Hyperspectral Imaging as a Tool for Assessing Coral Health Utilising Natural Fluorescence

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I. Introduction: Corals

Corals are marine invertebrates in the class Anthozoa of phylum Cnidaria, they often live in sessile colonies of many individual polyps. The geographical distribution of reef building corals is tropical and subtropical waters, typically occurring between the 300° north and 300° south latitudes [1].

Corals primarily responsible for building modern reef systems are hermatypic corals, belonging to the group Scleractinia or Stoney corals. Hermatypic corals contain photosynthetic algae specifically dinoflagellates called zooxanthellae, belonging to the genus symbiodinium, that live symbiotically within its cells. The relationship is thus, the algae provides the corals with energy and in exchange receive protection and nutrients [2].

Hermatypic coral communities exhibit a natural fluorescence, the significance of which is yet to be determined. Previous studies have suggested many possibilities for the role that these florescent proteins (FPs) play: such as acting as a sunscreen by providing a photobiological system for regulating the light environment[3, 4]; or as a host stress response, through their action as antioxidants; to attract prey [5], all that is known is that downregulation of FPs frequently occurs in injured or compromised coral tissue [6]. With such broad functional activity, the presence of FPs can potentially be exploited as a proxy for measuring coral health. Analysis of the natural variability in fluorescence intensity for a given species, as well as the differences between diseased and healthy specimens, enables the development of an index relating fluorescence to disease.[7]

II. Device Details

A push broom style hyperspectral camera (Headwall Nano USA) was used to obtain hyperspectral data at each stage within the experiment. A secondary hyperspectral camera being developed for underwater imaging will also be used, the Coral fluorescence imaging payload (C-FIP). The payload consists BlueRobotics Lumen light pods (UV light (395-405nm)), a Delta Optics Bifrost Continuously Variable Bandpass Filters (LV VIS NIR Bandpass Filter HIS) and a Monochrome camera (Atik Horrizon).

III. Experimental Techniques

The experiment set out to deliberately bleach coral samples in a laboratory setting by slowly increasing the water temperature until Zooxanthellae expulsion occurred (Bleaching). The laboratory system was designed to provide reproducible temperature treatments under recirculating conditions for a diversity of species of scleractinian corals. The system consists, two tanks (Aqua One NanoReef 35L Aquarium L33 x W33 x H33 cm) fitted with integrated life systems. One tank was a control with optimal temperature conditions (26°C) constantly maintained with the second tank as an Experiment tank where temperature was varied. The coral sample was imaged in 3 light conditions, under white light (Aquarium light bar), Deep Blue light (Aquarium light bar) and UV light (BlueRobotics UV light pod). The temperature was altered by +2°C each week. The coral was then imaged using the Headwall hyperspectral camera every 48h of each week where temperatures were between 24-28°C as these represent the temperature range of coral. At 30°C, where we expect to see bleaching, imaging was undertaken every 24h to try to observe the expelling of the Zooxanthellae from the coral cells. The hyperspectral data collected by the headwall camera is then compiled into a hypercube and loaded in to image analysis software, ENVI (v5.4), where it can be viewed and spectrum's obtained.

IV. Results and Analysis

Hypercubes are loaded into user defined RGB bands, here we use R:649 G:500 B:460 for white light and houselights. The UV data was loaded in greyscale at band 440nm, allowing the coral to been seen and used in the ROI (Region of interest) method (the data was too 'noisy' to be loaded in full). The white light spectra provides a baseline of what can be seen without the use of fluorescence. It clearly shows as the intensity of colour decreasing. This colour change is not necessarily indicative of loss of zooxanthellae which is why using fluorescence provides an advantage as we can characterize Zooxanthellae by its unique spectral profile.

