Changes in Belize Coral Reef Bivalve Assemblages Over Time Contradicts What is Seen in Panama

by

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Abstract

Caribbean coral reef ecosystem health has drastically declined since large-scale monitoring began in the 1970s, due to local human stressors and climate change. However, we know less about anthropogenic change on Caribbean reefs before monitoring began. Reef sediment cores can help provide context for understanding the causes and consequences of changes in reef ecosystems as they can provide a millennial-scale record of reef communities and environments. For example, reef sediment cores from Panama suggest that coral reef decline began as early as the 18th century and was closely linked to land use change. We utilized bivalve subfossils preserved within a 3.5m-long sediment core collected from a lagoonal reef in central Belize to track changes in reef environmental conditions from the early 1500s to the late 1930s. In the bottom of the core, dating to 1516, the percent of infaunal bivalves is 0.48%. In the top of the core, dating to 1938, the percent of infaunal bivalves increased to 39.13%. The increase of infaunal bivalve species suggests a loss of hard substrate in the reef ecosystem. This trend has been observed in other places around the Caribbean, and suggests a loss in coral reef substrate, possibly due to changes in water quality and/or a loss of reef herbivory from fishing. This later loss is contrasting what is seen in Panama, where there is loss as early as the 1700s.

1. Introduction

1.1 Background of Coral Reef Decline

Following the beginning of large-scale monitoring of reefs in the 1970s, there has been a recorded loss of almost 50% of live reef-building corals (Cramer et al 2015). Many of these reef-building corals have been replaced by macroalgae and corals which are tolerant of low water quality (Cramer et al 2020). However, because wide-spread reef monitoring only began in the 1970s and previous data is sparse, we cannot accurately construct an ecological baseline from the available monitoring data.

Additionally, this 50% average of reef decline could be underestimated due to the limited knowledge of the spatial distribution of coral reefs throughout time (McClenachan et al 2017). An analysis of British Imperial nautical charts from the 18th century has supplied useful data regarding this gap in our knowledge. Analyzing these charts shows an average loss of about 52% live corals with some areas reaching almost 90% loss since the 1770s (McClenachan et al 2017). Much of this massive loss of live coral cover is due to coral bleaching events and disease epidemics. These events can be mainly attributed to anthropogenic climate change, overfishing, changes in land use, and run-off pollutants (Cramer et al 2012, 2015). Coral bleaching is largely caused by the rise in global sea water temperature. Corals live symbiotically with zooxanthellae algae which cannot live at such high temperatures, causing the corals which host them to expel the algae and starve (Pelley 2004). But these bleaching events aren't the only cause of coral decline, there have been numerous outbreaks of diseases which are wiping out coral colonies worldwide, like white band disease in acroporid corals and black band disease which has been observed on about 42 different species (Green and Bruckner 2000). In addition to this, overfishing and land run-off are causing a loss of grazing species as well as an increase of algae and seaweed (Pelley 2004). All of these combined factors are resulting in the drastic shift of coral dominated reefs to algae and seaweed dominated environments (Pelley 2004).

While the dramatic loss of corals and the biodiversity their reefs host is a tragic loss, some ask why we should care. Outside of the fact that much of this loss is the result of human activities, the economies of many countries which border coral reefs, making up about two-fifths of the total global population, depend on their health for tourism, coastal protection, and fisheries. It is estimated that healthy coral reefs can bring in around US$ 30 billion worldwide (Cesar et al 2003). Understanding all that we can about coral reefs is critical to preserving them for future generations as well as for the life they currently support.

1.2 Molluscs as Environmental Indicators

The majority of reef monitoring efforts focus on corals, algae, urchins, and fish, with little work focusing on other reef organisms or on reconstructing environmental factors like water quality and clarity. Bivalve and gastropod molluscs are abundant, diverse, and their ecologies are well-documented, making them important indicators of environmental conditions. The dominant feeding habits and substrate relationships observed in these molluscs have been used to determine changing environmental conditions in reefs such as: substrate, turbidity, salinity, and stress (Cramer et al 2015).

