A Novel Use of Photogrammetry for 3D Underwater Imaging of Patch Reef Biodiversity, San Salvador Island, The Bahamas

Abstract

The Bahamian Archipelago consists of over 3,000 islands and small cays that extend about 800 km southeastward from Grand Bahamas island. San Salvador Island is an isolated carbonate small island located approximately 300 km from Nassau. Patch reefs encompassing the waters of San Salvador Island, The Bahamas were studied using a novel 3D photogrammetry method to assess coral reef biodiversity and health. This underwater study utilized a scale bar with three axes: "X," "Y," and "Z," with pre-measured distances between endpoints that allow accurate 3D models to be developed via Agisoft Metashape software. There were a total of six underwater 3D models successfully made from three different sites: one model from French Bay, four consecutive models from a shallow reef at Columbus Monument, and one model from a farther out reef at Columbus Monument. There were varying coral abundances observed at each of the three locations. At French Bay, there were predominantly encrusting corals and branching corals. Corals were largest at this reef location compared to the others, several measuring ≥50 cm in diameter. At the Columbus Monument reef closest to shore, there were several algae species noted, with minimum coral observed, consisting of small encrusting coral that measured on average <10 cm. The reefs farther from the shoreline at Columbus Monument were composed mostly of soft corals and small encrusting coral species. The methodology practiced was successful in producing 3D underwater models that did not affect reef health and were cost-effective. While this 3D method worked, water turbidity was a barrier to the model size, as evident at one of the Columbus Monument locations where images had to be collected closer to

the reef reducing the dimensions of the scene. Wave intensity also affected the efficiency of retrieving data, with stronger waves experienced at French Bay. There were fewer corals observed at all sites than expected. The reef diversity at Columbus Monument lacked corals, and in its place had multiple types of algae. Other reef locations studied had coral present, much of it in poor health being bleached or already dead. This project allowed us to test the data collection technique and prove that it successfully produced 3D patch reef models. The methodology can be practiced again in the future; comparisons of past and future models will allow researchers to better visualize reef trends in health and biodiversity. Monitoring and understanding trends in reef biodiversity are vital to understanding how reefs are evolving in a warmer global climate.

Introduction

Patch reefs can be found all around San Salvador, The Bahamas. These reefs are home to several different types of coral, sponges, fish, and other varying marine life. The GRC has had previous studies on these reefs done, allowing comparison of present to past diversity to be possible. Upon completing this study, it will allow the scientific community to better understand the effect of recent climate events on reef health and can be used to predict future trends.

This project will produce 3D models of patch reefs at various locations and distances from shore in San Salvador, The Bahamas. Creating these models will help strengthen my data collection techniques and will allow for more accurate comparison of the biodiversity at different depths and with historical data collected from the Gerace Research Center (GRC). The study will help us understand how climate change is affecting reef health through changes in species composition in both quantity and quality.

This project will contribute to conservation efforts and studies. There are current efforts in place at San Salvador with coral trees. This study would help better understand the long-term trends in reef health and can help point out areas that require more effort than others. It can help show which species are more vulnerable to extinction and which are more resilient to continue the coral population. It can also help the general population visualize and better understand declining reef health.

Research questions to be answered upon completion of this project will include:

1. How does the biodiversity between different patch reefs differ?
2. How did the biodiversity change between current and past reefs?

Development Methods:

Due to the nature of water, LiDAR and GPS do not work for underwater subjects. In order to successfully do underwater photogrammetry, a local, independent coordinate system was needed to be constructed. The first prototype consisted of naked, white PVC pipe, three wooden cubes with each face painted a different color of either: white, blue, red, or green. Each face of the cube matched the others once the model was made. Along the PVC pipe, stainless steel weights were taped along the “X” and “Y” axes. The test resulted in the scale floating. It also revealed that the software being used: Agisoft Metashape, doesn’t recognize the PVC pipe due to it being white, as it didn’t pick up on the pipe being there.

