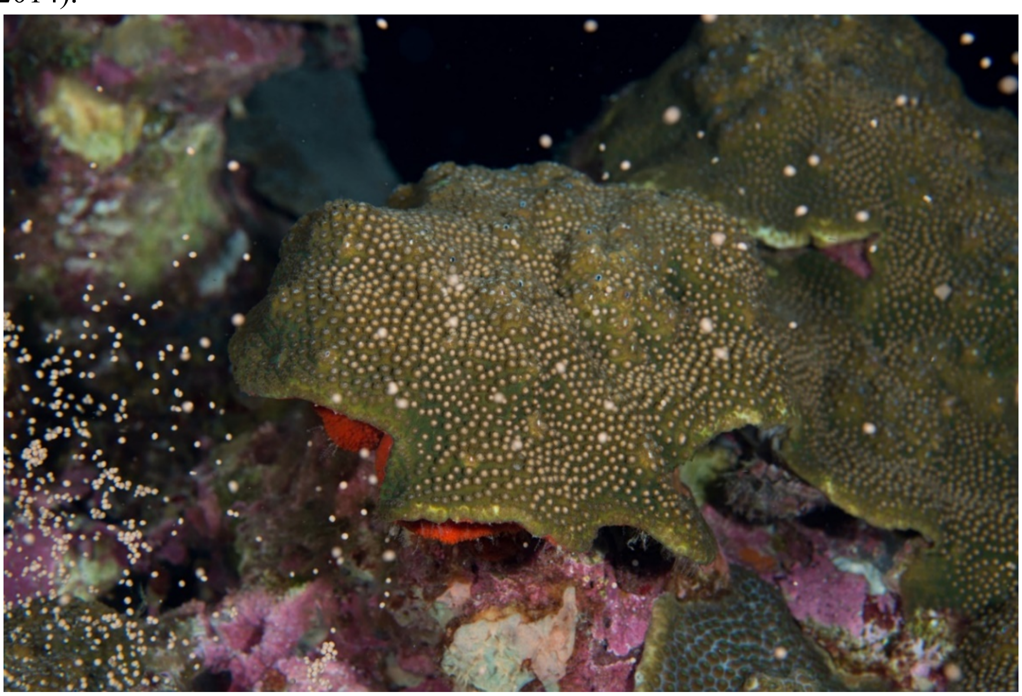

Figure 6. Boulder star coral (*Orbicella fraksi*) spawning at Flower Garden Banks National Marine Sanctuary (Image Courtesy: NOAA)

Reduced growth

Another important aspect of climate change is increased ocean acidification. Current atmospheric carbon dioxide (pCO_2) levels are approximately 387 ppm and is increasing by 0.5% per year (IPCC 2007). 387 ppm is 30% higher than the typical range over the last 650,000 years (Siegenthaler et al. 2005). The ocean pH is generally more alkaline than it is acidic. Increasing levels of carbon dioxide (CO_2) in the atmosphere causes the ocean to absorb more CO_2, which in turn, increases the presence of hydrogen ions in the water. This process forms carbonic acid and makes the oceans become "acidic".

Stony corals have hard skeletons made of calcium carbonate. Changes in ocean acidity can affect growth rates and levels of calcification. Higher concentrations of carbonic acid in the water could degrade the abilities of corals to form reefs and weaken the structural integrity of the existing corals. This translates to slower vertical reef growth and higher susceptibility to physical disturbances from wave-action. The keep-up and catch-up of corals are dependent upon the rate of sea-level rise and the rate of calcification. Coral reefs can drown if sea level rises faster than they can grow. Elevated pCO_2 also negatively affected fertilization success and reduced settlement on corals (e.g., *A. palmata*) (Albright et al. 2010).

Staghorn coral (*Acropora cervicornis)* exhibited no change in growth rates, but a decrease in calcification was observed as a result of increased pCO_2 (levels projected to occur by the end of the century)(Enochs et al. 2014a). However, samples of the mountainous star coral (*O. faveolata)* population collected in the Florida Keys from 1937- 1996 showed no evidence of change in calcification rates (Helmle et al. 2011). Additionally, increased pCO_2 is also known to negatively affect the fertilization success of corals (Albright et al. 2010).

