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INTRODUCTION

Coral Gardens is a diverse reef system located off the east coast of Belize and westward from the primary barrier reef complex in the region (Fig. 1, Greer et al., this volume). Some areas of Coral Gardens are characterized by large patch reefs (up to ~15x30 m) dominated by acroporid corals with a high percentage of live coral cover; while other areas exhibit much lower percentages of live coral. In areas with a high percentage of coral cover, some strands of *A. cervicornis* show distinct evidence for growth alignment due to the tendency of their branches to grow in a single direction. This study uses two transects within this patch reef system (transects 1 and 5), to compare the differences in the quality of growth alignment of *A. cervicornis.* These two transects were chosen for detailed data collection and analysis because they exhibit obvious differences in percent live coral cover and alignment in the field. Figure 1 is a photograph of *A. cervicornis* from transect 5 that shows this growth alignment.

A few previous studies have examined the growth patterns of branching corals; some of these studies focused specifically on *A. cervicornis*. Chamberlain and Graus (1975) examined how water flow through branching corals affects their growth. Their study determined that a coral species may grow differently depending on the velocity of the current that flows around and through it; branching coral species have optimal flow velocities that allow them to grow healthier (Chamberlain and Graus, 1975). Their study also suggested that the branching morphology of the coral affects its possible food source. Loosely branched corals waste significant potential resources because the nutrients can flow readily around the branches. Tightly branched corals make better use of their resources because the food cannot escape around

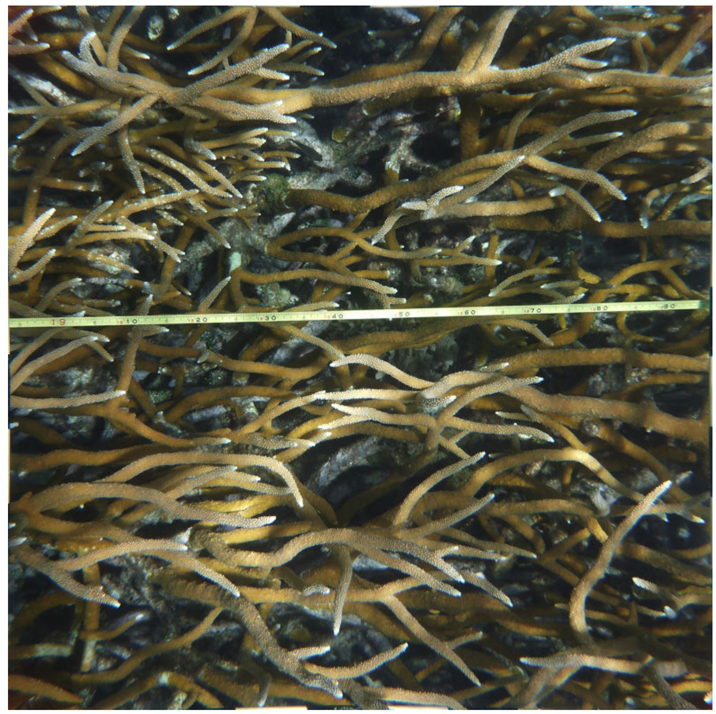

Figure 1. Photograph of Acroprora cervicornis from quadrat 17 of transect 5. The alignment of the coral branches can be seen as most of the branches are pointing toward the right.

the branches as easily (Chamberlain and Graus, 1975).

A study by Bottjer (1980) reviewed the differences in morphology of *A. cervicornis* in low-energy systems (usually deeper) compared to high-energy systems (usually shallower). In this study, a 90 m long transect was laid out along reef near San Salvador, Bahamas and split it into two separate patches. A plexiglas protractor was used to measure the orientations of the *A. cervicornis* branches. The branch measurements were divided into two categories, 1st order and 2nd order. 1st order branches were the smaller coral tips that grew from the thicker coral branches. The thicker branches that had 1st order branches growing from them were considered 2nd order branches. Bottjer (1980) noticed that almost all of the branches were aligned in one direction and that the current in the area was parallel with the direction the branches were growing. With this information, Bottjer (1980) determined that the preferred orientation may have made the branches less susceptible to breakage in strong prevailing currents and/or storms.