The second model had three different colored duct tape colors lining the outside of each axes of PVC pipe. In order to help weigh down the scale, sand was added inside the pipe, and the stainless steel weights were drilled into the “X” and “Y” axes cubes. The “Z” axis was left

without weights to help the scale stay in correct orientation via “Z” being more buoyant. The second prototype revealed that the colored pipe was much better. However, the scale was still too buoyant. Between the second and third, final prototype, two weights were zip tied to the bottom of the “X” and “Y” axes. During the third, and final pool test, the scale successfully sunk and stayed still at the bottom of the pool. The model had to be collapsable in order for transport. Each cube was connected to the PVC pipe via a hole drilled in the center of the cube, and tape around the pipe to ensure a tight fit. The two were then hammered together on site. The three pipes were connected in a similar manner with an elbow connector.

The final scale measurements (taken at site) between the different cubes were:

- Cube 1 (“Y”): (0, 0, 0)
- Cube 2 (“Z”): (0, -27.8, 51.5)
- Cubs 3 (“X”): (100, -28.4, 0)

Field Methods:

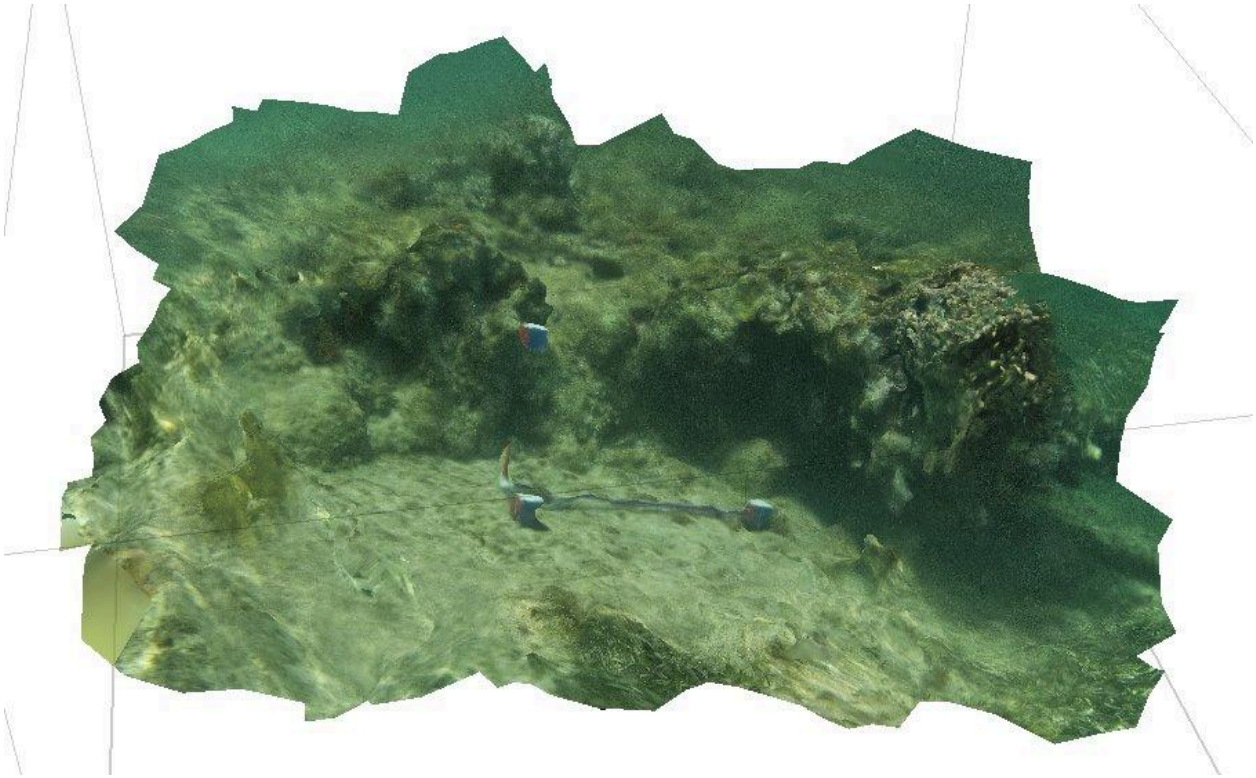
Data was collected from three different sites at San Salvador, The Bahamas. Two of which were in the waters at Columbus Monument at different distances from shore. Another was taken along the French Bay.

