Cayman Crown Reef: Characterization and Reef Health Changes between 2019 and 2021

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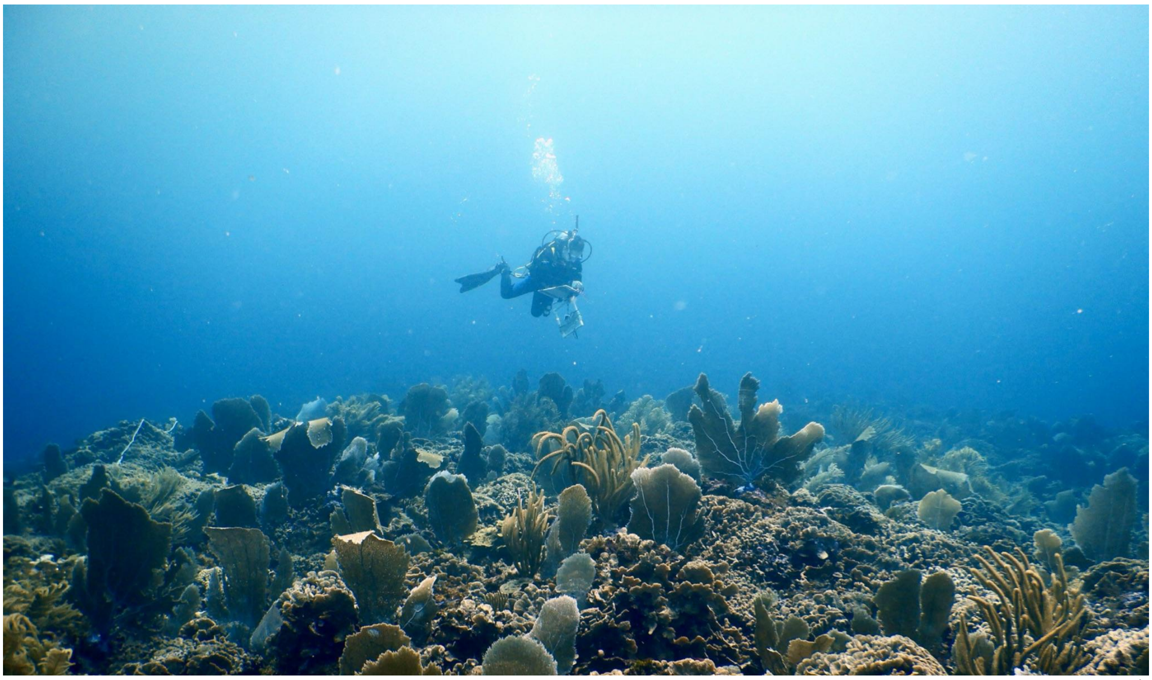

Photo: Ana Giró

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1. Executive summary

During the duration of the grant (March 15th 2020 through May 23rd 2022), we were able to further investigate and monitor the Cayman Crown reef beyond earlier explorations (those developed in Phase I) to better understand its current health state, ecological composition and recent ecological changes. We continued to study the two sites selected within the reef system as permanent study sites for Phase I (Sites 1 and 2) and we added two additional study sites for this project (Site 3 and 4; total of 4 sites). The two additional study sites were selected based on the location, biological and physical parameters such as coral cover, diversity, reef rugosity and depth. Coral reef rugosity is a measurement of the surface roughness or substrate complexity, which is considered a key ecological feature promoting biodiversity. On these sites we conducted biological monitoring of reef health using the AGRRA methodology, coral bleaching and disease monitoring focusing mainly on Stony Coral Tissue Loss Disease (SCTLD). We also monitored water temperature and pH changes using underwater sensors. A hydrophone was also installed to identify potential fish aggregations.

The main results for reef health show that the sites surveyed in 2019 (Site 1 and 2) have lowered their reef health index for 2021. Site 1 lowered from fair to poor condition and Site 2 from poor to critical condition, respectively, based on the four Reef Health Index (RHI) indicators (coral cover, macroalgal cover, herbivorous fish biomass and commercial fish biomass) and threshold values (going from positive to negative values: Very Good, Good, Fair, Poor and Critical). The results suggest that this is mainly due to the critical condition of herbivorous and commercial fish biomass on both sites and the increase in macroalgae cover (critical condition). Despite these changes, live coral cover for both Site 1 and 2 is still in good and very good condition, which is a key ecological aspect for the ecosystem health. The two new sites selected for this phase (Sites 3 and 4) have an overall reef health of poor (Site 3) and critical (Site 4) reef health condition, mainly because of their high cover of fleshy macroalgae; Site 3 has a fair coral cover and Site 4 has good coral cover. High macroalgal coral cover is considered negative given their direct competition with corals and the fact that macroalgae can be also indicators of both an increase in nutrients and a decrease/lack of sufficient grazing by key herbivorous species present in the ecosystem. Cayman Crown reef herbivorous and commercial fishes are in decline, which jeopardizes key ecological processes; our observations are consistent with the general trends observed for the country by HRI since 2014 (McField *et al.*, 2022). Some factors that might have affected the reef health results on the study sites include overfishing and an increase in nutrient pollution from watersheds such as the Motagua River. The lack of fishing regulations compliance and lack of control and surveillance during the pandemic (2020 -2021) has been a common topic in the MAR region affecting important ecological and commercial species. In Guatemala no fishing restrictions were imposed during the pandemic as a support measure to the fishermen and their families, given the economic and food safety crisis for local communities. Additionally, the hurricane season during 2020 broke records with 30 named storms; the landing of Eta and Iota tropical storms during the first half of November 2020 devastated several departments in the country, potentially bringing a huge amount of nutrients through the watersheds draining into the Caribbean coast of Guatemala, thus supporting macroalgae population increase. Adequate watershed management, improving sewage treatment and sustainable fishing practices while promoting the monitoring and compliance of fishing regulations are needed to increase reef health.

Biophysical indicators such as water temperature and pH were measured with in-situ permanent loggers placed underwater during Phase I and II of the grant (data recording periods encompass a total of 18 months of data from May 29th 2019 through February 6th 2022 with some gaps in between due to the COVID pandemic and maintenance of the loggers). The information on local temperature and pH variations are key aspects to develop a better understanding of how corals are responding to these variables, which are directly linked to climate change. We observed that Site 2 exhibited slightly higher average temperatures than Site 1. For the first recording period Site 1 had an average temperature of

28.77°C and Site 2 was 29.35°C, making a difference of 0.58°C, which might be attributed to the location, depth and equipment used for recording on both sites. For the second recording period Site 2 had a higher average temperature with a difference of 0.4°C (Site 1 was 29.23°C and Site 2 was 29.63°C). On both sites and for more than 61% of the time for which data is available (11 from 18 months), the recorded temperature surpassed the 29.5°C which is above the thermal tolerance for corals (29°C), suggesting corals at the Cayman Crown study sites have been under some thermal stress for the last couple years.

When analyzing pH data, we observed that the logger we deployed in Site 1 had an average recording of 8.6 during the first readings from May 29th 2019 to June 16th 2020. Even though we calibrated the logger before the deployment, there might be an error in the recording of this parameter. Taking this into consideration during the second deployment of the logger we did a thorough calibration and tested the logger before placing it in the water. The second deployment was made for from August 31st 2021 to February 6th 2022. The average ocean pH registered for this site during this recording period was of 8.32. Calcifying organisms such as corals tend to calcify best at a pH of 8.2-8.5 due to a variety of factors such as calcium and alkalinity availability, and carbon dioxide levels. If the pH is between 7.6-8.0 then corals will not calcify properly (Delbeek and Sprung, 2005; Comeau *et al*., 2012), we can say that the pH for this site is within the appropriate and expected range for coral reef ecosystems.

Very positive findings were the lack of SCTLD on the sites surveyed throughout Phase I and II (from March 2019 through February 2022), as well as the low bleaching impact observed in 2021 which indicate that only 30% of the corals presented some paleness and partial bleaching and no fully bleached corals were recorded. Compared to the bleaching impacts of coral affected we have documented in previous years (2019: 76.8%, 2017: 54.3%, 2016: 44.9%), impacts during 2021 are considered low.

The data from the loggers helped increase our understanding of the impact of high temperatures linked to bleaching events in the Cayman Crown reef. During Phase I and Phase II of the project we were able to monitor bleaching on the reef and determine the overall percentage of corals affected by bleaching (pale, partially bleached and bleached corals) and see the average temperature for the months before the bleaching event happened. For 2019 we had one of the worst bleaching events recorded for the site with 76.8% of the corals being greatly affected. We recorded five months of high temperature (over 29.5°C) before the bleaching event occurred in October. During the next months (November - February 2019) temperature decreased reaching 27°C. For 2021, only 30% of the corals showed signs of affection, mostly attributed to corals being in a pale condition (20%) and partially bleached (10%) condition. Before the 2021 BleachWatch monitoring we also recorded several months (August - October 2021) of high temperatures (29.5°C) but corals were not greatly affected, probably because there were less months that had high temperatures. The temperature started to decrease in October 2021.

The initial passive acoustic monitoring equipment for fish noise mapping we had included in the proposal could not be acquired because the developers discontinued the production of this exact model due to the COVID19 pandemic. A simpler hydrophone (no camera included) was purchased instead, the Hydrophone SNAP from loggerhead instruments, given that it is being used in other Mesoamerican Reef countries like Mexico, which could allow for data comparison in the future. The installation was done near a coral reef wall at 18.5 m deep from December 2021 through February 8th, 2022. The location where the hydrophone was installed in one of the reef areas where we have seen different fish aggregate in past trips (jacks, Atlantic spadefish, snappers, and ocean triggerfish) and have also seen a few groupers with colorations of possible spawning. The analysis of the recordings are still in progress.

The following report presents information on site characterization of the Cayman Crown reef using the AGRRA protocol, determining the health of the reef through the analysis of four main indicators which are: percent live coral and macroalgal cover, herbivorous and commercial fish biomass. It also shows the analysis of the local effects of climate change (both temperature and pH), coral disease, bleaching and its impacts on the Cayman Crown reef.

2. Introduction: Cayman Crown Reef, a new reef discovered in Guatemala

The Cayman Crown reef is located in the heart of the Gulf of Honduras, between Guatemala and Southern Belize. The reef system is large and highly complex; previous explorations and bathymetric mapping done by the Healthy Reefs Initiative (HRI) indicate that the reef covers an area of at least 15 km x 6 km (90 km^2). The reef has a high complexity and geomorphology, it is composed of spur and groove reefs with steep walls that drop vertically from the shelf edge from 30 m to waters that are over 300 m deep. This project was mostly focused on the reef area and reef crest of the crown which lies approximately at 10 -12 m deep and has the most diverse and healthy corals. The explorations in the site and the monitoring carried out have documented that the Cayman Crown reef is the most developed and complex reef in Guatemala, providing refuge and habitat for innumerable species of ecological and commercial importance.

Bathymetric analyzes of the area and site explorations done by HRI and PixanJ'a reveal that the reef structure and geomorphology of Cayman Crown are spectacular, there are reef spurs perpendicular to a drop (similar to buttress and valley reefs) but the size of these reefs dwarfs any previously documented structure for Guatemala. The spurs are cut by caves and fissures, which serve as homes for fish and other benthic organisms. The shallower reefs (10m) are rich in corals and have a high diversity of water-filtering sponges. Geomorphology, combined with good live coral cover, is essential to having and maintaining a healthy reef system and supporting the survival of species that depend directly on coral reefs.

The sandy parts near the reef are full of nesting marine fish, the vertical walls are full of aggregating fish such as Atlantic spadefish, jacks and snappers (species of commercial importance). The shallow and deeper parts of the reef are composed of corals and barrel sponges, important water filter feeders. In the deep zones, the presence of several species of marine megafauna have been previously documented, such as sharks, dolphins and pilot whales, important migratory species. The Cayman Crown reef is vital for the connectivity, resilience and biodiversity of the Guatemalan Caribbean and southern Belize.

3. Methodology

For this project different methods were used to study and research the current health state of the reef, its resilience to bleaching events, and the ecosystem health impact linked to water temperature and pH changes. When possible, standardized monitoring protocols already used in the MAR were employed to facilitate comparison with other studies.