Using advances in image analysis technology, this study analyzes a much larger data set with more advanced statistics. The goals of this project were to: (1) calculate the direction of coral alignment along transects 1 and 5 at Coral Gardens with statistical analysis, (2) hypothesize on the factors that affect the alignment of *A. cervicornis*, and (3) define the reasons why transects 1 and 5 are so different from each other.

METHODS

Field

Data for this project was based largely off of photographs taken of transects 1 and 5. Photos were taken while floating directly above a 1 m^2 quadrat that was placed on top of the *A. cervicornis* at each meter along each transect. Photos were also taken around the perimeters of the reefs so that the outer portions of the reef could be compared to data from the transects, which were positioned through the middle of the reef. Data was also collected by Gregory Mak, who assembled bathymetry data by swimming along each transect while lowering a depth gauge to the seafloor.

Lab

Lab work began with drawing lines using ImageJ on top of the *A. cervicornis* branches on the photos that were taken. ImageJ is a program that allows its users to draw straight lines and that provides the direction of these drawn lines. As the lines were drawn on top of the branches the data was divided into 1st and 2nd order branches, following the branch definition of Bottjer (1980). This directional data from ImageJ of the coral branches was then input into spreadsheets. The photos used were not originally oriented, but the ImageJ data was corrected within the spreadsheets so that the directional values represented true azimuth directions.

The compiled data was used to make rose diagrams so that the orientation of the branches could be easily observed graphically and analyzed statistically. The program Stereonet was selected for the rose diagrams, because it allows its users to input data sets that can quickly be converted into circular graphs. Rose diagrams were made for the 1st and 2nd order branches of every individual quadrat in both transects 1 and 5. Then, summary rose diagrams for transects 1 and 5 were also made to represent all of the 1st order data and the 2nd order data.

Statistics on the orientation data were run with the program Oriana. Oriana is a user-friendly software package that can run a series of tests on large data sets and quickly find results. A list of the statistical tests that were used in this study, along with brief definitions of each test are shown below (Kovach, 2011). Holistically, these tests helped determine if an individual data set shows uniformity in its distribution or if it shows a preferred direction. Statistical tests used in this study include: mean vector, length of mean vector, median, concentration, circular variance, circular standard deviation, standard error of mean, Rayleigh Test (p), and Watson's Test.

Specific coral data were also analyzed by Erin Peeling, who calculated the percentage of live coral cover for each transect using the program MATLAB. This percentage data was used to compare the differences between the quality and density of coral branches in transects 1 and 5.

RESULTS

Rose Diagrams

This study required a graphical method to visually represent the differences between branch alignment in transect 1 and transect 5. To do this, rose diagrams were made for each order branch of each transect. Rose diagram software is useful, because it allows for both qualitative and quantitative (statistical) analysis of the data. Two significant rose diagrams, shown in Figure 2, contain all of the 1st order data from transects 1 and 5. The 1st order data is presented because there is more data from the 1st order branches than the 2nd order branches; therefore, statistical analyses are more robust.

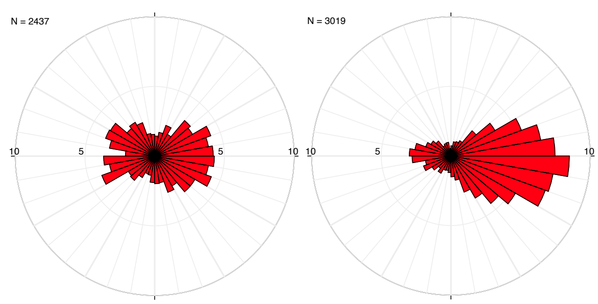

Figure 2. Rose diagrams for all of the 1st order data from transect 1 (left) and transect 5 (right). The rose diagrams for transect 5 shows a much stronger preferred direction toward the east than transect 1.