French Bay was the first site visited. At this site, the scale was placed in front of the subject, and 82 photographs were taken from a multitude of angels. Photos were taken using a Samsung Galaxy S 23+ inside a clear plastic phone case. Additional images were taken of the different species of resident coral with a GoPro Hero 10. Methodology was practiced at this location.

The next site data was collected from a patch reef close to the Columbus Monument shore. At this location, images were taken closer to the scale due to water turbidity. Four transects were taken from this location using an Olympus Underwater Camera. Photos of species present were taken with a GoPro Hero 10. The final site data was collected from a reef further from shore. At this location, 102 images were taken of a section of a patch reef via a GoPro Hero 10.

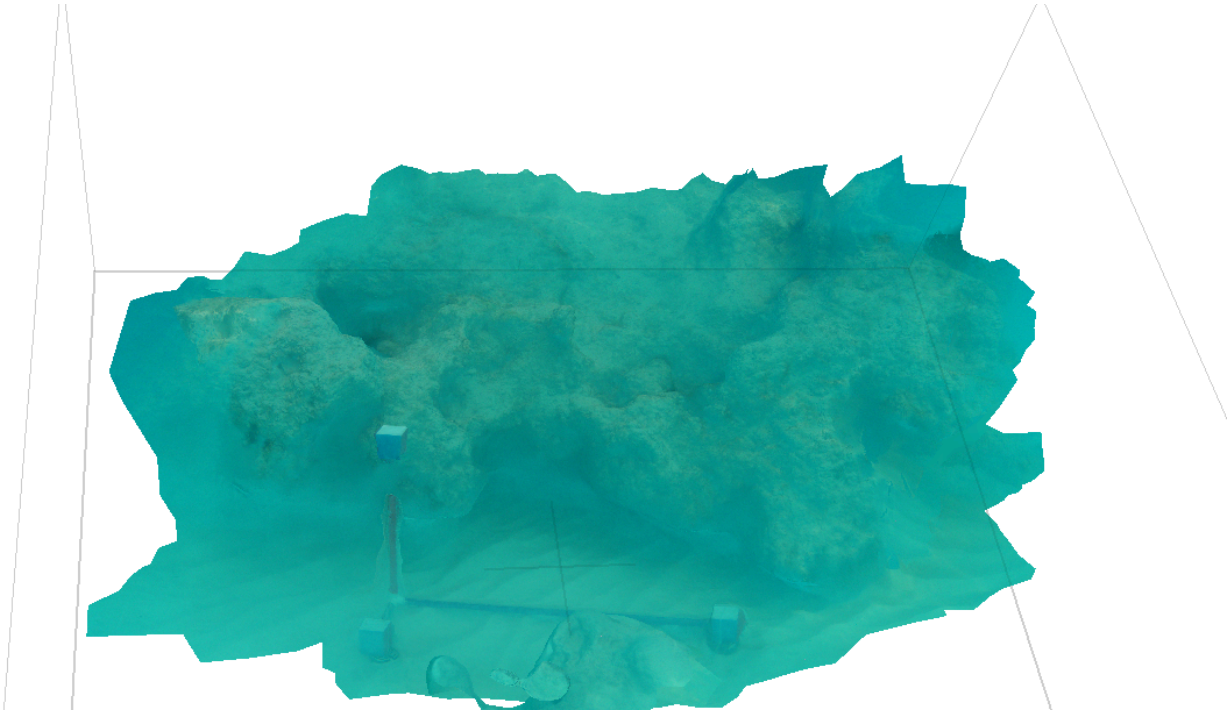
Methodology Results:

Reef #1 (French Bay Patch Reef) was used for determining whether or not the methods described above would be successful at further reefs. This reef also experimented with using mobile phone cameras, as only the GoPro and Olympus cameras had been previously practiced with. The photos taken resulted in a model. However, the area modeled is warped and not as clean as other models made from the other cameras.