Within the category of substrate relationships, there are two main relationships to look for: infaunal and epifaunal. Epifaunal bivalves attach themselves to hard substrates, like coral, therefore epifaunal dominated environments are indicative of higher coral cover, living or dead (Leonard-Pingel et al 2012, Stanley 1970). In contrast, infaunal bivalves live within or on the sediment at the floor, therefore infaunal dominated environments are indicative of low coral cover and high amounts of available soft substrate (Cramer et al 2015, Leonard-Pingel et al

2012). As for feeding habits, there are a few relevant groupings: suspension feeders as well as subsurface, surface, and chemosymbiotic deposit feeders. Chemosymbiotic bivalve dominance is indicative of low to no oxygen environments (Cramer et al 2015). Prevalence of suspension feeders is indicative of high wave action and/or low sediment suspension with coarser grained sediments, while the prevalence of other deposit feeders is indicative of low flow conditions and/or high organic debris with finer grained sediments (Cramer et al 2015, Stanley 1970). Additionally, the dominance of deposit feeding bivalves can be indicative of shallow water, seagrass dominated environments (Leonard-Pingel et al 2012).

1.3 Belize and its Reefs

The Belize Barrier Reef System is the largest reef system in the western hemisphere and has some of the highest marine biodiversity in the Atlantic (Gibson et al 1998). Because of this, the reef system has become a marine tourist attraction which draws in money but also can cause harm to the ecosystem (Gibson et al 1998). In comparison to other reefs of the Caribbean, the Belize Barrier Reef System is in good health. This is due to a number of factors including early conservation efforts in the form of establishing national parks, protected marine areas, and bird sanctuaries, as well as lack of Imperial British banana plantations like we see in other areas of the Caribbean. (Claudino-Sales 2019). Additionally, modern conservation efforts by the government include an integrated coastal management plan and establishing the reefs as World Heritage sites in 1996 have helped to maintain reef biodiversity and health (Claudino-Sales 2019).

When looking at reef health in other areas of the Caribbean, specifically in Panama where similar research has been conducted, we see reef degradation as early as the 1700s which has been associated with the implementation of banana plantations in the area (Cramer et al 2017, 2019).

Taking a look at the land-use changes of Belize, there is no record of major changes other than mahogany logging (Church et al 2019) until the Stann Creek banana plantations of the 1880s (Moberg 1996).

Looking through time, Belize's reefs have withstood many natural disasters. Specifically, between 1950 CE and 1980 CE, there was consistent *Acropora* growth in Coral Gardens, Belize whereas in other areas of the Caribbean there was widespread coral die off (Greer et al 2020). This is not just a recent observation, these corals have been resilient (i.e. had consistent growth) for at least a century (Greer et al 2020).

1.4 Research Questions and Hypothesis

Here, we examine the bivalve assemblage of a ~3.5 m core collected from Bakers Rendezvous, Belize to explore changes in the bivalve community through time. Variation in the proportion of epifaunal bivalves through time could be indicators of fewer available hard substrates (e.g. less reef) (Cramer et al 2015), changes in specific bivalve genera (e.g. *Dendostrea*) may also indicate changes in the species composition of reef corals (Cramer et al 2015), increasing proportions of chemosymbiotic deposit feeding bivalves (e.g. *Lucinidae*) are indicative of a low oxygen environment (Cramer et al 2015).

When conducting this research, there were a few things to look for. Answering these questions will be important for determining a baseline of ecological change in the area.

- Are there changes in dominance of a certain substrate relationship (e.g. epifaunal and infaunal) over time?
- Are there changes in dominance of a certain feeding type (e.g. chemosymbiotic deposit feeders) over time?

- Is there a significant relationship between *Dendostrea* and one of its host corals *A. cervicornis* over time?
- Are there any significant changes of *A. cervicornis* over time?

The lack of imperial banana plantations, such as the ones evident in Panama and other areas in the Caribbean, would indicate a healthier reef over historical time. Therefore, we should see a dominance of epifaunal bivalves throughout the core, indicating higher coral cover or availability of other hard substrate.

2. Methods

The core was collected in rubble zones adjacent to living coral reefs near Bakers Rendezvous, therefore the top of the core is not modern, and instead represents the last active coral growth at that area. Using SCUBA, collectors utilized a combination of push-coring and vibra-coring techniques to collect the ~3.5m long core.

Five total dates were acquired using Uranium-Thorium (U-Th) dating for this core, one at every 0.5m and an additional one at the bottom. These were used to assign a calendar year to every section of the core.