Bathymetry

Figure 3 depicts the bathymetry along transects 1 and 5. The bathymetry shown represents the depth below sea level vs. distance (from W to E) so that the profiles of the reefs can be easily visualized. Both transects show distinct differences in their bathymetry. Transect 1 contains multiple peaks that show that the depth of the coral top changes throughout its length. Transect 5 has a much flatter top that shows that the depth stays consistent through most of its length. Due to these morphological differences, the majority of transect 5 is shallower than transect 1.

2nd order rose diagrams were inserted beneath Figure 3 to show the trends of the branches at several selected depths along each transect. One interesting observation is that there was no live coral in transect 1, quadrats 20 and 21. These quadrats are located at a noteworthy point along the bathymetric profile, where the reef drops about a meter in depth as the current flows from east to west. Another important observation is that all of the quadrats in transect 5 were filled with live coral.

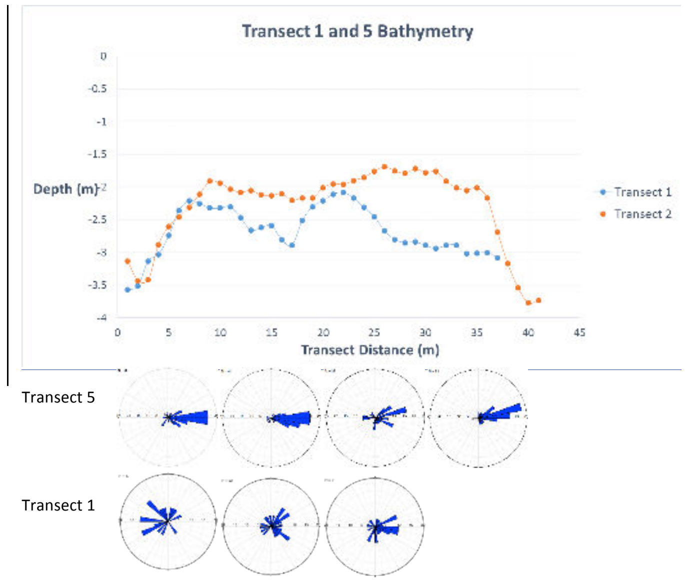

Figure 3. Graph showing the bathymetric profile along transects 1 and 5. The bathymetry shows that transect 5 is shallower with fewer peaks than transect 1. The rose diagrams beneath the graph represent the second order branches for transects 1 and 5 at quadrats 5, 15, 25, and 35. There is not a rose diagram for transect 1 at quadrat 35, because there was no live coral present within the quadrat.

Percentage Live Coral Cover/Statistics

The percent live coral cover is important because it shows which transects contain the most densely packed coral, allowing comparisons to be made between each transect. The percentage live coral cover for transect 1 was 14.3% and for transect 5 was 50.3%.

Oriana contains a fairly robust statistical package, so selected tests were run on the transect data sets. Data calculated by Oriana is shown below in Figure 4. The statistics in Figure 4 distinguish all 1st order and 2nd order statistics from transects 1 and 5. However, the statistics from the individual quadrats contained results that show important differences with respect to growth alignment. According to the Rayleigh Test (p), 24% of 1st order quadrats and 14% of 2nd order quadrats from transect 1 showed a preferred orientation. Meanwhile, 81% of the 1st order quadrats and 77% of the 2nd order quadrats from transect 5 showed a preferred orientation.