3.1. Monitoring the health of the reef ecosystem using the AGRRA methodology

All the sites were monitored using the Atlantic and Gulf Rapid Reef Assessment (AGRRA[1]) methodology to determine the health of the reef system, the standardized and most widely used method applied in the MAR region. This scientific monitoring provided information on reef health based on the Reef

[1] AGRRA methodology: https://www.agrra.org/coral-reef-monitoring/

Health Index (RHI), the four main indicators and the threshold values made by the HRI and AGRRA (Table 2). The indicators measured include: 1) coral cover, 2) macroalgae cover, 3) commercial fish biomass and 4) herbivorous fish biomass. With the analysis of these four main indicators we are able to say what is the current condition of the reefs monitored. The Cayman Crown reef has been surveyed in the past; however, no specific study sites have been chosen to follow up over time, just the general reef area has been monitored as it is a large system. This is why we increased the number of sites surveyed from 2 (Phase I) to 4, to increase the sample size. The information gathered serves as a solid baseline for future monitoring activities. The HRI-AGRRA monitoring is developed once a year, generally during the time frame of May - August (for the data to be comparable across the MAR region). During this time the four countries carry out annual monitoring to facilitate the systematic comparison of data at the local and regional level. The data gathered through this project was used for the Essentials Report Card of the Health of the Mesoamerican Reef 2022 and will be used in the full Reef Health Report Card of the Mesoamerican Reef that will be launched at the end of 2022.

We conducted two field expeditions to monitor the health of the reefs in Guatemala. Given the challenges and the urgent need to get out in the field, efforts were combined between this project and funding from HRI (Summit Foundation) to develop a country level monitoring that included the study sites of this project along with the national monitoring sites for Guatemala. A total of nine sites were monitored using the AGRRA methodology to determine the health of the reef system. This scientific monitoring provided information on reef health based on the RHI, the four main indicators and the threshold values made by the HRI and AGRRA (Table 1).

The first expedition was done during August 29th through September 2nd, 2021. A total of 8 sites were monitored using AGRRA and also to determine the presence or absence of Stony Coral Tissue Loss Disease (SCTLD), in the Caribbean of Guatemala: 3 sites in the Cayman Crown reef, 2 sites in Motaguilla and 3 sites in Cabo Tres Puntas. The second trip to the Cayman Crown reef was held during the 6th to the 8th of December 2021, during which a total of 4 sites were monitored, the same 3 sites monitored in the first trip and we added 1 more site (4 study sites in total). We were not able to monitor this last site during the first trip because of difficult weather conditions. This site was monitored for reef health using AGRRA and all 4 study sites were monitored for SCTLD and bleaching. A third trip to the Cayman Crown reef was made with funds from HRI and Beluga Smile from the 3rd to the 8th of February 2022; we were able to retrieve the hydrophone and ph/temperature logger, download the information and reinstall them on the reef.

Table 1. Threshold Values for determining the stare of the reef (McField et al., 2020).

Threshold Values for Indicators | Valores de los Indicadores
(ASSIGNED THE HIGHEST RANK MEETING THESE MINIMUM VALUES)
(SE ASIGNA EL RANGO MÁS ALTO QUE CORRESPONDE A ESTOS VALORES MÍNIMOS)

Grade Rango	Coral Cover Cobertura de Coral	Fleshy Macroalgae Cover Cobertura de Macroalgas Carnosas	Herbivorous Fish Biomass Biomasa de Peces Herbívoros	Commercial Fish Biomass Biomasa de Peces Comerciales
Very Good | Muy Bien	40%	1%	3,290	1,620
Good | Bien	20%	5%	2,740	1,210
Fair | Regular	10%	12%	1,860	800
Poor | Mal	5%	25%	990	390
Critical | Crítico	<5%	>25%	<990	<390

3.2. Measuring water temperature and pH

We installed loggers in two different sites of the Cayman Crown reef (Site 1 and Site 2) during Phase I of the project (Table 2). The logger on Site 1 has been placed on one of the sides of a spur (coral reef habitat specific formation) in the coral reef area (12.2 m deep). This site is located near a wall that drops from 9 m to 180 m. This pH/Temperature logger was placed in the water May 29th, 2019 and was retrieved August 30th, 2021, the logger had to be cleaned and maintained with a special solution and since it had multiple fish bites near the sensor, it wasn't put back in the water. A new logger was placed in the same site (Site 1) for Phase II of the project on August 31st, 2021 and left to record until February 6th, 2022; the old logger was maintained and calibrated, it was placed in the same site to see if it is still working well so we will compare the recordings of the two loggers when we retrieve them. The temperature logger on Site 2 was installed (during Phase I of the project) on top of a spur; there are no walls or drop-offs close to the site, the logger was placed in the water May 29th 2019, this sensor was not retrieved until December 6th 2021 because we couldn't find the logger during our trip in August 2021. However, a new logger was installed in the same area during the August 2021 field expedition (Phase II) and left to record until December 2021; then it was retrieved and left to record again. We were able to find and retrieve the logger installed in Phase I during the field trip in December after a vast search for the logger, however the logger only stored information from May 29th, 2019 to August 16th 2020 (linked to memory capacity). The information was downloaded and the logger was cleaned and since it needed maintenance because of the excess of crustose coralline algae covering the sensor and a display saying that there was an error in the reading, the sensor was taken to the city and re-checked with the computer. It is now ok and will be installed in the next field expedition.

Table 2. Site characteristics and location of the temperature and pH loggers.

Characteristics	Site 1 – AGRRA Code 13CCNRC	Site 2- AGRRA Code 011CCNRC
GPS coordinates:	Latitude: 15.9556 Longitude: -88.28128	Latitude: 15.96983 Longitude: -88.29862
Logger:	pH and Temp logger	Temp logger
Depth:	12.7m	15.5m
Rugosity description:	High	High
Site Habitat:	Spur and groove	Spur and groove
Reef Zone:	Fore Inner Reef	Fore Inner Reef

The pH/temperature on Site 1 was recorded using an Onset HOBO pH and Temperature Data Logger. The data was collected during May 29th 2019 to June 16th 2020. Because of the COVID pandemic, the logger was retrieved until August 30th 2021 and placed again in the water on August 31st 2021 and left to record until February 6th 2022.

The temperature for Site 2 was recorded using an Onset HOBO TidbiT v2 Water Temperature Data Logger. The recordings for this site were from May 29th 2019 to August 16th 2020. Because of the COVID pandemic we weren't able to go to the field, the logger was retrieved until August 30th 2021 and placed again in the water on August 31st 2021and left to record until December 6th 2021.

4. Results

4.1. Reef health biological monitoring

The data gathered during the biological monitoring of the two field expeditions (described in the monitoring the health of the reef ecosystem using the AGRRA methodology section 3.1 of this report) was analyzed through the HRI and AGRRA online platform, which offers an online data entry system that analyzes the collected data. The products generated by the software include over fifty different analysis that we have reduced to show the major findings through the four main indicators - Reef Health Index[2] (Table 1).

We monitored a total of 4 sites for reef health using the AGRRA monitoring in the Cayman Crown reef. All the sites are within the Spatial Closure Zone - Cayman Crown, declared in Guatemala in May 2020 by a Ministerial Agreement, no fishing is allowed in this area (Fig 1).

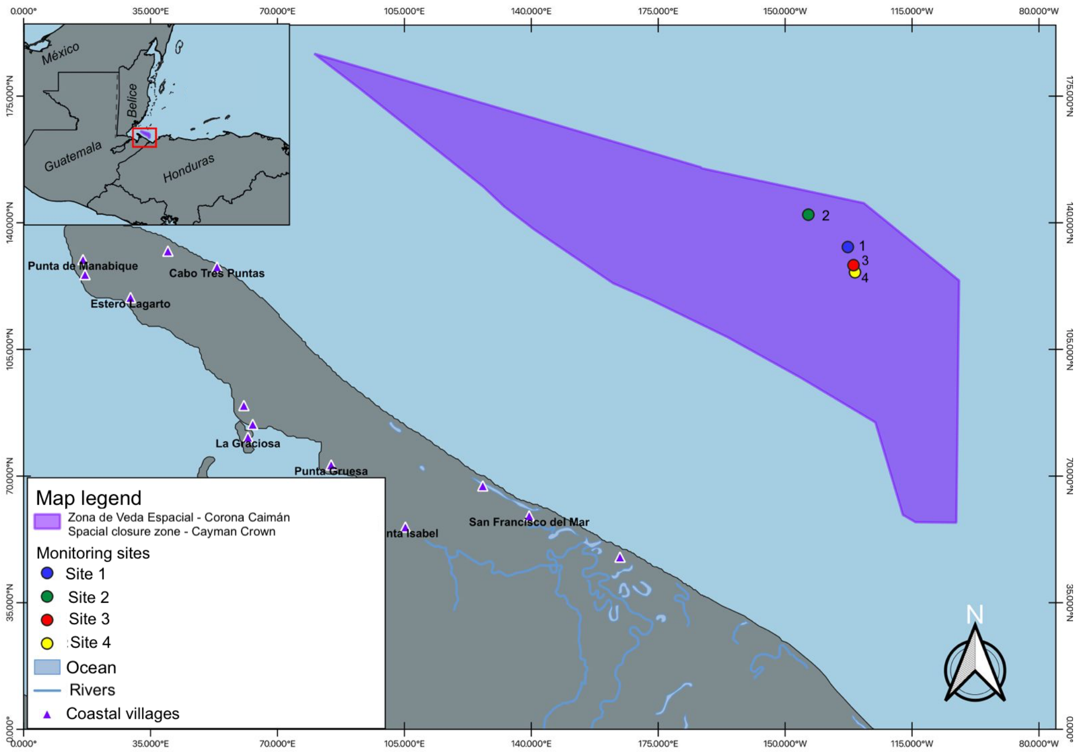

Fig 1. Map of study area and selected study sites (Own source) (Own source).

The main results shown in Table 3, indicate that the 2 sites that were selected and monitored during Phase I decreased their health from Fair (Site 1) and Poor (Site 2) in 2019 to Poor and Critical in 2022; while the two new sites incorporated during the current Phase (II), obtained a qualification of Poor (Site 3) and Critical (Site 4) based on the Reef Health Index (RHI) (Table 1).

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[2] AGRRA Biological Monitoring Products Dropbox link: link:https://www.dropbox.com/sh/bxj3t4o97immpr0/AACtIkO-XOoaXs8cDI3RRoLaa?dl=0

Table 3. Technical characteristics and Reef Health Index of the selected sites for Phase 1 and Phase II of the project (Own source) (Own source)).

	Phase I - 2019		Phase II - 2021			
Characteristics	**Site 1 – AGRRA Code 13CCNRC**	**Site 2- AGRRA Code 011CCNRC**	**Site 1 – AGRRA Code 13CCNRC**	**Site 2- AGRRA Code 011CCNRC**	**Site 3 - Bajon GT008**	**Site 4- Corona 022 GT0010**
GPS coordinates:	Latitude: 15.9556 Longitude: -88.28128	Latitude: 15.96983 Longitude: -88.29862	Latitude: 15.9556 Longitude: -88.28128	Latitude: 15.96983 Longitude: -88.29862	Latitude: 15.94762 Longitude: -88.2788	Latitude: 15.9445 Longitude: -88.27815
Name:	13 Cayman Crown, pH and Temp logger	11 Cayman Crown, Temp logger	13 Cayman Crown, pH and Temp logger	11 Cayman Crown, Temp logger	Bajón Corona Caimán	Corona 022
Depth:	10.2 m	11.4 m	12.7m	15.5m	13.1m	12.1m
Rugosity description:	High	High	High	High	High	High
Site Habitat:	Spur and groove	Spur and groove	Spur and groove	Spur and groove	Spur and groove	Spur and groove
Reef Zone:	Fore Inner Reef	Fore Inner Reef	Fore Inner Reef	Fore Inner Reef	Fore Inner Reef	Fore Inner Reef
Reef Health Index (RHI):	**Fair 3**	**Poor 2**	**Poor 2**	**Critical 1**	**Poor 2**	**Critical 1**
Live Coral cover	5	5	5	4	3	4
Fleshy macroalgae cover	4	2	3	1	1	1
Herbivorous fish biomass	2	2	1	1	2	1
Commercial fish biomass	1	1	1	1	2	1

The AGRRA methodology uses several codes so it's easier to fit all the information required in the underwater data sheets. Below are the tables for benthic codes and names (Table 4), coral codes and names of species (Table 5) and fish codes and names of the species included per family (Table 6) so you can understand the results in the following section so you can understand the results in the following section.

Table 4. AGRRA benthic codes and names.