The core was sectioned into ~5cm sections and sieved such that only particles >2mm remained for taxonomic analysis. Using a dissecting microscope and tweezers, the sieve residue was picked through to pull out bivalve valves and valve fragments to set aside for identification. To count each valve as an individual, there needed to be an intact hinge and umbo (Gilinsky and Bennington 1994). They were identified to the lowest taxonomic level possible, typically to genus but to family if it was not possible to go further, which was done using Keen (1971) and Redfern (2003). Using the NMITA database (1996), mobility, substrate relationship, and shell fixation were determined for each taxonomic group. The proportional abundances of these groups, as well as select genera, were graphed against dates obtained using the U-Th dating to observe changes to the community throughout the time period of the core.

3. Results and Discussion

3.1 Bivalves as Environmental Indicators

For most of the core from Bakers Rendezvous, which stretches from 1516 CE to 1938 CE, epifaunal bivalves are dominant, staying between 85% - 100% of the total bivalves, as seen in Figure 1 below. However, around the 1920s there is an abrupt and large drop in the percentage so that the amount of infaunal and epifaunal bivalves are almost equal. After this event, the amount of epifaunal bivalves began to increase again reaching 71.43% at the top of the core.

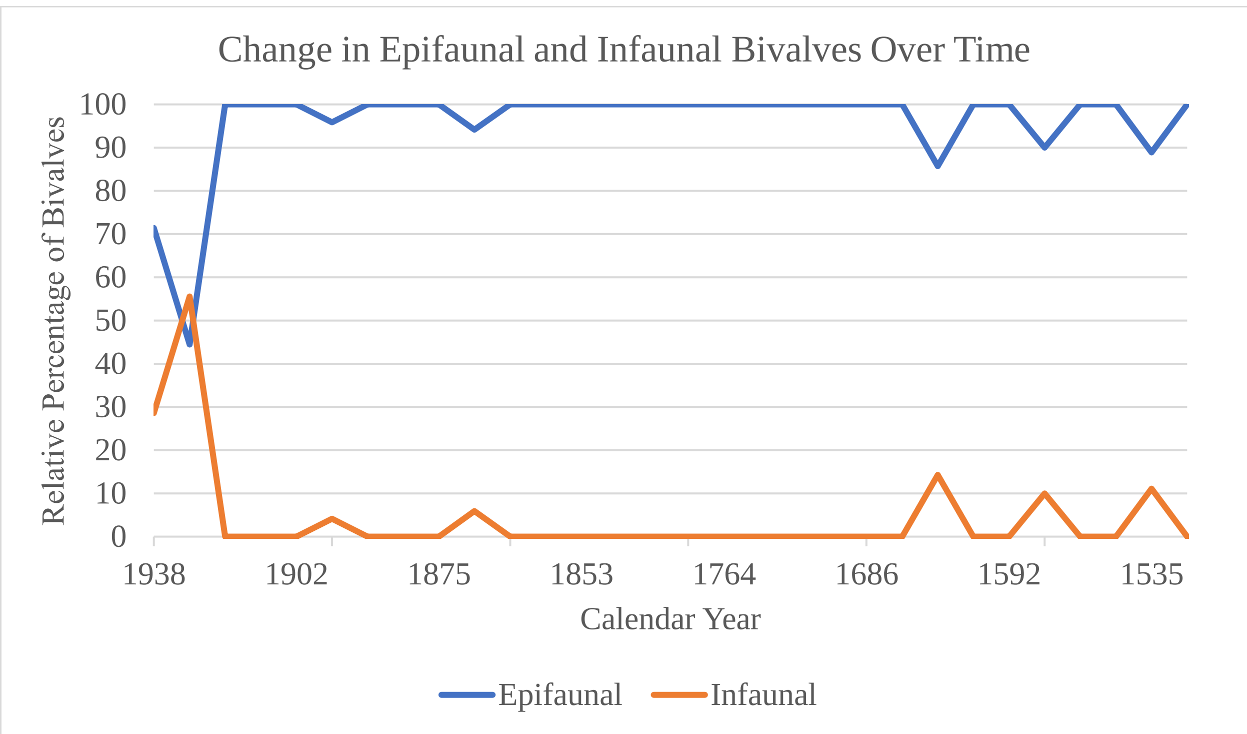

Figure 1: Relative percentage of epifaunal and infaunal bivalves over time

The dominance of epifaunal bivalves throughout the core shows that there are larger amounts of hard substrates available whether that be rocks, live or dead corals, or both. This shows that there should be a relatively healthy reef throughout the length of the core. However, we see the drastic shift to an almost equal amount of epifaunal and infaunal bivalves at about 44% and 56% respectively. Because there was a recovery afterwards, this could be linked to an event which caused a massive die off of epifaunal bivalves and created an environment where infaunal bivalves would flourish. Because there were no chemosymbiotic deposit feeding bivalves throughout the entirety of the core, we can assume that there were acceptable oxygen levels in this reef throughout the length of this core, 1516 CE-1938 CE. In fact, bivalves from the core show very little variability in feeding habit; all of the bivalves identified were suspension feeders, suggesting that the substrate was relatively coarse-grained (e.g. sand-sized particles) and low in organic content.

3.2 A Closer Look at Dendostrea and A. cervicornis

The percentages of the genus *Dendostrea* vary quite a bit through the core but seem to be holding a pattern until the early 1900s when their numbers decrease and stay low.

While there appears to be a correlation between the relative abundance of *Dendostrea* with one of its host corals *Acropora cervicornis*, the correlation is weak and statistically insignificant (Pearson's $r = 0.157$ $p = 0.426$).