DISCUSSION

T1 All 1st order data		T5 All 1st order data	
Number of Observations	2437	Number of Observations	4465
Mean Vector (μ)	81.426°	Mean Vector (μ)	101.802°
Length of Mean Vector (r)	0.07	Length of Mean Vector (r)	0.326
Median	85°	Median	99°
Concentration	0.14	Concentration	0.69
Circular Variance	0.93	Circular Variance	0.674
Circular Standard Deviation	132.252°	Circular Standard Deviation	85.756°
Standard Error of Mean	11.765°	Standard Error of Mean	1.807°
Rayleigh Test (Z)	11.829	Rayleigh Test (Z)	475.242
Rayleigh Test (p)	7.29E-06	Rayleigh Test (p)	< 1E-12
Watson's U² Test (Uniform, U²)	1.952	Watson's U² Test (Uniform, U²)	32.533
Watson's U² Test (p)	< 0.005	Watson's U² Test (p)	< 0.005

T1 All 2nd order data		T5 All 2nd order data	
Number of Observations	690	Number of Observations	1183
Mean Vector (μ)	94.004°	Mean Vector (μ)	98.241°
Length of Mean Vector (r)	0.103	Length of Mean Vector (r)	0.453
Median	101°	Median	96°
Concentration	0.207	Concentration	1.016
Circular Variance	0.897	Circular Variance	0.547
Circular Standard Deviation	122.189°	Circular Standard Deviation	72.078°
Standard Error of Mean	14.949°	Standard Error of Mean	2.455°
Rayleigh Test (Z)	7.306	Rayleigh Test (Z)	243.044
Rayleigh Test (p)	6.72E-04	Rayleigh Test (p)	< 1E-12
Watson's U² Test (Uniform, U²)	0.611	Watson's U² Test (Uniform, U²)	16.262
Watson's U² Test (p)	< 0.005	Watson's U² Test (p)	< 0.005

Figure 4. 1st and 2nd order statistics from all of the quadrats in transects 1 and 5.

Qualitative

The results of this research is qualitatively shown in rose diagrams. In almost all of the rose diagrams from transect 5, the overall trend of the branches is toward the east. A select few of these rose diagrams are shown Figure 3. This qualitative assessment shows a strong preferred orientation to the data set for transect 5. The same cannot be said about the transect 1 rose diagrams. In fact, it is difficult to see any preferred trend in transect 1 based solely on qualitative observations; therefore, based on qualitative assessment of the data transect 1 appears to have no preferred orientation to its data set.

The bathymetry of transect 5 is different from transect 1, since transect 5 has a flatter bathymetric profile along the top of the reef. These differences in bathymetry across the transects affect the hydrodynamic conditions present. The flatter reef top would allow for a surge flow (i.e., moderate wave action) to be present along transect 5. Transect 1 contains multiple changes in its depth that create several reef troughs along the transect. Corals in these troughs might not feel the effects of healthy surge flow as readily. *A. cervicornis* relies on the current to provide nutrients from the surrounding water (Sorokin, 1973). The surge flow along the reef top of transect 5 would carry a consistent supply of quality nutrients that would positively affect the coral health and promote coral feeding efficiency, while the current flow at transect 1 would transport an uneven supply of nutrients and reef debris that would negatively affect the coral health (Rogers et al, 2013). Transect 5 appears much healthier than transect 1, with this health discrepancy of the coral defined by the density of live coral cover and also by observations of the length and thickness of the *A. cervicornis* branches. Large portions of the branches in transect 1 were already dead or were showing signs diseases like white band disease, whereas transect 5 did not show the same extent of disease (Aronson and Precht, 2001).

In addition, transect 5 is located closer to the barrier reef crest than transect 1. The reef crest consistently had waves breaking over it that created a westward flowing current (Taebi et al., 2012). This close proximity provides transect 5 with a stronger current than transect 1. A strong current can be beneficial to *A. cervicornis* because it carries more nutrients, removes waste, and assists in reproduction. However, if a current is too strong, especially during storm events, it can damage and break the coral branches (Chamberlain and Graus, 1975). The current at transect 5 was not too strong because few broken branches were noticeable, and the percentage live coral cover was higher than the other transects with weaker currents.