Benthic code	Name
SAND	Sand
MUD	Mud
GRASS	Seagrass

LC	Live Coral
NDC	Newly Dead Coral
CCA	Algae-Crustose
NDCCA	Algae-Crustose-Newly Dead
OC	Other-Calcifiers (Gypsina, Calcified Worm Tubes)
TA	Algae-Turf
TAS	Algae-Turf-Sediment
TAM	Algae-Turf-Mat
MA	Algae-Macro
CMA	Algae-Macro-Calcareous
FMA	Algae-Macro-Fleshy
CYAN	Cyanobacteria
FILM	Biofilm
AINV	Invertebrates-Aggressive
OINV	Invertebrates-Other
PEYS	Algae-Peyssonnelid
O	Other (Rubble, Hole, Unknown, etc. but NOT Sand/Mud/Seagrass)

Table 5. AGRRA coral codes and names of the species

Coral Code	Species
ATEN	*Agaricia tenuifolia*
PAST	*Porites astreoides*
SSID	*Siderastrea siderea*
HCUC	*Helioseris cucullata*
OFAV	*Orbicella faveolata*
AAGA	*Agaricia agaricites*
CNAT	*Colpophyllia natans*
PDIV	*Porites divaricata*
ACER	*Acropora cervicornis*

MCAV	*Montastraea cavernosa*
PPOR	*Porites porites*
PSTR	*Pseudodiploria strigosa*
SCUB	*Scolymia cubensis*
MMEA	*Meandrina meandrites*
MLAM	*Mycetophyllia lamarckiana*
ALAM	*Agaricia lamarcki*
MANG	*Mussa angulosa*
MFER	*Mycetophyllia ferox*
DLAB	*Diploria labyrinthiformis*
MAUR	*Madracis auretenra (mirabilis)*
SINT	*Stephanocoenia intersepta*
SRAD	*Siderastrea radians*
MCOM	*Millepora complanata*

Table 6. AGRRA fish codes and names of the species included per family.

Fish code	Name and species included in the analysis
ANGE	Angelfishes (all species in family)
BARR	Barracudas (only Great Barracuda)
BOXF	Boxfishes (all species in family)
BUTT	Butterflyfishes (all species in family)
CHUB	Chubs (all species in family)
DAMS	Damselfishes (only Threespot and Yellowtail Damselfish)
FILE	Filefishes (all species in family)
GROU	Groupers (all species in family)
GRUN	Grunts (all species in family)
JACK	Jacks (only Bar Jack and Permit)
MORA	Morays (only Goldentail, Green, and Spotted)

PARR	Parrotfishes (all species in family)
PORC	Porcupine Fishes (only Balloonfish and Porcupinefish)
PORG	Porgies (only Jolthead, Saucereye, Sheepshead and Pluma)
PUFF	Porcupine Fishes (only Bandtail Puffer)
SCOR	Scorpionfishes (only exotic Lionfish)
SNAP	Snappers (all species in family)
SURG	Surgeonfishes (all species in family)
TRIG	Triggerfishes (all species in family)
WRAS	Wrasse (only Hogfish, Spanish Hogfish, Slippery Dick, Yellowhead Wrasse, and Puddingwife)

4.1.2 Results of the AGRRA monitoring Phase II sites

- **Site 1**

The summary of the four main indicators for reef health for Site 1 are shown in Table 7.

Table 7. Reef health in Site 1 monitored using the AGRRA protocol during 31st of August 2021 (Own source).

Site Name	AGRRA Code	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
Cayman Crown, pH and Temp logger	CC01	60	10	763	46	
		5	3	1	1	**Poor 2**

Benthic cover: a total of six 10m long transects were surveyed to register the benthic diversity and composition. The substrate was identified every 10cm to total 100 substrate points per transect, adding a total of 600 substrate points for each site. The most dominant substrate on this site are corals with 59.8%, the other benthic substrates that are less dominant are CCA (crustose coralline algae) with 11.7%, FMA (fleshy macroalgae) both with a 9.7%, other invertebrates (OINV) with 7.5%, cyanobacteria (CYAN) with 6.5%. Other recorded organisms include aggressive invertebrates (AINV), turf algae (TA), turf-algae sediment (TAS), calcareous macroalgae (CMA), crustose algae-newly dead coral (NDCCA) and newly dead coral (NDC) (Fig 2).

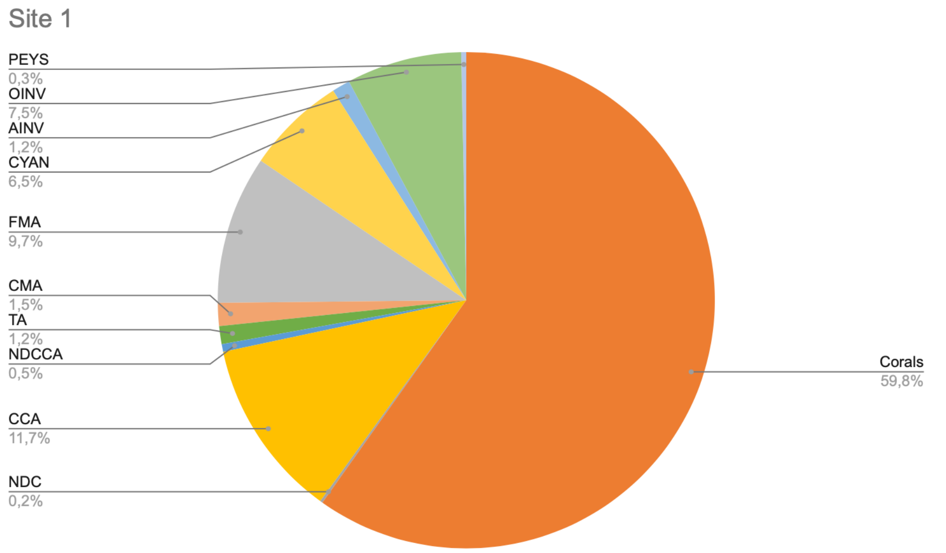

Fig 2. Percent of benthic cover for Site 1 of the Cayman Crown Reef, monitored the 31st of August 2021 (Own source).

Live Coral Cover: the live coral cover for Site 1 is 60%, which means the site has a very good coral cover. The AGRRA methodology monitors live coral cover, meaning that we record all corals that are alive. No diseased corals were observed during the monitoring. The most dominant species is *Agaricia tenuifolia* with 34% followed by *Agaricia lamarcki* with 13.4%, Orbicella faveolata with 14.2 %. These coral species are important because they provide a higher rugosity (higher three-dimensional complexity) to the reef system (Fig 4).

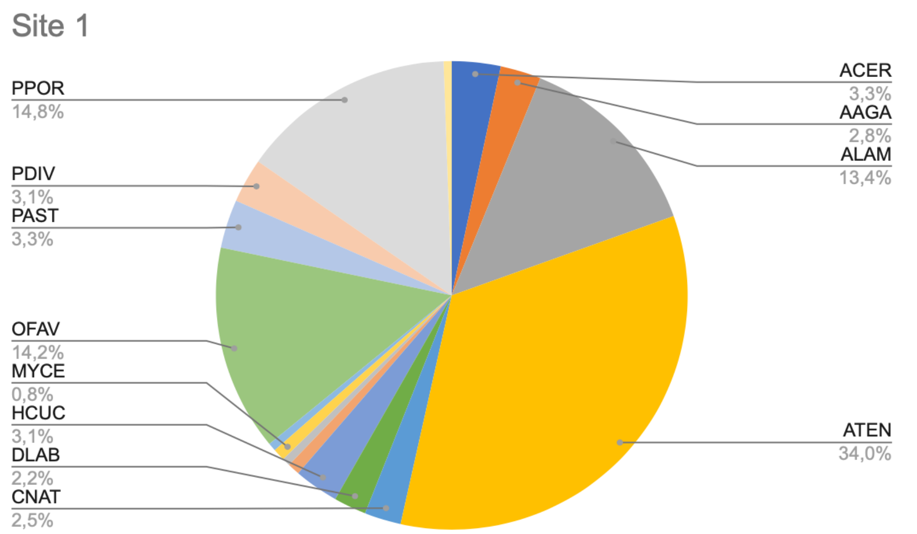

Fig 3. Percent of coral cover on Site 1 of the Cayman Crown Reef, monitored the 31st of August 2021 (Own source).

The coral species reported for Site 1 are considered of Least Concern under the IUCN Red List, except for *Agaricia teunifolia* the major reef builder of Cayman Crown reef, which is considered Near Threatened (Table 8).

Table 8. Complementary legend for Figure 3 (Own source based on the IUCN Red list of threatened species database).

Codes	Scientific name	IUCN Red List Status
ATEN	*Agaricia teunifolia*	NT – Near threatened
ALAM	*Agaricia lamarcki*	VU- Vulnerable
AAGA	*Agaricia agarites*	LC - Least concern
SSID	*Siderastrea siderea*	LC - Least concern
SINT	*Siderastrea intercepta*	No information available
PPOR	*Porites porites*	LC - Least concern
PFUR	*Porites furcata*	LC - Least concern
PDIV	*Porites divaricata*	LC - Least concern
PAST	*Porites astreoides*	LC - Least concern
MMEA	*Meandrina meandrites*	LC - Least concern
MDEC	*Madracis decactis*	LC - Least concern
CNAT	*Colpophyllia natans*	LC - Least concern

Disease Data: there was no coral disease identified for the site.

Fish biomass by family: fish were registered over 10 transects (30 m each) within the study site. The most abundant fish species for the site were Angelfish, with 583 g/100m^2, Parrotfish with 533 g/100m^2 and Surgeonfish with 230 g/100m^2. Even though parrotfish were one of the most abundant fish species, the total biomass recorded of these important herbivores is in critical condition as shown in the RHI (Table 3). The RHI value for herbivorous fish biomass was 763 g/100m^2 and for commercial fish biomass was 46 g/100m^2 (Table 7). This means that this indicator is in Critical (1, red) condition since it is well below the minimum threshold value for the critical condition category of <390 g/100m^2. The total biomass per family of fish for Site 1 are shown in Fig 4.

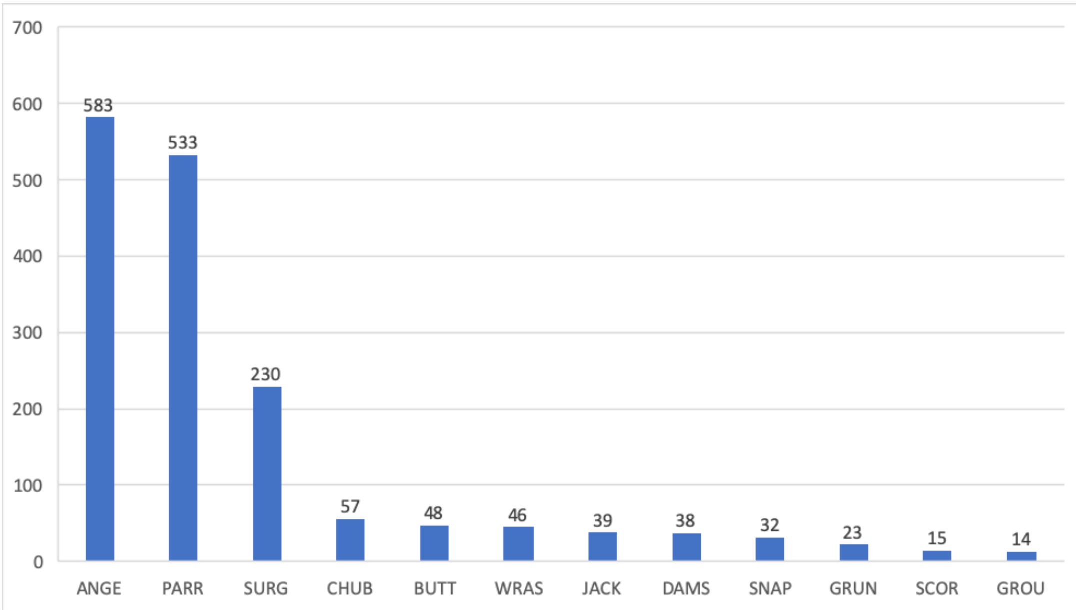

Fig 4. Biomass of the different families of fish (g/100m^2) on Site 1 of the Cayman Crown Reef (Own source).

- **Site 2**

The summary of the four main indicators for reef health foron Site 2 are shown in Table 9.

Table 9. Reef health of Site 2 monitored using the AGRRA protocol during 31st of August 2021 (Own source).

Site Name	AGRRA Code	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
11 Cayman Crown, Temp logger	CC01	31	38	853	301	
		4	1	1	1	**Critical 1**

Benthic cover: a total of six 10m long transects were surveyed to register the benthic diversity and composition. The substrate was identified every 10cm to total 100 substrate points per transect, adding a total of 600 substrate points for each site. The most dominant substrate on this site are fleshy macroalgae (FMA) with 38.4% and corals with 31.3%, the other benthic substrates that are less dominant are other invertebrates (OINV) with 9.2%, CCA (crustose coralline algae) with 5.1%, calcareous macroalgae (CMA) with 3.8%, aggressive invertebrates (AINV) with 3.2%. Other recorded organisms include algae-peyssonnelid (PEYS), turf algae (TA), turf-algae sediment (TAS) and cyanobacteria (CYAN) (Fig 5).