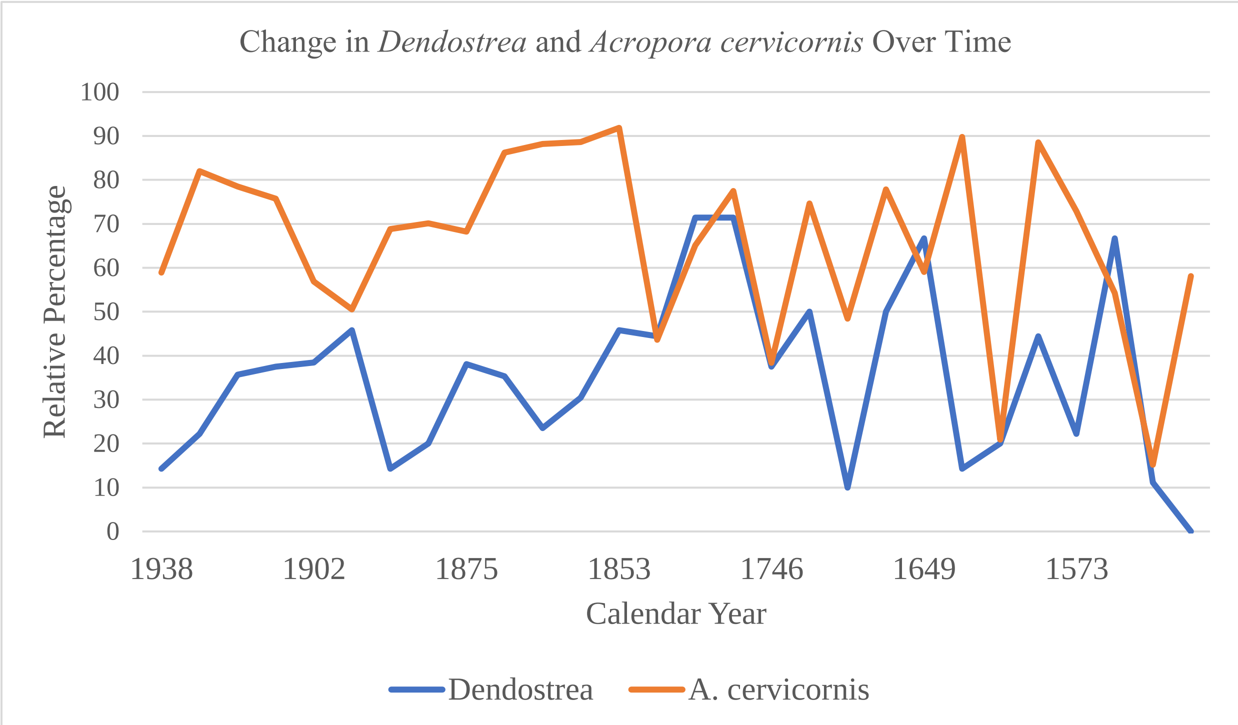

Figure 2: Relative percentage of Dendostrea and A. cervicornis over time

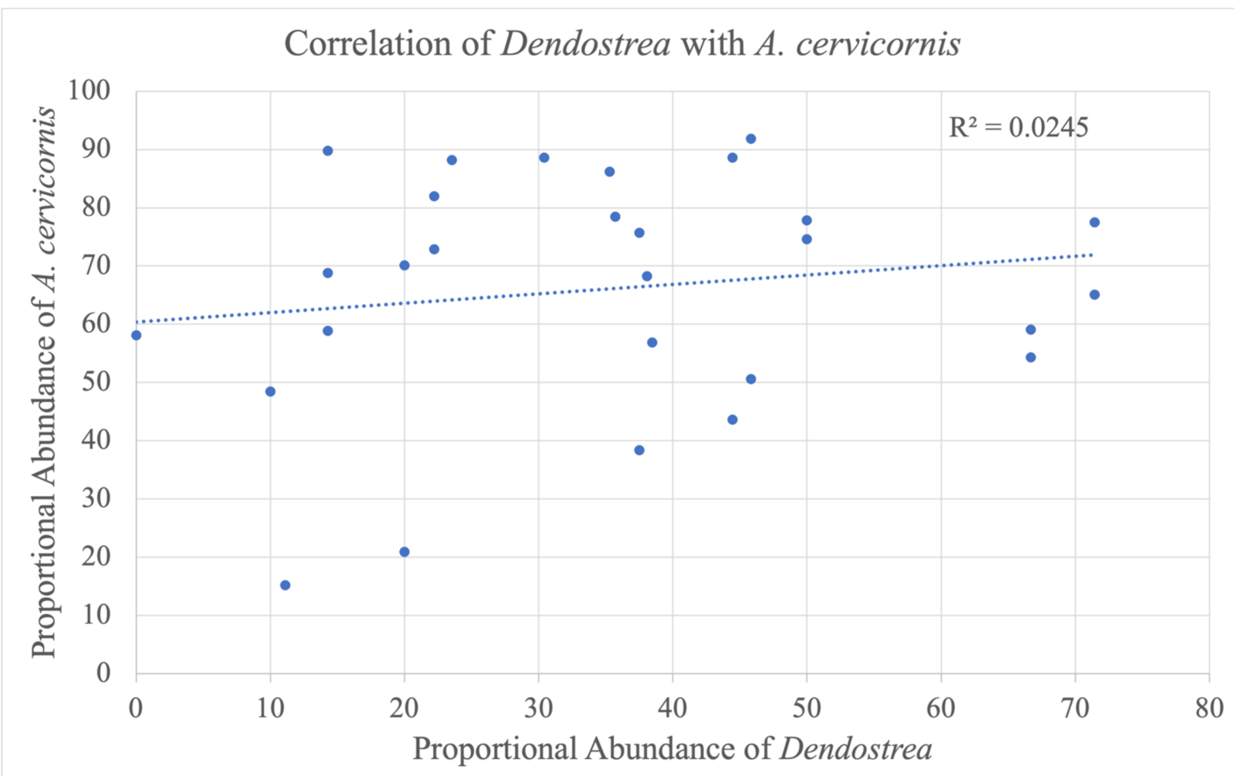

Figure 3: Correlation of the proportional abundances of Dendostrea and Acropora cervicornis

	Dendostrea	*A. cervicornis*
Dendostrea	364.075996	
A. cervicornis	58.9794604	389.25862

Table 1: Covariance table of Dendostrea and A. cervicornis

	Dendostrea	*A. cervicornis*
Dendostrea	1	
A. cervicornis	0.156669931	1

Table 2: Correlation table of Dendostrea and A. cervicornis

The lack of significance in the correlation between *Dendostrea* and *A. cervicornis* was surprising, because they appear to co-vary in the core. This apparent lack of correlation could be attributed to differential preservation, as corals have a much more robust skeleton than bivalves. It could also be explained by how the corals and bivalves were counted. All coral pieces were counted and identified, but we only counted bivalve shells with a hinge, so it is likely that *Dendostrea* were undercounted compared to *A. cervicornis*. Additionally, *A. cervicornis* is not the only host coral for *Dendostrea*, they are also found on soft corals which aren't preserved so it is hard to say whether they were present in this area.

While they appear to co-vary through the core, this seems to stop around 1819. So, to determine if this was the case, more tests were run. While there was a difference in covariance and correlation compared to each half, as well as to the original statistics run, the p-values were high and therefore not significant. This lack of significance could also be explained by the reasons listed above.