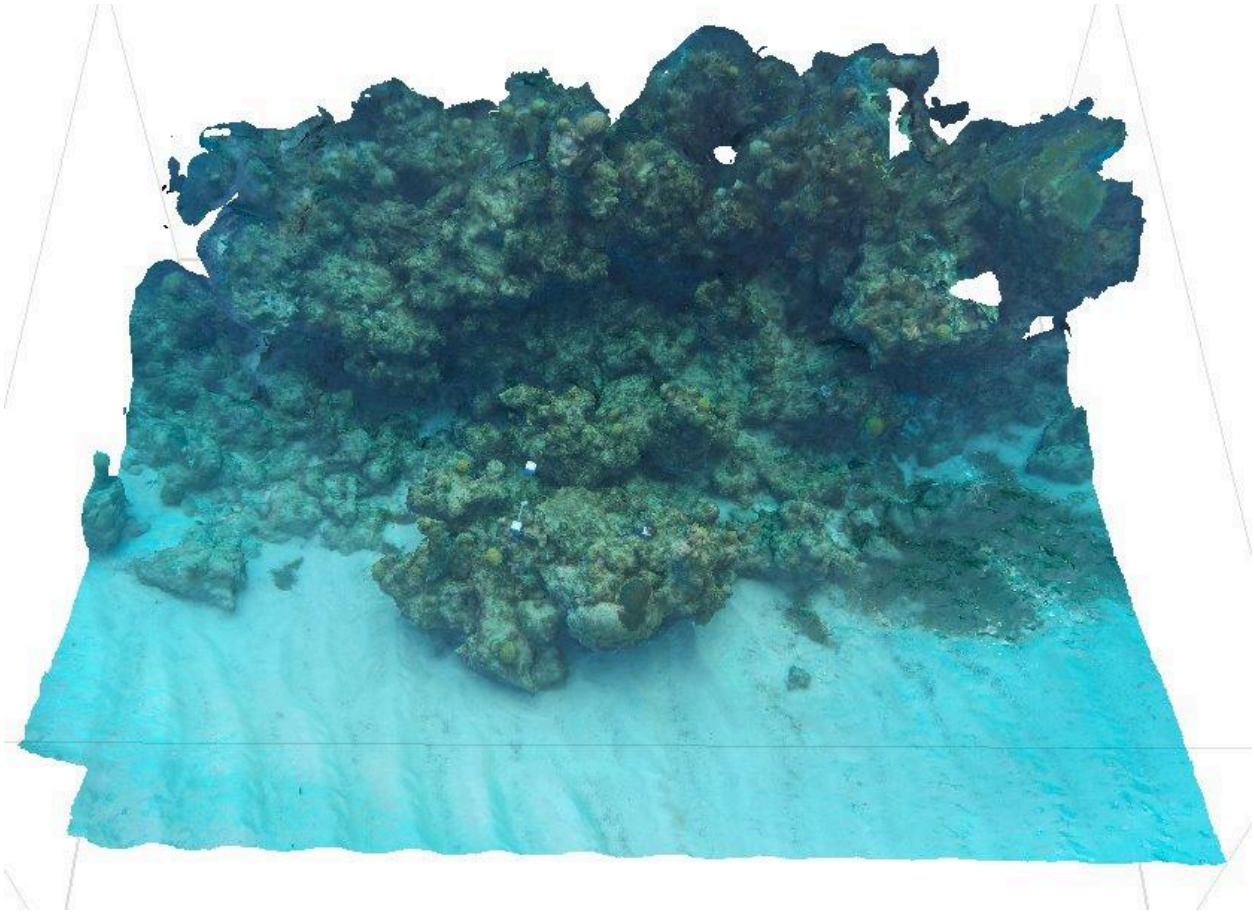
Reef #1

Reef #2 (Close to shore Columbus Monument Patch Reef) Transect 1 was recorded at 10:30 AM. A total of 64 images were used taken from the Olympus Underwater Camera to create the model. The total error in pix for this reef for each point was 0.686 pixels, with point 1 (“Y”) error being 0.666 pix, point 2 (“Z”) being 0.841 pix, and point 3 (“X”) being 0.266 pix. I was pleasantly surprised with point 3 having a lower error than point two, due to the greater distance it was between the other points. The generative report showed a projection error of 1.72 pix, and resolution of 3648 x 2736 pix with pixel size measuring 1.67 x 1.67 μm.



Reef #2

Reef #3 (Far from shore Columbus Monument Patch Reef) was recorded around 2:00 PM. A total of 102 images were taken from the GoPro Hero 10 using the narrow setting, (due to technical difficulties from the Olympus) to create this model. Unlike Reef #1, this reef was further away from the scale, and as expected, resulted in a greater error. The total error given from the reference markers was 5.716 pix, with each point being: point 1 (“Y”) 2.317 pix, point 2 (“Z”) 8.190 pix, and point 3 (“X”) 1.447 pix. This model followed the same trend as Reef #1, having point 2 has the greatest point of error. This was to be expected of this model. When the photos were aligned, points 1 and 3 didn’t need to be corrected whenever the program generated the unmarked points. However, point 2 needed to be corrected on several of the images. The generative report showed a projection error of 3 pix, with a resolution of 5568 x 4176, and pixel size of 1.12 x 1.12 μm.



Reef #3

Study Results:

The island of San Salvador, The Bahamas also offers insight on how reefs were like during the Pleistocene era. The fossilized reef didn’t show any greater biodiversity than today's reefs. However, today's individual corals are significantly smaller than those of long ago.

The largest corals were found to be located at Reef #1: French Bay Patch Reefs, with several measuring >50 cm in diameter. At this reef, corals were predominantly hard encrusting corals, portie corals, with some soft fan corals. Reef #2 had significantly less and smaller corals compared to the other reefs studied. In the transections taken, there were three different hard encrusting corals noted, with an abundance of feather duster marine tube worms. Reef #3