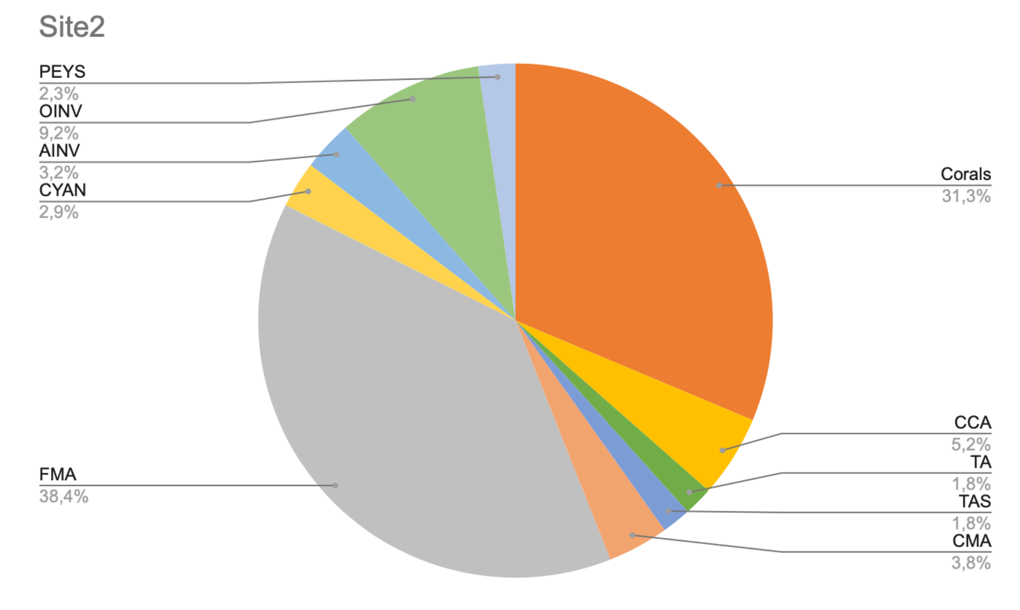

Fig 5. Percent of benthic cover for Site 2 of the Cayman Crown Reef, monitored the 31st of August 2021 - Phase II (Own source).

Live Coral Cover: the live coral cover for Site 2 is 31%, which means that this indicator is in good condition. The AGRRA methodology monitors live coral cover, meaning that we record all corals that are alive. No diseased corals were observed during the monitoring. The most dominant species is *Orbicella faveolata* with 20.2 %, *Agaricia tenuifolia* with 17.6% followed by *Agaricia agaricites* with 13.3% and *Meandrina meandrites with* 11.2% (Fig 6). These coral species are important because they are reef building species which provide great habitat for other species, they also provide a higher rugosity (higher three-dimensional complexity) to the reef system.

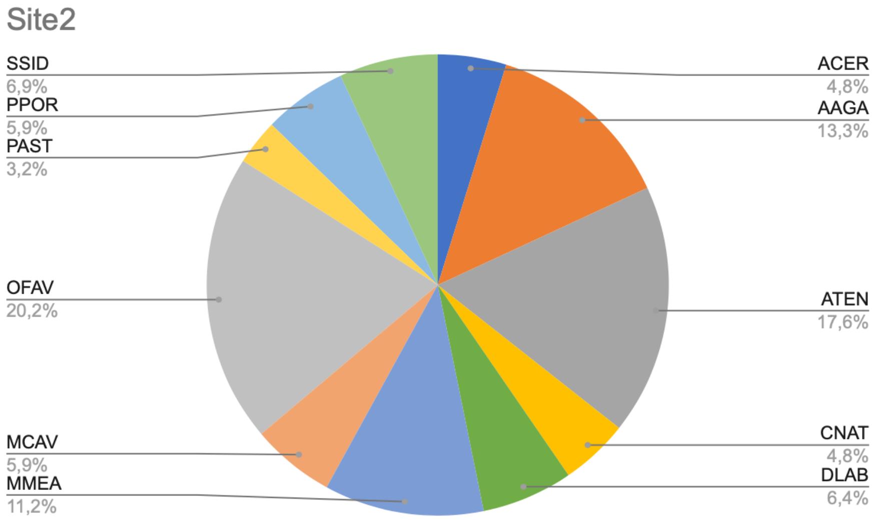

Fig 6. Percent of coral cover on Site 2 of the Cayman Crown Reef, monitored the 31st of August 2021 (Own source).

Disease Data: there was no coral disease identified for the site.

Fish biomass by family: fish were registered over 10 transects (30 m each) within the study site. The most abundant fish species for the site were Parrotfish with 491 g/100m^2, Surgeonfish with 362 g/100m^2 and Groupers with 285 g/100m^2. However, both herbivore and commercial fish biomass for this site are in critical condition. The RHI value for herbivorous fish was 853 g/100m^2 and commercial fish biomass was 301g/100m^2, which means that both of these indicators is in Critical (1, red) condition since it is well below the minimum threshold value for the critical condition category (<990 g/100m^2 for herbivorous fish and <390 g/100m^2 for commercial fish.) (Table 9). The total biomass per family of fish for Site 2 are shown in Figure 7.

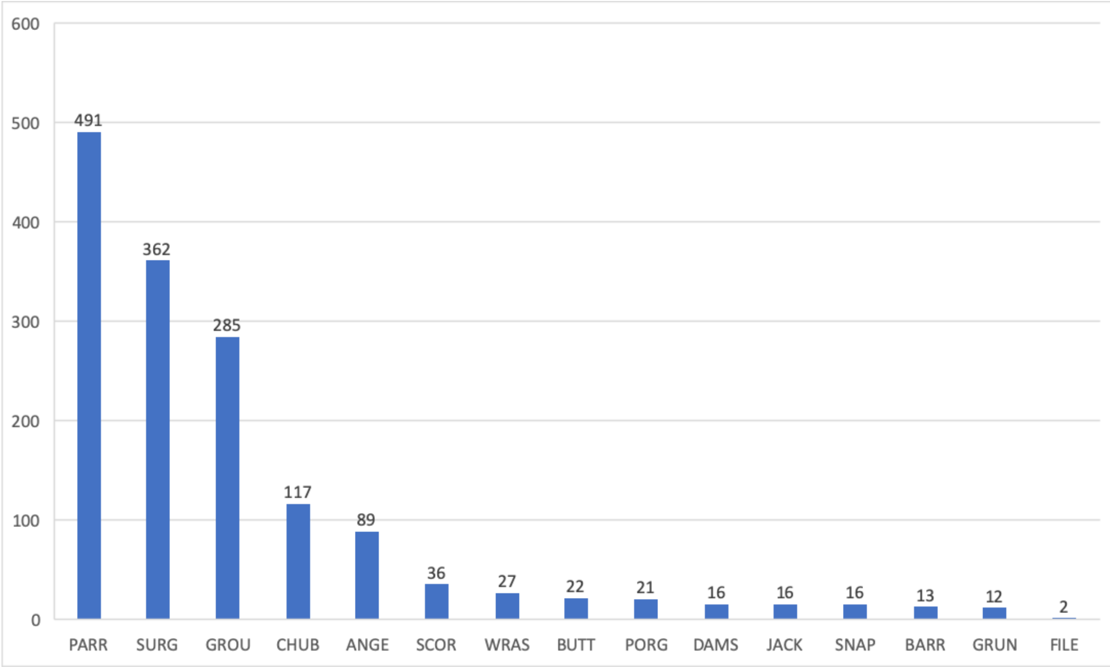

Fig 7. Biomass of the different families of fish (g/100m^2) on Site 2 of the Cayman Crown Reef (Own source).

- **Site 3**

The summary of the four main indicators for reef health foron Site 3 are shown in Table 10.

Table 10. Reef health of Site 3 monitored using the AGRRA protocol during 1st of September 2021 (Own source).

Site Name	AGRRA Code	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
Bajón Corona Caimán	CC02	18	50	1070	744	
		3	1	2	2	**Poor 2**

Benthic cover: a total of six 10m long transects were surveyed to register the benthic diversity and composition. The substrate was identified every 10cm to total 100 substrate points per transect, adding a total of 600 substrate points for each site. The most dominant substrate on this site are fleshy macroalgae (FMA) with 49.9% and corals with 17.7%, the other benthic substrates that are less dominant are CCA (crustose coralline algae) with 6.7%, other invertebrates (OINV) with 6.4%, calcareous macroalgae (CMA) with 5.6%, aggressive invertebrates (AINV) and cyanobacteria (CYAN) with 4.6%. Other recorded organisms include algae-peyssonnelid (PEYS), turf-algae sediment (TAS), newly dead coral (NDC) and sand (Fig 9).

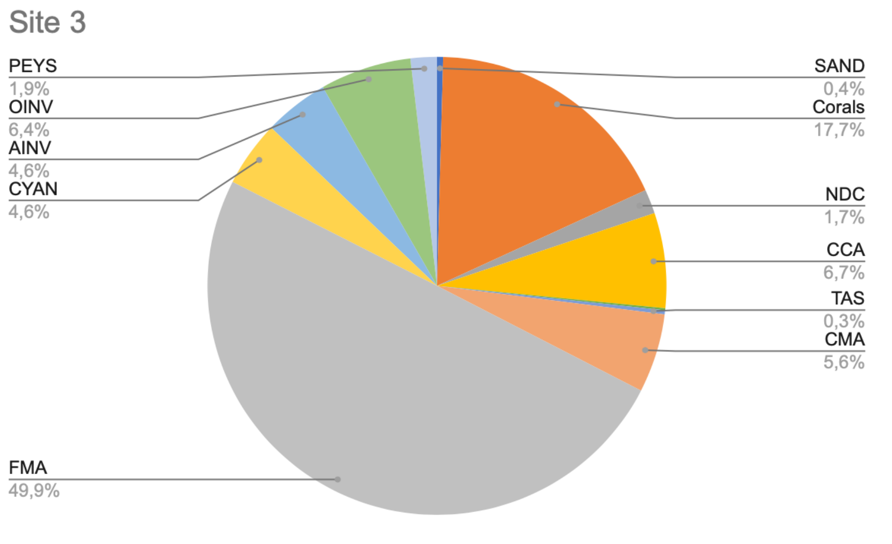

Fig 9. Percent of benthic cover for Site 3 of the Cayman Crown Reef, monitored the 1st of September 2021 (Own source).

Live Coral Cover: the live coral cover for Site 3 is 18%, which means that this indicator is in fair condition. The AGRRA methodology monitors live coral cover, meaning that we record all corals that are alive. No diseased corals were observed during the monitoring. The most dominant species for this site is *Orbicella faveolata* with 27.4 %, *Agaricia humilis* with 12.9%, *Porites porites* with 12.1%, *Siderastrea siderea* with 10.5%, *Porites astreoides with* 10.5%, *Agaricia tenuifolia* with 5.6%, *Orbicella annularis* with 4.8%. The rest of the species were less dominant (Fig 10). This site has more diversity of corals, the coral species that are present in the site are important because they are reef building species which provide great habitat for other species.

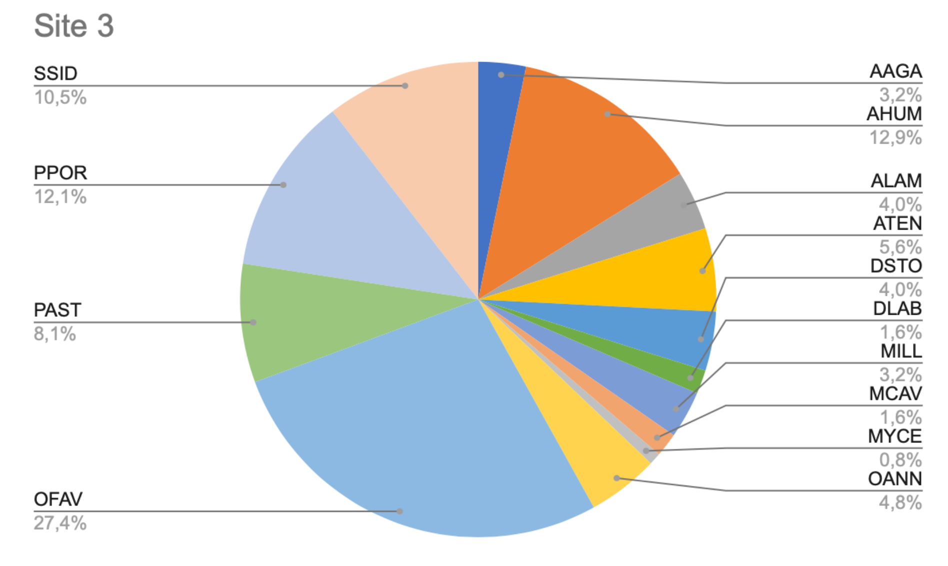

Fig 10. Percent of coral cover on Site 3 of the Cayman Crown Reef, monitored the 31st of August 2021 (Own source).