1.5 Altered Life History of corals by Climate Change

Climate change and the life cycle of coral are tightly interlinked because climate change can alter life history. Elkhorn coral *(Acropora palmata)* experienced proportional growth rates similar to changes in sea surface temperature, until temperatures approached those at which bleaching can occur, at this point growth rates were decreased (Crabbe 2007). All this means is that with increased temperature there was increased growth rate, to a point. If it gets too hot, the growth rate decreased.

In the *Orbicella* species complex (lobed star coral *O. annularis,* mountainous star coral *O. faveolata*, and boulder star coral *O. franksi*) bleaching events observed in Panama from 2005 to 2010 caused a reduction in spawning density across the entire complex, which lasted for several years following the event. Of these species, *O. annularis* was most affected by the bleaching event, and *O. franksi* was least affected: however, *O. annularis* recovered the ability to spawn more quickly than *O. franksi* (Levitan et al. 2014).

Studies exposing Staghorn corals to pCO_2 levels projected to occur by the end of the century resulted in reduced calcification, but no reduction in linear extension. So while the growth rate may not change as a result of ocean acidification, the coral skeleton will be more fragile which could reduce the resilience of the species (Enochs et al. 2014b; Dee et al. 2019).

1.6 Indirect Effects of Climate Change

Disease outbreak and prevalence

Climate change and elevated SST can impact the incidence and severity of disease on corals. Some of the most common coral diseases include white band disease, black band disease, and white plague infection. Extensive research has been conducted on this relationship and overarchingly suggests that bleaching can lead to a greater risk of disease and that diseased corals are at a greater risk of bleaching.

A mass bleaching event in the Florida Keys in 2005 was followed by an outbreak of coral diseases. The extent of bleaching on colonies of *O. faveolata* was significantly greater in diseased colonies than colonies without the disease (Brandt and Mcmanus 2009). Another disease found in the Florida Keys is black band disease, which is most common during summer and early fall and is associated with temperatures greater than 29 °C. While *Dendrogyra cylindrus* are not commonly affected by black band disease, it was observed in 2014 and 2015 for the first time, immediately following a high-temperature bleaching event. The disease was seen in about 5% of *D. cylindrus* in 2014 and about 7% in 2015 (Lewis et al. 2017). The spread of white-band disease in *A. cervicornis* and *A. palmata* has increased significantly with increasing sea surface temperature (Randall and Van Woesik 2015). Additionally, the white-band prevalence in elkhorn coral was positively related to changes in water temperature (Muller et al. 2008)

White band disease has caused significant die-off (Vollmer and Palumbi 2007; Hemond and Vollmer 2010), and in the Florida Keys in 2002/2003, the disease impacted at least 72% of tagged colonies (Figure 7). White band disease is transmitted by *Coralliphila abbreviate* (a corallivorous snail) via contact with *A. palmata* (Williams and Miller 2005).

Figure 7. Disease affected Elliptical Star Coral *(Dichocoenia stokesi)* at Florida Keys National Marine Sanctuary (Image Courtesy: FKNMS)

Increasing ocean temperatures also contribute to disease prevalence in pillar corals (*D. cylindrus)*. When temperatures exceed 29°C on the Florida Reef Tract, black band disease has been reported in *D. cylindrus*. In 2014, 4.7% of surveyed *D. cylindrus* had been impacted by black band disease, and in 2015 that increased to 6.8%. In each case, the disease appeared immediately following a hyperthermal event (Lewis et al. 2017). The temperature certainly affects this species, as a bleaching event in Puerto Rico in 2005 impacted more than 90% of colonies surveyed there (García-Sais et al. 2017).

White plague and yellow band disease have resulted in *O. annularis* population declines in Puerto Rico where they have persisted in populations long-term. An outbreak was still manifesting in affected colonies four years later (Bruckner and Bruckner 2006).

1.7 Conclusion

Rising ocean temperatures and global climatic changes are among the primary threats to coral reefs around the world, as well as in the Gulf (Anthony et al. 2015). Coral bleaching has likely been one of the most important factors that have affected coral reefs in the Gulf and wider Caribbean region over the last 30 years; the 2005 bleaching was recorded as the most intense event of this type in the region.

Climate change will undoubtedly be the major factor determining the future survival of most coral reef and associated organisms, impacting them through all life stages and through a variety of mechanisms. Recent ecological advances provide some capacity for predicting the future, but great uncertainty remains. More research needs to be given to identify the potential for acclimation and adaptation of reef organisms to a changing climate. Ultimately, it is the potential for species to adapt that will determine whether tolerance limits can keep pace with the changing environment.

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