3.3 Changes in Corals

As seen in Figure 4, there is fluctuation in the amount of *A. cervicornis* present in the core. It appears that there is major loss of coral around 1535 and 1611 as well as more steady loss from about 1853 through 1938. However, looking at Figure 2, the total amount of coral by weight seems to be increasing during these times.

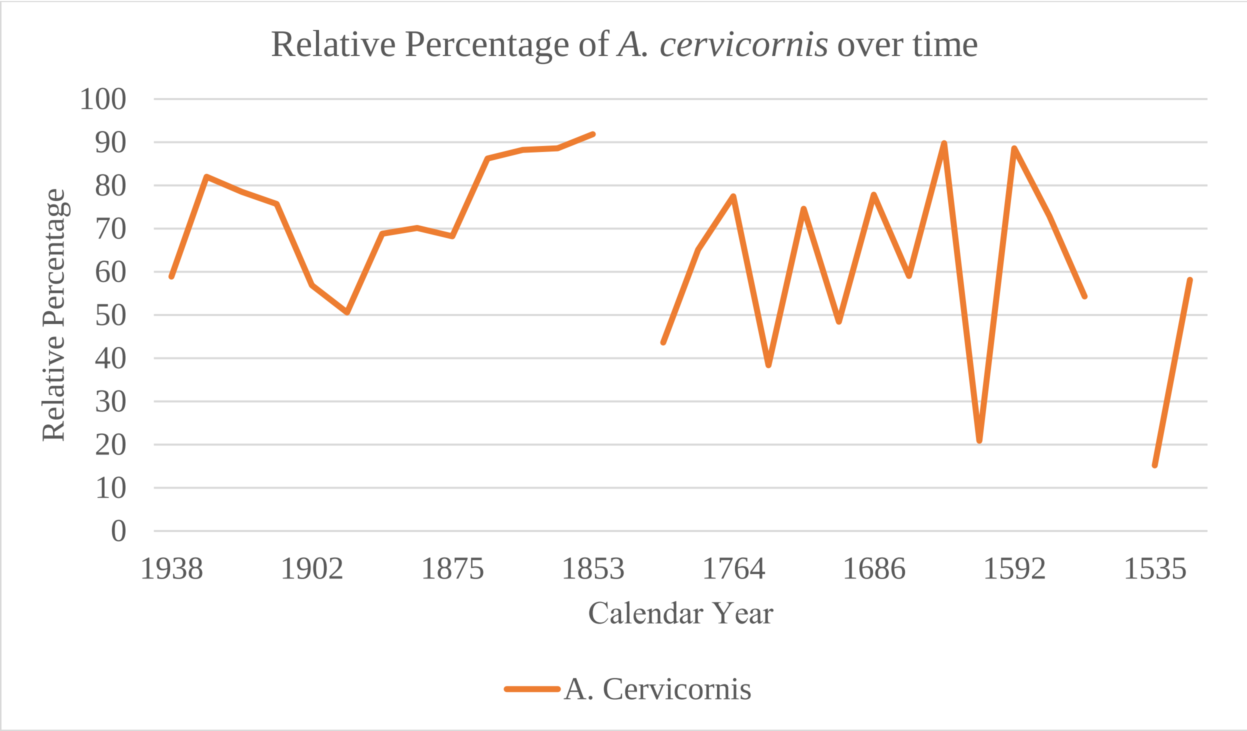

Figure 4: Relative percentage of Acropora cervicornis corals over time

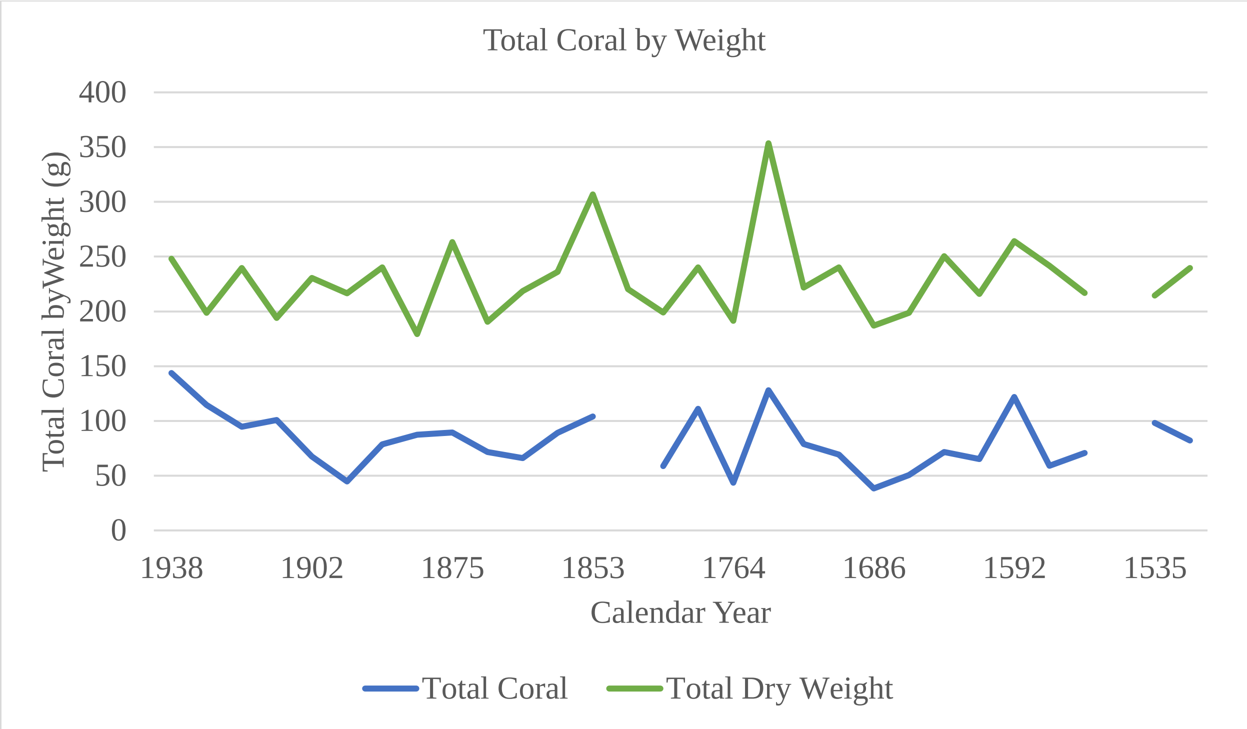

Figure 5: Total coral abundance by weight compared to the total weight of core over time

This loss of *A. cervicornis* coral and subsequent increase of total coral could indicate replacement with other coral species during these times. Looking back to Figure 1, the loss of *A. cervicornis* seems to correspond to the fluctuations of epifaunal bivalves we see for most of the core.

Overall, here we are seeing relatively normal fluctuations of *A. cervicornis* which contrasts what has been seen in Panama where there is drastic loss of these corals (Cramer et al 2015).

4. Conclusions

Throughout the core, there are few indicators of reef degradation until the very top of the core, the early 1900s. We found no chemosymbiotic deposit feeders (e.g. *Lucinidae*), indicating that anoxic, hypoxic, or low-flow conditions (Cramer et al. 2019), did not exist on this reef during the time period captured in the core. We also found that epifaunal bivalves (including *Dendostrea*) dominate throughout the core until the early 1900s. This probably indicates a healthy coral reef with lots of available hard substrates for corals to attach to, with little degradation until the early 1900s. Changes in reef health in the early 1900s, as indicated by the decrease in epifaunal bivalves and *A. cervicornis* corals, may be related to land clearing and establishment of banana plantations in the Stann Creek district in the 1880s (Moberg 1996). In general, bivalves from this core collected at Bakers Rendezvous suggest healthy reefs through almost the entirety of the core. This is in direct contrast to similar studies in Panama that indicate reef degradation as early as the 1700s (Cramer et al. 2017; 2019).

These results are very interesting, especially compared to what has been seen in a similar study in Panama. It would be beneficial to do similar work around the Caribbean to understand the regional trends and establish a baseline of information which would benefit conservation efforts.