Disease Data: there was no coral disease identified for the site.

Fish biomass by family: fish were registered over 10 transects (30 m each) within the study site. The most abundant fish species for the site were Parrotfish with 608 g/100m^2, Groupers with 587 g/100m^2

and Surgeonfish with 462 g/100m^2. Even though these families are the most abundant for the site, both herbivorous and commercial fish biomass are in poor condition (2, orange) (Table 10). The RHI value for herbivorous fish was 1070 g/100m^2 and commercial fish biomass was 744 g/100m^2. The total biomass per family of fish for Site 3 are shown in Figure 11.

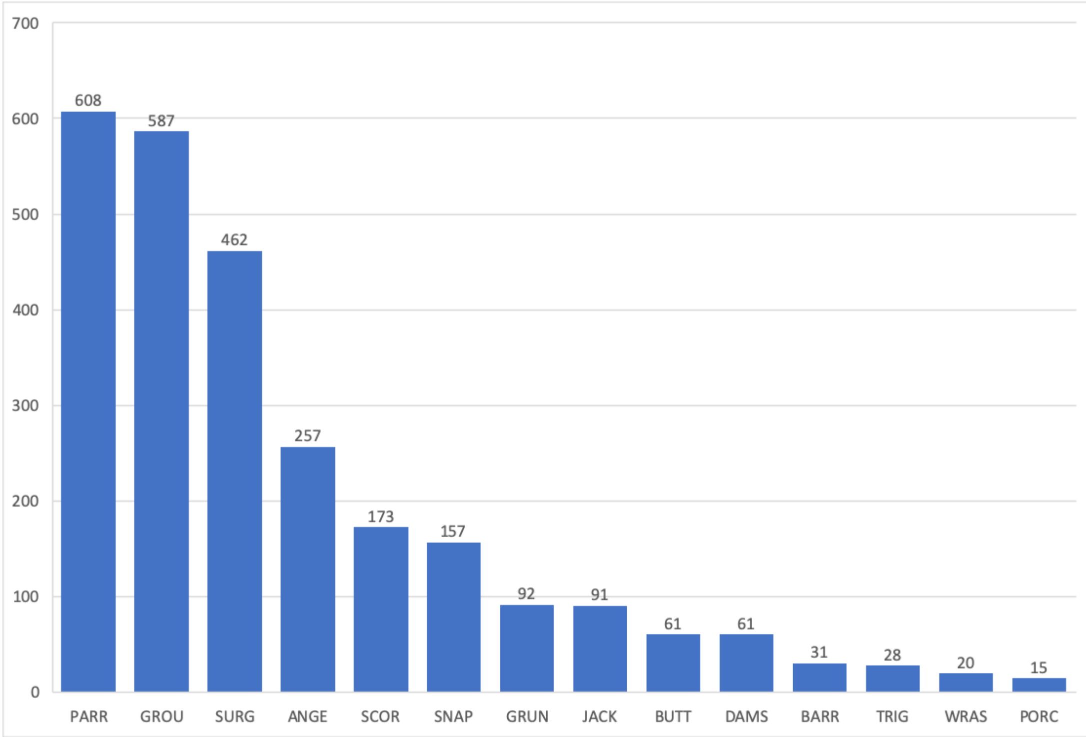

Fig 11. Biomass of the different families of fish (g/100m^2) on Site 3 of the Cayman Crown Reef (Own source).

- **Site 4**

The summary of the four main indicators for reef health for Site 4 are shown in Table 11.

Table 11. Reef health of Site 4 monitored using the AGRRA protocol during 6th of December 2021- Phase II (Own source).

Site Name	AGRRA Code	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
Corona 022 Lucido	GT010	39	35	261	37	
		4	1	1	1	**Critical 1**

Benthic cover: a total of six 10m long transects were surveyed to register the benthic diversity and composition. The substrate was identified every 10cm to total 100 substrate points per transect, adding a total of 600 substrate points for each site. The most dominant substrate on this site are fleshy macroalgae (FMA) with 35.3% and corals with 39%, the other benthic substrates that are less dominant are CCA (crustose coralline algae) with 12.3%, other invertebrates (OINV) with 5.5%, calcareous macroalgae (CMA) with 5%, cyanobacteria (CYAN) with 1.5% and newly dead coral (NDC) with 0.3% (Fig 12).

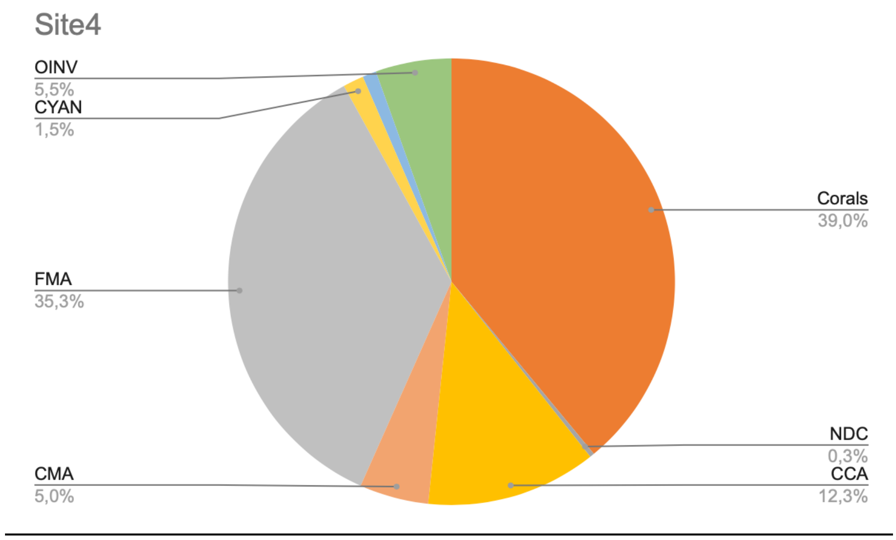

Fig 12. Percent of benthic cover for Site 4 of the Cayman Crown Reef, monitored the 6th of December 2021 - Phase II (Own source).

Live Coral Cover: the live coral cover for Site 4 is 39%, which means that this indicator is in good condition. The AGRRA methodology monitors live coral cover, meaning that we record all corals that are alive. No diseased corals were observed during the monitoring. The most dominant species for this site is *Porites porites* with 34.6%, *Porites astreoides with* 26.9%, *Agaricia agaricites* with 19.2%, *Agaricia tenuifolia* with 16.3%, *Agaricia humilis* with 0.9%, *Porites divaricata* with 2.1% (Fig 13). This site has less diversity of corals compared to the other sites monitored.

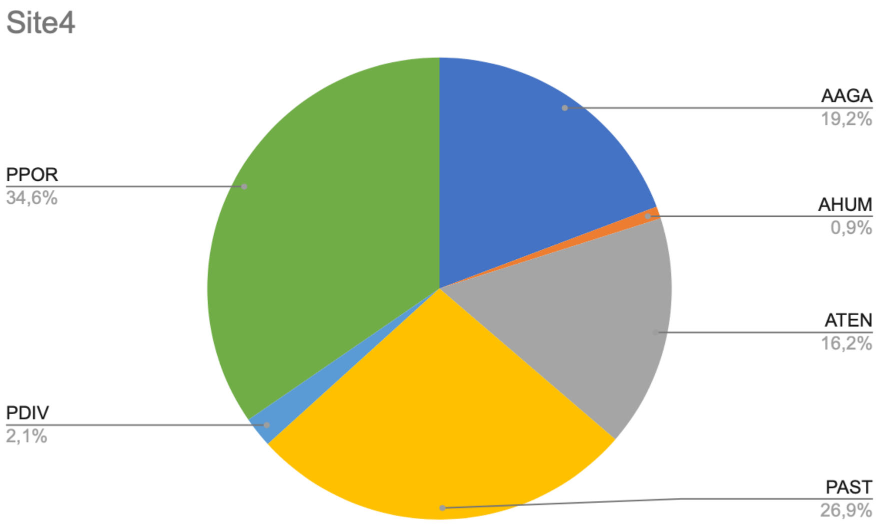

Fig 13. Percent of coral cover on Site 4 of the Cayman Crown Reef, monitored the 6th of December 2021 - Phase II (Own source).

Disease Data: there was no coral disease identified for the site.

Fish biomass by family: fish were registered over 10 transects (30 m each) within the study site. The most abundant fish species for the site were Grunts with 279 g/100m^2, Parrotfish with 225 g/100m^2 and Angelfish with 110 g/100m^2. This site has the lowest biomass of herbivorous and commercial fish of the 4 sites monitored, with only 261g/100m^2 for herbivorous fish and a low 37 g/100m^2 for commercial fish, which means that both of these indicators are in Critical (1, red) condition since it is well below the minimum threshold value for the critical condition category (<990 g/100m^2 for herbivorous fish and <390 g/100m^2 for commercial fish) (Table 11). The total biomass per family of fish for Site 4 are shown in Figure 14.

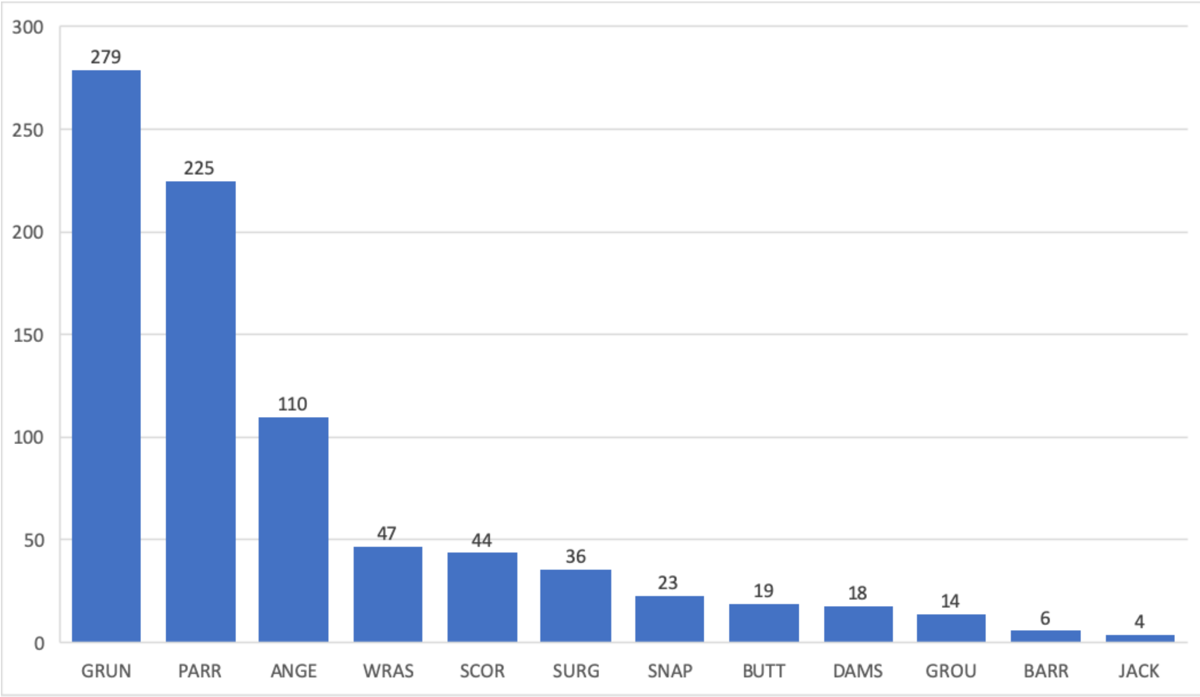

Fig 14. Biomass of the different families of fish (g/100m^2) on Site 4 of the Cayman Crown Reef (Own source).

4.1.3 Data comparison for Site 1 and Site 2 for 2019 and 2021 monitoring periods.

The monitoring data gathered for both 2019 and 2021 served as a consistent 2-year baseline to compare and track changes in the different reef health indicators on the two reef sites (Site 1 and 2). The data comparison for Site 1, including the depth and RHI can be seen in Table 12, and the data comparison for Site 2 can be seen on Table 13.

Table 12. Data comparison for Site 1(Own source).