contained the most biodiversity of the three areas. There were mostly mustard hill corals and purple sea fans.

Discussion:

I believe that some of the error in Reef #2 resulted from not only greater distance from the subject, but also the choice of camera used. The greater distance away also resulted in a less detailed model. While the initial photos it picked up were more detailed than the photos the Olympus Underwater Camera picked up, once it was made into a model, the closer one had better details on specific parts of the model. I think that somewhere in the middle of the two distances the models had photos taken from would be ideal.

Each camera resulted in something different being lost. The GoPro was able to capture the true colors of the objects in the study better, however the accuracy of the model was slightly lower. The Olympus had better accuracy and more details, but the color and depth were harder to see.

If I were to do this project again, I would focus on having different colors for the cube faces. While the colors I used worked, the red and blue were difficult at times to find where one ended and the other began. I would instead rather use colors that were determined by their grayscale. I would also recommend using SCUBA equipment or other underwater breathing equipment. Something to anchor yourself down would also be nice, as at one point a wave pushed me into a rock. Wildlife at these locations weren't a problem, as there weren't any fish at either location recorded. Water turbidity was also something needing to keep in mind, which caused Reef #1's model to be so close to the scale size. I would also recommend adding another cube in the Z plane, to possibly help with the greater error in the vertical direction compared to

its horizontal counterparts. I would also recommend getting a hard plastic case for your phone rather than soft plastic if you were to use a mobile phone camera rather than an underwater camera.

In conclusion, my methods for underwater photogrammetry were successful, however there is still plenty of room for improvement. Three different areas of patch reefs were made, with varying cameras and distances from the scale used. The smaller the model was, the more accurate and detailed the results were. The further away you were, you had less details on rocks and coral, and a greater error.

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