5. References

1. Cesar, Herman, et al. *The Economics of Worldwide Coral Reef Degradation*. Cesar Environmental Eco-Nomics Consulting (CEEC), Feb 2003
2. Church M.C. et al. Re-Centering the Narrative: British Colonial Memory and the San Pedro Maya. In: Orser Jr. C. (eds) Archaeologies of the British in Latin America. Contributions To Global Historical Archaeology. 2019. Springer, Cham. https://doi.org/10.1007/978-3-319-95426-4_5

3. Claudino-Sales V. Belize Barrier Reef System, Belize. In: Coastal World Heritage Sites. Coastal Research Library, vol 28, 2019. Springer, Dordrecht. https://doi.org/10.1007/978-94-024-1528-5_66
4. Cramer, Katie L., et al. “Anthropogenic Mortality on Coral Reefs in Caribbean Panama Predates Coral Disease and Bleaching.” *Ecology Letters*, vol. 15, no. 6, 2012, pp. 561–567., https://doi.org/10.1111/j.1461-0248.2012.01768.x.
5. Cramer, Katie L., et al. “Millennial-Scale Change in the Structure of a Caribbean Reef Ecosystem and the Role of Human and Natural Disturbance.” *Ecography*, vol. 43, no. 2, 2020, pp. 283–293., https://doi.org/10.1111/ecog.04722.
6. Cramer, Katie L., et al. “Molluscan Subfossil Assemblages Reveal the Long-Term Deterioration of Coral Reef Environments in Caribbean Panama.” *Marine Pollution Bulletin*, vol. 96, no. 1-2, 2015, pp. 176–187., https://doi.org/10.1016/j.marpolbul.2015.05.031.
7. Cramer, Katie L., et al. “Prehistorical and Historical Declines in Caribbean Coral Reef Accretion Rates Driven by Loss of Parrotfish.” *Nature Communications*, vol. 8, no. 1, 2017, https://doi.org/10.1038/ncomms14160.
8. Gibson, J, et al. “Coral Reef Management in Belize: An Approach through Integrated Coastal Zone Management.” *Ocean & Coastal Management*, vol. 39, no. 3, 1998, pp. 229–244., doi:10.1016/s0964-5691(98)00007-6.
9. Gilinsky, Norman L., and Bennington, J Bret. “Estimating Numbers of Whole Individuals from Collections of Body Parts: A Taphonomic Limitation of the Paleontological Record.” *Paleobiology*, vol. 20, no. 2, 1994, pp. 245–258., doi:10.1017/s0094837300012719.

10. Green, Edmund P., and Bruckner, Andrew W. “The Significance of Coral Disease Epizootiology for Coral Reef Conservation.” *Biological Conservation*, vol. 96, no. 3, 2000, pp. 347–361., doi:10.1016/s0006-3207(00)00073-2.
11. Greer L, et al. Coral Gardens Reef, Belize: A refugium in the face of Caribbean- wide Acropora spp. coral decline. PLoS ONE 15(9): e0239267. 2020. https://doi.org/10.1371/journal. pone.0239267
12. Keen, A. Myra. *Sea Shells of Tropical West America; Marine Mollusks from Baja California to Peru*. Stanford University Press, 1971.
13. Leonard-Pingel, Jill S., et al. “Changes in Bivalve Functional and Assemblage Ecology in Response to Environmental Change in the Caribbean Neogene.” *Paleobiology*, vol. 38, no. 4, 2012, pp. 509–524., doi:10.1666/10050.1.
14. McClenachan, Loren, et al. “Ghost Reefs: Nautical Charts Document Large Spatial Scale of Coral Reef Loss over 240 Years.” *Science Advances*, vol. 3, no. 9, 2017, doi:10.1126/sciadv.1603155.
15. Moberg, Mark. “Crown Colony as Banana Republic: The United Fruit Company in British Honduras, 1900–1920.” *Journal of Latin American Studies*, vol. 28, no. 2, 1996, pp. 357–381., doi:10.1017/s0022216x00013043.
16. Pelley, Janet. “Untangling the Causes of Coral Reef Decline.” *Environmental News Perspective - American Chemical Society*, 1 Aug 2004, pubs.acs.org/doi/pdf/10.1021/es040590r.
17. Redfern, Colin. *Bahamian Seashells: 1161 Species from Abaco, Bahamas*. Bahamianseashells.com, Inc, 2013.

18. Stanley, Steven M. *Relation of Shell Form to Life Habits of the Bivalvia*. The Geological Society of America, Inc, 1970.

19. Todd, Johnathan A. “Bivalve Life Habits Database.” *Neogene Marine Biota of Tropical America*, https://nmita.rsmas.miami.edu/database/bivalves/Bivalve_eco.html.

20. Todd, Johnathan A. “Introduction to Molluscan Life Habits Databases.” *Neogene Marine Biota of Tropical America*, https://nmita.rsmas.miami.edu/database/mollusc/mollusclifestyles.htm.