Year surveyed	Site Name	AGRRA Code	Depth average	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
2019	Cayman Crown, pH and Temp logger S	13CCNRC	10.2	77	5	1,178	41	**Fair 3**
2021	Cayman Crown, pH and Temp logger S	CC01	12.7	60	10	763	46	**Poor 2**

Table 13. Data comparison for Site 2 (Own source).

Year surveyed	Site Name	AGRRA Code	Depth average	Live Coral Cover %	Fleshy Macroalgae Cover %	Herbivorous Fish Biomass (g/m^2)	Commercial Fish Biomass (g/m^2)	RHI
2019	Cayman Crown, pH and Temp logger S 11	011CC NRC	11.4	47	25	1,131	162	**Poor 2**
2021	Cayman Crown, Temp logger	CC01	15.5	31	38	853	301	**Critical 1**

Discussion of changes over time:

It is important to mention that to be able to track changes over time it requires more years studying the current sites; a two year study like this current grant is a short period of time to draw conclusions; however, these kind of studies are critical to generate solid baselines that allow us to track changes, identify patterns and discover evolution traits over time; without this effort we wouldn't be able to further comprehend the scale and intensity of these changes and perturbations, as well as the resilience capacity of these ecosystem to overcome current challenges such as global warming, bleaching and the SCTLD.

- The **variations in average depth** between the two years may be one factor that is causing the differences between the indicators. Based on our experience and familiarity with the reefs in Guatemala and with Cayman Crown, as well as the literature, we have seen that the deeper we go on the reef, the less corals and more macroalgae there are. One of the main reasons for shallow reefs to host a wider biodiversity and abundance is the availability of light, a limiting factor for the corals to settle, grow and survive over time. For Site 1 we had an average depth of 10.2 m during our monitoring for 2019 and a very high coral cover of 77%, however, the average depth for 2021 reached 12.7 and the coral cover significantly dropped to 60%. For Site 2, coral cover also dropped from 47% (2019) to 31% (2021) and the average depth for the site increased by 4.1 m, which might be incurring in these changes. Changes in the recorded depth when applying the AGRRA methodology can arise given that we work within a general study site we revisit based on specific GPS coordinates, but we do not have fixed transects. This means that we work within a general study site and the transects are laid haphazardly, and this kind of variation is possible. Even though the diving team stays close by during a specific monitoring, the fact that corals, benthic and fish transects are developed simultaneously means that the team has to spread to keep some distance to avoid scaring the fish and/or avoid overlapping transects. This factor could have contributed to moving around the general area more than expected, compared to the original depth level. The difference in the depth and the associated reef biodiversity and abundance will be a key factor for future monitoring to continue exploring, given that we currently do not know specific depth thresholds to identify significant changes below a specific depth.
- **An increase in fleshy macroalgae cover** might be due to the variation in the depth when monitoring compared to previous years (10.2 m in 2019 vs. 12.7 m in 2021), and also to the potential increase in nutrients input from the numerous watersheds. The Caribbean coast of Guatemala is characterized by the presence of several rivers such as the Motagua, Río Dulce and Sarstun; the fresh water input brings nutrients washed from agricultural lands across the watersheds. Poor watershed management as well as the lack of sewage treatment plants in the Caribbean coast of Guatemala, fuel macroalgae growth, without herbivorous fish that

graze dawn macroalgae, corals get overgrow, suffocate and die. Additionally, to the annual nutrient inputs that these reefs usually receive, 2020 was a super active hurricane season which resulted in three hurricanes affecting Guatemala (Hurricane Nana, Amanda (mostly affecting southern Guatemala, but causing river runoff increase in the Caribbean)) and Eta. Even though they were degraded to tropical storms before entering the national territory, the amount of rain that arrived from the watersheds was greatly significant, mostly bringing a much larger amount of nutrients, supporting the increase we detected during the 2021 monitoring. This is a theory that we were not able to track or measure given the COVID restrictions that year and the lack of water quality equipment to have collected water samples. The impact of these hurricanes was widely documented, showing great extension of agricultural lands and coastal plains flooded for days, which further support our thinking. A monthly watershed, coastal and marine water quality monitoring paired with *in situ* monitoring of marine currents to better understand the area could generate valuable and new data to support the great need for improved watershed management and agricultural practices in line with the regenerative agriculture and holistic ridge to reef concepts.

- Decline in both **herbivorous and commercial fish biomass**, might be attributed to increased fishing pressure because of the lifting of restrictions from the fisheries department in Guatemala and lack of enforcement in the area due to the COVID pandemic. The decline in fish, both herbivorous and commercial, is a trend we have observed during the last years that also applies to other parts of the MAR, indicating the huge risk of fish populations collapsing.

We conducted two coral reef monitoring expeditions. The first expedition took place during August 29th through September 2nd, 2021, during which 3 sites in the Cayman Crown reef. The second trip to the Cayman Crown reef was held during the 6th to the 8th of December 2021, during which a total of 4 sites were monitored, the same 3 sites monitored in the first trip and we added 1 more site. The monitoring protocol for SCTLD was done using the AGRRA and Drop Bar methodologies to evaluate the health of the reef with a special focus on this disease, meaning we looked for the disease or any sign of disease on the reefs. During both expeditions we were able to determine the great news that there is no presence of SCTLD on the reefs monitored in Guatemala.

The data collected in all of the sites monitored has been uploaded to the AGRRA SCTLD portal and dashboard: https://www.agrra.org/coral-disease-outbreak/

For each of the reef sites monitored we reported date, reef name, location, coral species seen, signs of disease focusing mostly in SCTLD and also bleaching to be able to see how the disease is unfolding. The map showing the sites monitored for Guatemala can be seen in Fig 15.

For SCTLD in the Cayman Crown reef, we monitored a total of 7 sites, 200 coral colonies per site. In the sites monitored there is no presence of the disease. However, monitoring must continue since the disease is still spreading in other parts of the MAR and might eventually affect this reef.

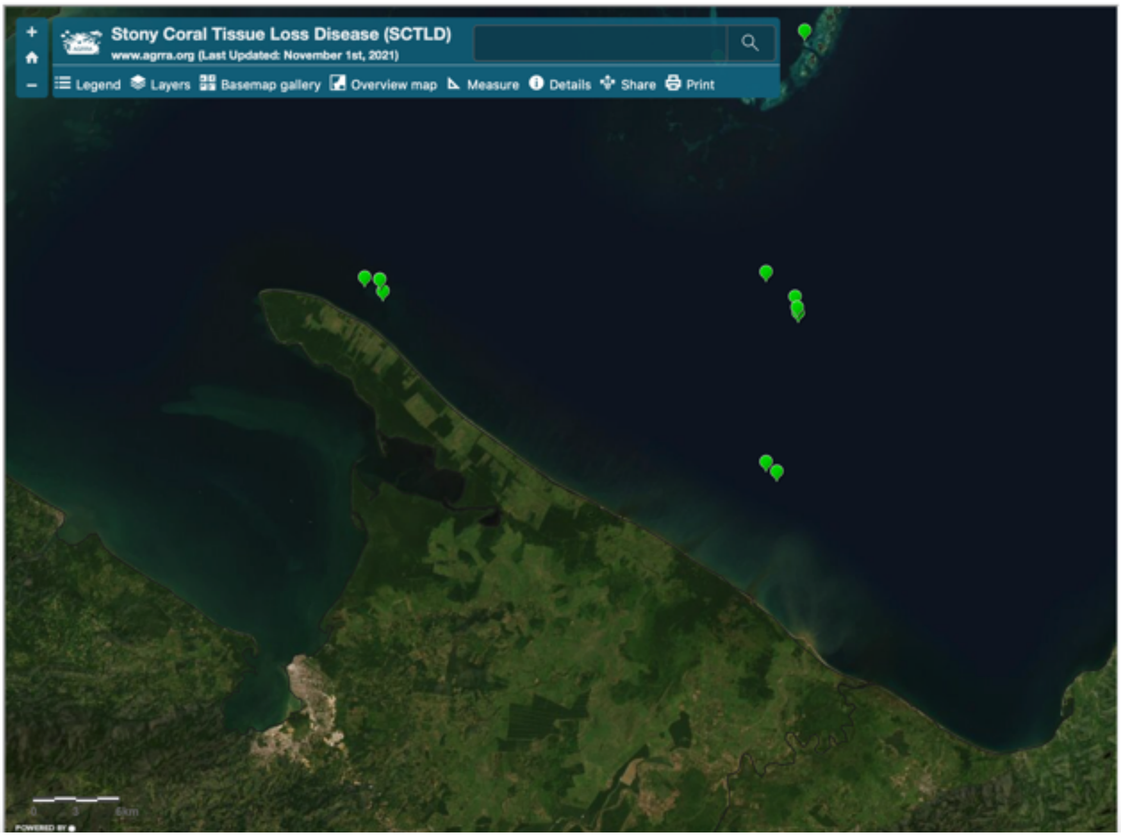

Fig 15. Map of the SCTLD for the monitored sites in Guatemala- AGRRA disease platform. The data and sites monitored are in green, suggesting that there is no presence of SCTLD for the sites monitored in Guatemala based on our most recent data (AGRRA, 2022).

4.2. Temperature and pH data

We installed loggers in two different sites of the Cayman Crown reef (Site 1 and Site 2) during Phase I of the project (Table 13). The logger on Site 1 has been placed on one of the sides of a spur (coral reef habitat specific formation) in the coral reef area (12.2 m deep). This site is located near a wall that drops from 9 m to 180 m. The temperature logger on Site 2 was installed (during Phase I of the project) on top of a spur; there are no walls or drop-offs close to the site.

Table 13. Site characteristics and location of the temperature and pH loggers (Own source).

Characteristics	**Site 1 – AGRRA Code 13CCNRC**	**Site 2- AGRRA Code 011CCNRC**
GPS coordinates:	Latitude: 15.9556 Longitude: -88.28128	Latitude: 15.96983 Longitude: -88.29862
Logger:	pH and Temp logger	Temp logger
Depth:	12.7m	15.5m
Rugosity description:	High	High
Site Habitat:	Spur and groove	Spur and groove
Reef Zone:	Fore Inner Reef	Fore Inner Reef

- **Site 1: Temperature recordings**

The temperature and pH data for Site 1 was recorded using an Onset HOBO pH and Temperature Data Logger. The data was collected during May 29th 2019 to June 16th 2020. Because of the COVID pandemic, the logger was retrieved until August 30th 2021 and placed again in the water on August 31st 2021 and left to record until February 6th 2022.

The average temperature recorded for Site 1, during May 29th 2019 to June 16th 2020 was 28.77°C (Fig 16) and the average temperature for the second recording period from August 31st 2021 to February 6th 2022 was 29.23°C (Fig 17).There were several months during which the temperature was higher than 29.5°C (11 months from the total 18 months recorded) which is above the thermal tolerance of corals, which tends to be 29 °C. Below or above their natural temperature range, coral stress and their natural biophysical processes are affected. The highest peaks went above 30.5 °C were some days of May, June, September and November 2019 and May, June 2020 for Phase I and some days of August, September and October 2021. The data is consistent with both our field observations from October 2019, when we documented strong bleaching in both sites and with the literature documenting coral bleaching as a response to prolonged warmer seas. The lower peaks were mainly in the months of January and February 2020 and some days of January and February 2022.

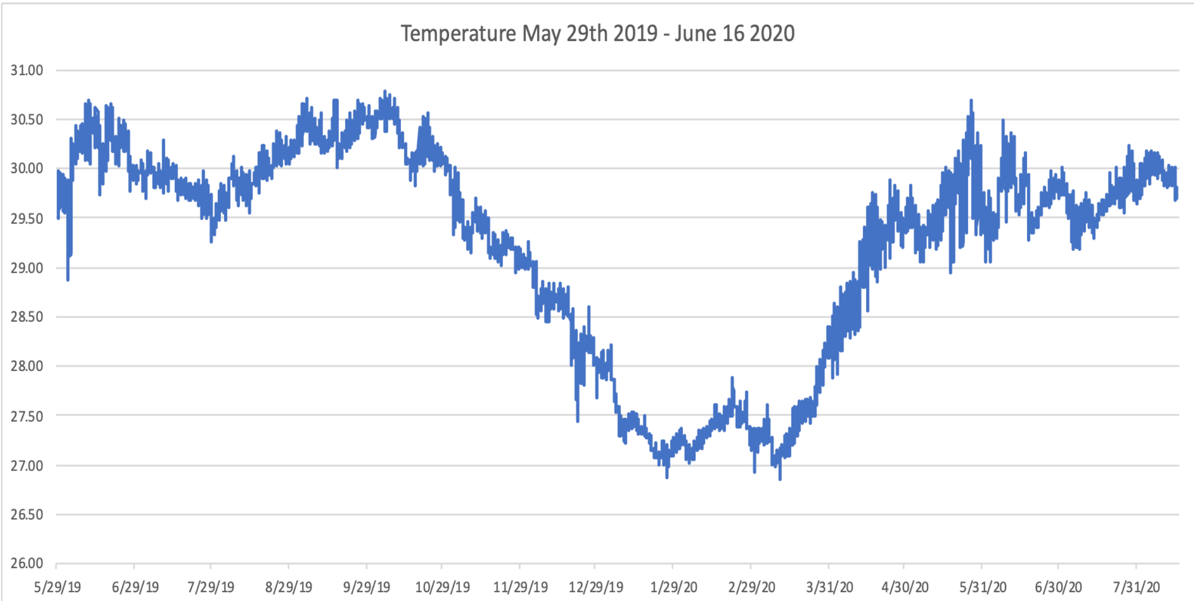

Fig 16. Temperature recording in °C, Site 1 (May 29th 2019 - June 16th 2020) (Own source).