The alignment of the *A. cervicornis* branches with the current in transect 5 could explain why there was little branch breakage. This theory agrees with the conclusions made by Bottjer (1980). One likely cause for the alignment of *A. cervicornis* is budding, which is when coral polyps create copies of themselves (Szmant, 1986). When new polyps are copied, it makes ecological sense for them to grow into the best possible position for maintaining health. In this situation, by growing into the current the new polyps are in a good position to gain nutrients, while resisting breaking during times of more severe wave action.

Quantitative

The mean vectors of the 1st and 2nd order branches in transects 1 and 5 show an average branch orientation toward the east. The mean vectors of transect 1 were 81.4° for 1st order branches and 94.0° for 2nd order branches. The mean vectors for transect 5 were 101.8° for 1st order branches and 98.2° for 2nd order branches. These numbers do not mean much by themselves. In this case, the standard error of the mean needs to be used to show how well grouped the data are. The standard error of the means for transect 1 were 11.8° for 1st order branches and 14.9° for 2nd order branches. The standard error of means for transect 5 were 1.8° for 1st order branches and 2.5° for 2nd order branches. Therefore, the branches in transect 5 exhibit a stronger preferred orientation since they statistically have a smaller margin of error than transect 1.

The statistics calculated for the Rayleigh Test (p) for all of the transect data is puzzling, because the results for this test were low. The default null hypothesis for the Rayleigh test is that the data are uniform, or show a randomness. For the Rayleigh Test (p) to show that a data set has a preferred orientation the value should be below 0.05. The results for the Rayleigh Test (p) for transect 1 were 7.29E-6 for 1st order branches and 6.72E-4 for 2nd order branches. The results for transect 5 were < 1E-12 for 1st and 2nd order branches. This shows that both data sets show a preferred orientation, with transect 5 having a stronger preferred direction because its values were lower. This analysis is interesting when the statistics for the individual quadrats of these transects are examined. The percentages for these quadrats show how different the branch alignment was for the two transects. For transect 1, only 24% of the 1st order and 14% of the 2nd order quadrats showed preferred directions in the coral branches. Transect 1 has a smaller value for its length of the mean vector, which is often used as a check for uniformity (randomness) in a sample. The smaller the value for the length of the mean vector, the more uniform the data set is. On the other hand, 81% of the 1st order quadrats and 77% of the 2nd order quadrats of transect 5 showed a preferred direction. Transect 5 has a larger length of mean vector value, which translates to less uniformity (less randomness; more preferred orientations).

Transect 5 contained the densest amount of live coral when compared to transect 1; this is determined by the number of branches that were counted along each transect. Transect 1 contained 2,437 1st order branches and 690 2nd order branches in its data set, while transect 5 nearly doubled the branch count of transect 1 with 4,465 1st order branches and 1,183 2nd order branches. The density of *A. cervicornis* in each transect can also be shown by the percentage of live coral cover. Transect 5 had a percent live coral cover of 49%, while transect 1 had a percent live coral cover of 31%. These values show a distinct difference in the density of branches between the two transects. These variations in live coral cover were likely due to differences in current flow and strength that affected the nutrients supplied to the reefs, thereby affecting coral feeding efficiency.

CONCLUSION

The *Acropora cervicornis* at Coral Gardens show differences in percent live coral cover and growth alignment. Transect 5 exhibits a more robust preferred orientation to the growth alignment of *A. cervicornis* branches when compared to transect 1. In this region, the branches of *A. cervicornis* along transect 5 grew toward the oncoming current, which flows from east to west, generally perpendicular to the Belize Barrier Reef crest that runs north to south. Eastward coral growth alignment into the primary current allows newly budded polyps to be oriented in a position where they can receive a more consistent supply of healthy nutrients during surge flow while decreasing the chance of current damage. The theory of the branches growing parallel with the current to be more resistant to breakage agrees with the conclusions made by Bottjer (1980). This alignment was stronger along transect 5 (and not transect 1) because of its proximity to the Belize Barrier Reef crest that caused an increase in current strength. In future work, the alignment of *A. cervicornis* can be used to determine direction of current flows and if the current suits the corals needs.

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