The data collected using the Deep Blue (450nm) shows the fluorescence peak of the coral on the shoulder of the excitation peak. The true nature of the whole peak is masked by the overwhelming broad signal from the

excitation source. To improve the spectral capture and differentiation of the induced fluorescence we adopted an excitation source with a narrower emission peak shifted further along the spectrum from the fluorescence peak in the UV. This UV spectra reveals the true nature of the fluorescence emission peak. There is also a secondary peak in the red which corresponds with macroalgae which was likely settled on the surface of the coral or on the glass of the tank. The tank glass was cleaned before each hyperspectral image to reduce this, but the algae was likely still present. The presence of algae on the coral itself is suggestive that the natural self-defense capability of the coral was gradually deteriorating as the corals health did (alternatively the warmer water temperatures favored algae productivity better).

Fig. 1. Spectrum highlighting fluorescence difference [excited by UV (405nm)] between *Montipora digitata* sample using Region of interest tool Pre (26°C) and post Bleaching (32°C).

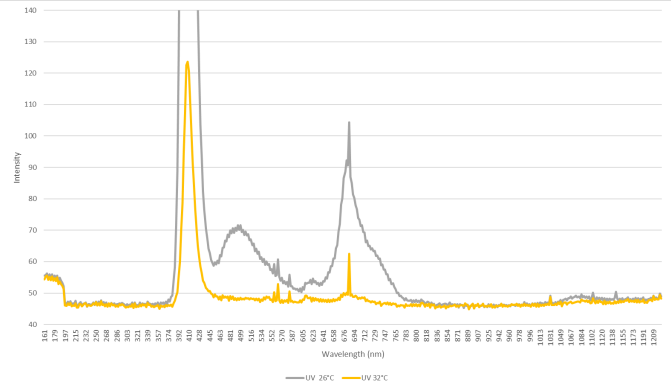

Fig.1 shows a corals spectral profile before and after a bleaching event stressed by temperature rise. The peak at 385-450 nm shows the emission peak of the excitation source, the two peaks after this represent the fluorescence emited by the coral. The data depicts the difference in the presence/absence of Zooxanthellae. As the coral is stressed by the temperature increase, coral exhibited typical bleaching behavior and expel Zooxanthellae thus reducing the measured fluorescence. We also observe a decrease in the reflectance of the coral as demonstrated by the reduction in the peak intensity of the reflected primary light until the calcium carbonate exoskeleton is exposed where reflectance increases.

V. Conclusion

The corals main stressor was the temperature rise but other stressors could have played a part in the beaching process. Other stressors may include the presence of macroalgae and the water parameters shifting such as salinity, phosphates and nitrates.However, the response is largely consistent across most stressors resulting in the same outcome of zooxanthellae expulsion from the host coral.

Future work Will develop a portable Hyperspectral imaging system (Payload) that can be mounted to an ROV (Remotely operated vehicle). A Remotely Operated Vehicle (ROV) is essentially a tethered underwater robot, which provides a stable, highly maneuverable platform for characterising the marine environment. The final payload will consist of UV LEDs 395-405nm to provide sufficient energy to excite corals at a reasonable distance (1 m approx.) and high enough power to mitigate against the effects of light absorption by seawater. The LEDs will be mounted in series powered from the ROVs (BlueROV2) control board, coupled with a BlueRobotics watertight enclosure and custom frame. This will be the platform to be used to test the method proposed for developing fluorescence photogrammetry models of active reefs for the purpose of monitoring coral health. These 3D models will also provide an insight into reef structure and morphology and if done regularly will provide the ability to monitor changes to the reef, providing a quick and very visual data set that is easily understandable.

Previous work [8] has been conducted testing a UV light payload over a live reef in Aitutaki, Cook Islands, where natural coral fluorescence was successfully observed. The surveys revealed that intensities of coral fluorescence were often unable to be quantified due to the ROV moving too fast over the coral and not allowing enough time for the camera to focus. The project looked at gathering intensity measurements relative to brightness on the images. We intend to develop and demonstrate an improved florescence imaging payload over a live reef in the next 6 months.

VI. References

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