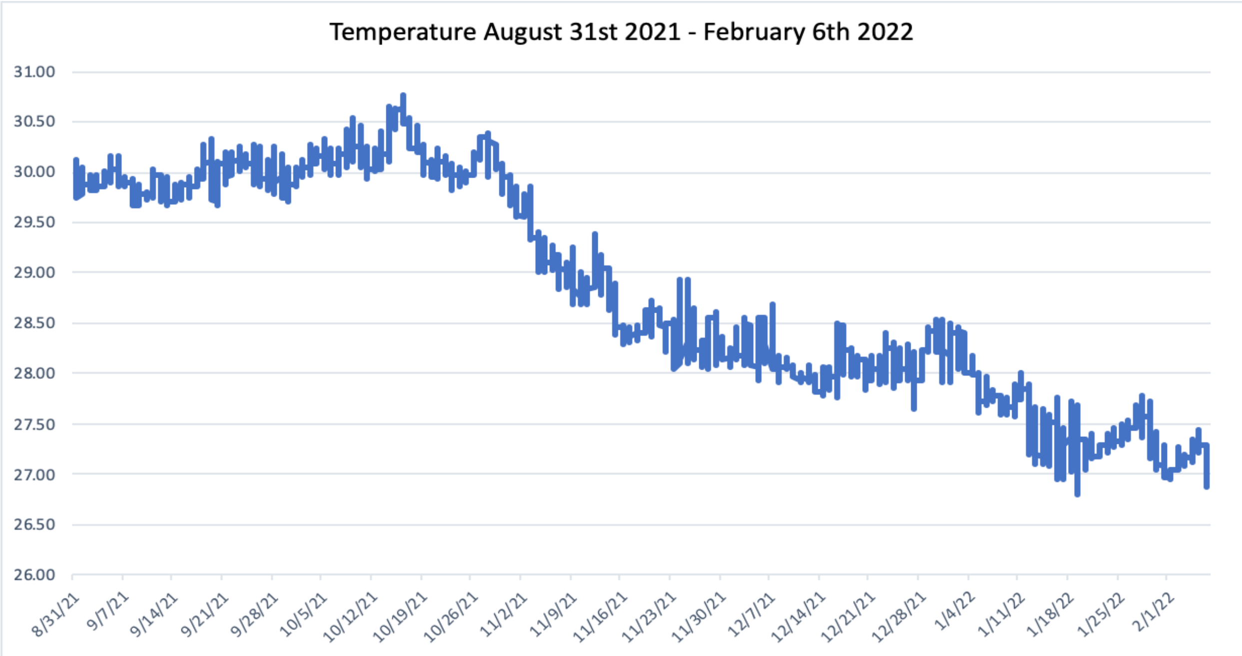

Fig 17. Temperature recording in ˚C, Site 1 (August 31st 2021- February 6th 2022) (Own source).

- **Site 2: Temperature recordings**

The temperature for Site 2 was recorded using an Onset HOBO TidbiT v2 Water Temperature Data Logger. The recordings for this site were from May 29th 2019 to August 16th 2020. Because of the COVID pandemic we weren't able to go to the field, the logger was retrieved until August 30th 2021 and placed again in the water on August 31st 2021and left to record until December 6th 2021.

The average temperature recorded for Site 2, during May 29th 2019 to June 16th 2020 was 29.35°C (Fig 18) and the average temperature for the second recording period from August 31st 2021 to December 6th 2021 was 29.63°C (Fig 19). There were many months that the temperature was higher than 29.5°C for this site (11.5 months from the total 18 months recorded) which is above the thermal tolerance of corals, which tends to be 29 °C; below or above their natural temperature range, coral stress and their natural biophysical processes are affected. The highest peaks went above 30.5 °C. The highest peaks went above 30.5 °C were some days of May, June, September and November 2019 and May, June 2020 for Phase I and some days of August, September and October 2021. The lower peaks were mainly in the months of January and February 2020 and some days of January and February 2022. The data of high and low temperature is consistent with Site 1.

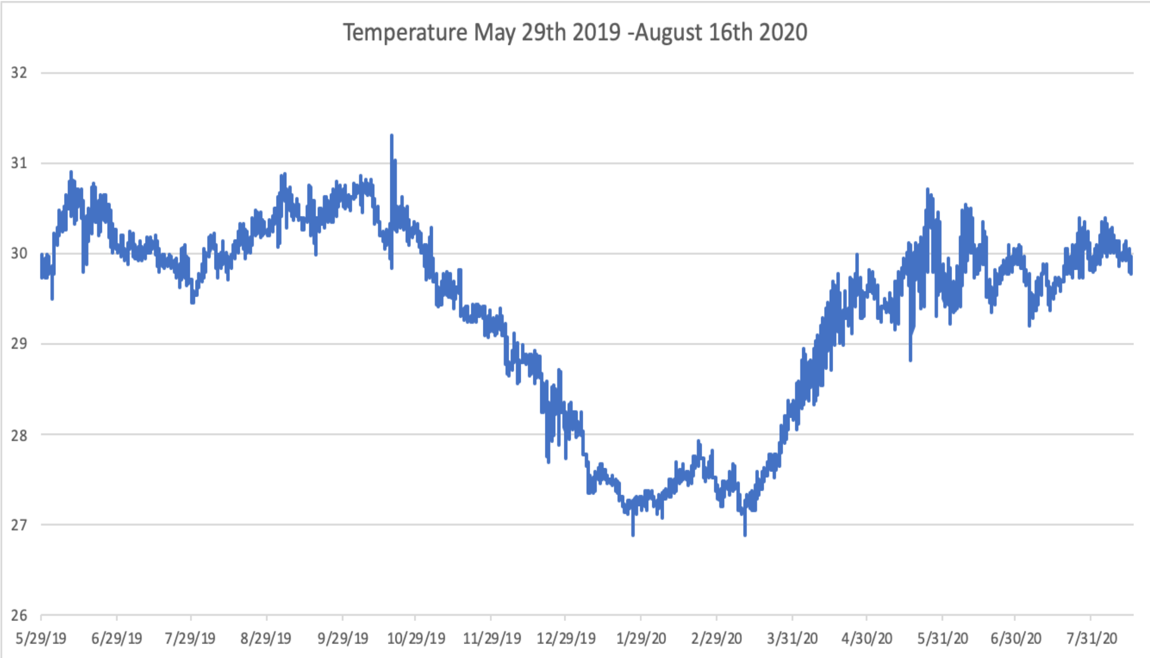

Fig 18. Temperature recording in °C, Site 2 (May 29th 2019- August 16th 2020) (Own source).

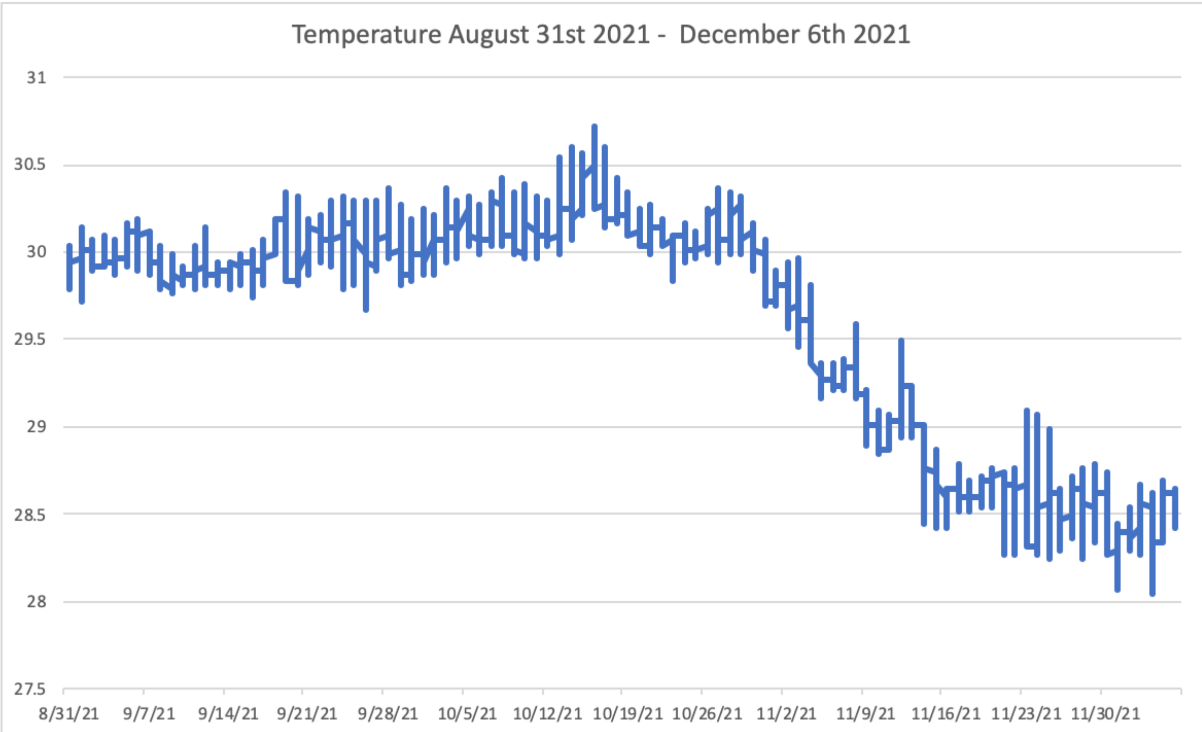

Fig 19. Temperature recording in °C, Site 2 (August 31st 2021- December 6th 2021) (Own source).

- **Temperature recordings comparison between Site 1 and 2**

The temperature variations recorded were the same on both sites, but Site 2 has approximately 0.3°C of warmer water variation on some specific dates of the year during the recording period of October 20th 2019 - August 16th 2020, however, these variations are small (Fig 20). During the second recording period (August 31st 2021- December 6th 2021) the variations between the sites were 0.5°C during some specific days of the year (Fig 21).

The temperature variations may be attributed to the location of the sites and depth as well as the different equipment used to record . The logger on Site 1 has been placed on one of the sides of a spur (coral reef habitat specific formation) in the coral reef area (12.7 m). This site is located near a wall that drops from 9 m to 180 m. This wall may be attributed to an upwelling, which carries cold water from the deep to the shallow coral reef area, or to currents on the area; however, further research is needed to be able to document the upwelling and current patterns in this particular site. The logger on Site 2 was placed on top of a spur (15.5 m), however it is deeper than Site 1, there are no walls or drop-offs close to the site. In general, temperature recordings from Site 1 and 2 during the same periods were consistent and similar with the slight variations mentioned before.

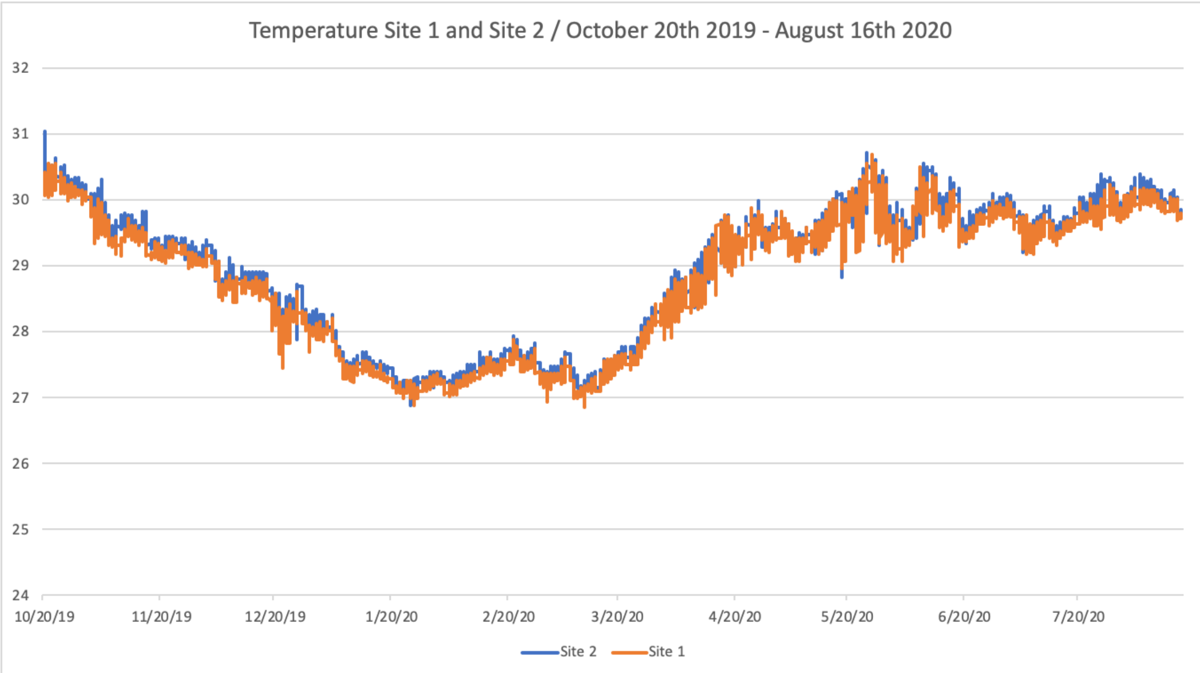

Fig 20. Comparison of temperature recording in °C for Site 1 and 2 (October 20th 2019 - August 16th 2020) (Own source).

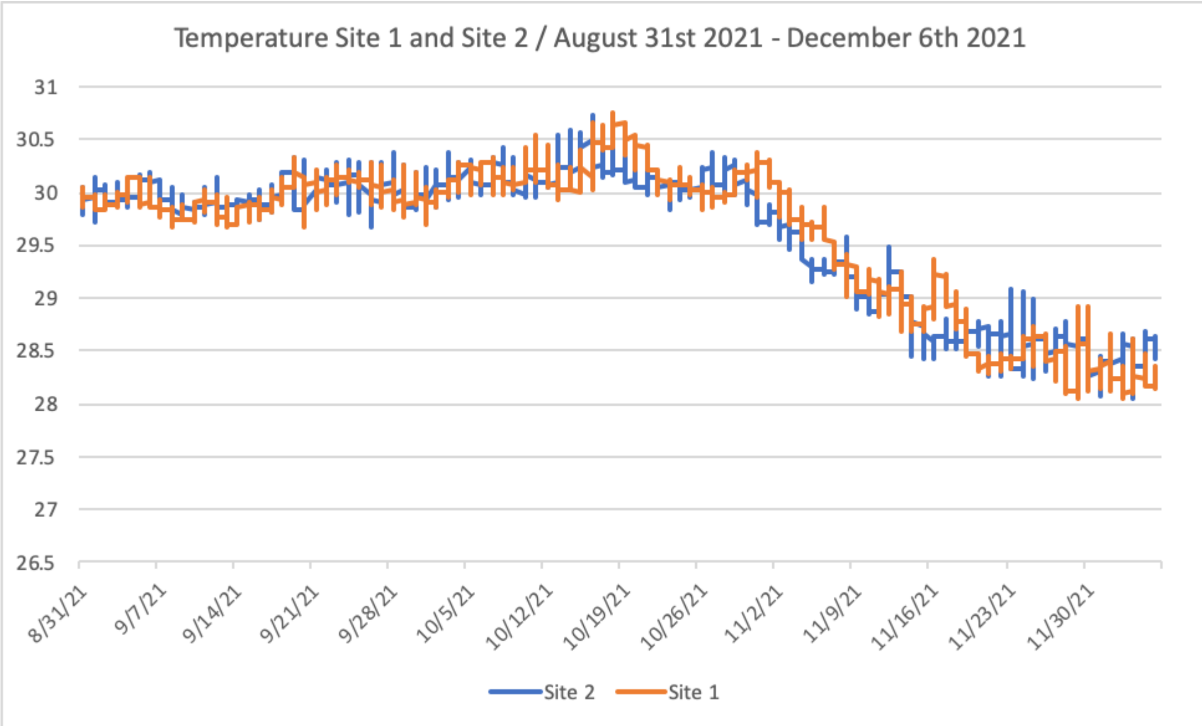

Fig 21. Comparison of temperature recording in °C for Site 1 and 2 (August 31st 2021- December 6th 2021) (Own source).

- **pH recordings**

The pH is a master variable of seawater analysis. It allows the tracking of numerous biogeochemical processes, including organic matter production and mineralization, and is the most direct measure for ocean acidification (Byrne et al., 2010; Byrne, 2014). Corals rely on water chemistry and light in order to build their calcium carbonate skeletons (calcification). Under the right conditions of calcium, alkalinity, pH and carbon dioxide they are able to grow well. The pH of seawater can vary depending on locale, but can range from 8.0 to 8.5. Calcifying organisms such as corals tend to calcify best at a pH of 8.2-8.5 due to a variety of factors such as calcium and alkalinity availability, and carbon dioxide levels. If the pH is between 7.6-8.0 then corals will not calcify properly (Delbeek and Sprung, 2005; Comeau *et al*., 2012).

The pH was measured using an Onset HOBO pH and Temperature Data Logger. The logger was deployed on Site 1. This site had an average pH recording of 8.6 during the first readings from May 29th 2019 to June 16th 2020 (Fig 22). Even though we calibrated the logger before the deployment, there might be an error in the recording of this parameter. Taking this into account during the second deployment of the logger we did a thorough calibration and tested the logger before placing it in the water. The second deployment was made from August 31st 2021 to February 6th 2022 (Fig 23). The average ocean pH registered for this site during this recording period was of 8.32. With this second recording period we made a correction of -0.75 to the data collected for the first recording period (May 29th 2019 to June 16th 2020).

Measuring the pH as part of the monitoring program we have carried out at Cayman Crown reef since 2019 is important because it provides key information of the marine environment helping us understand ecological changes over time; however, it is not a variable we can associate at this moment with immediate or short-term observable changes. The average pH values recorded during the different times the sensor was operating and recording shows that pH levels at Cayman Crown are within the expected seawater pH ranges (8.0 - 8.5) and within ranges at which calcifying organisms including corals tend to calcify best (8.2-8.5).

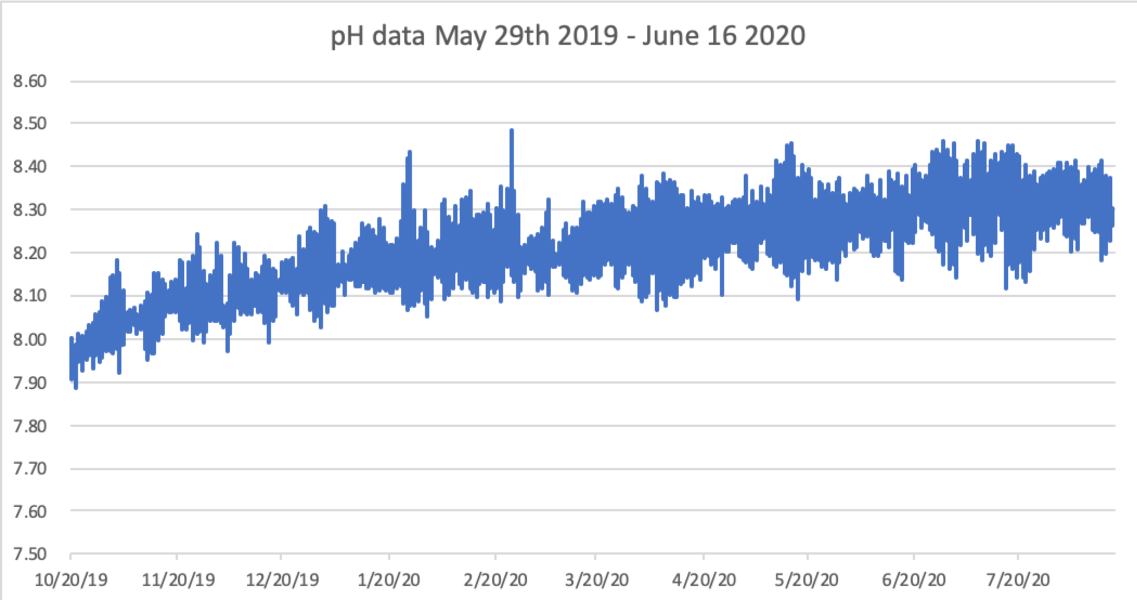

Fig 22. pH recording for Site 1 (May 29th 2019- June 16th 2020) (Own source).

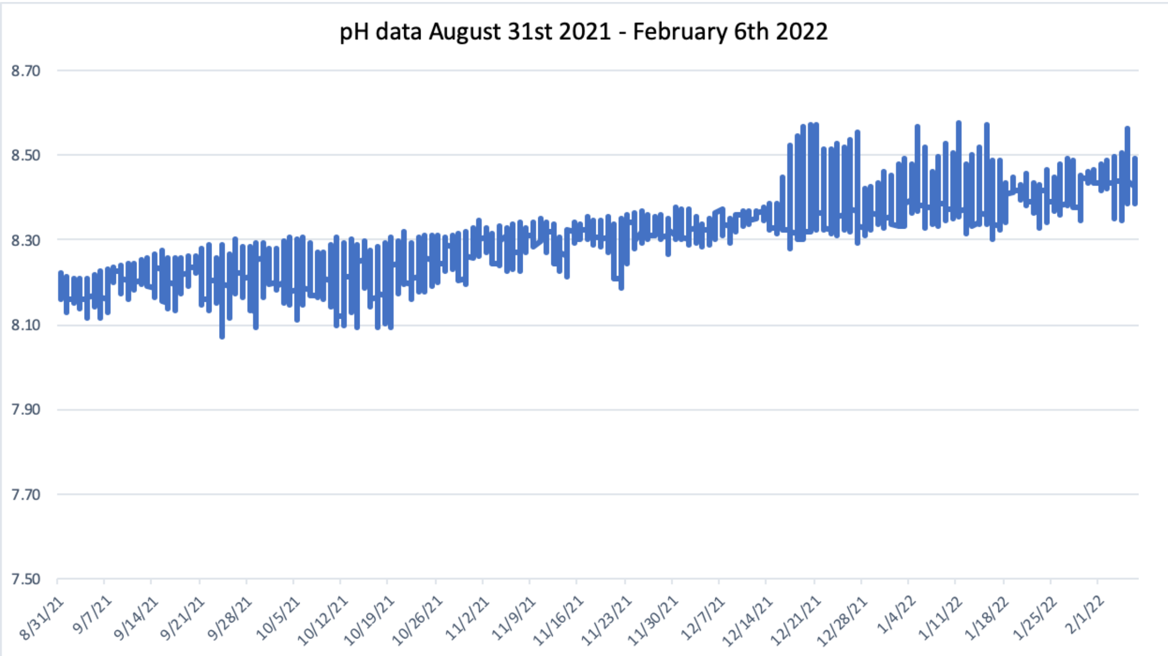

Fig 23. pH recording for Site 1 (August 31st 2021- February 6th 2021) (Own source).

4.3 BleachWatch monitoring

The HRI has been leading a MAR-wide Coral BleachWatch Network since 2015, mobilizing a coordinated network of trained surveyor teams to evaluate the extent of bleaching throughout the Mesoamerican Reef by using a systematic protocol called the Drop Bar[3] methodology. The

[3] Drop bar methodology: http://www.ecomarbelize.org/uploads/9/6/7/0/9670208/coral_bleaching_plan_final_2008_2013.pdf

BleachWatch monitoring gets activated once there is an alert issued by NOAA through the Coral Reef Watch[4], mainly due to the increase in water temperature due to heat stress[5] (usually happens during the hurricane season, from June through November).

During October 2019 we answered a global alert issued from NOAA due to the rise in water temperatures; the MAR was no exception. Due to this alert a coral bleaching monitoring was conducted during the month of October 2019 as part of Phase I on the two monitoring sites of the Cayan Crown Reef. This monitoring was important to be able to register the bleaching extent on the Cayman Crown Reef. This indicator is directly related to water temperature and the resilience capacity of coral reefs to recover from these stressful events. Though no bleaching alert was issued by NOAA in 2021 for the area (southern Belize station), we still monitored the sites during the 6th to the 8th of December 2021, to observe the state of the corals. A total of 200 colonies per site for the 4 sites were surveyed for bleaching as the methodology states for all the years surveyed.

Comparison of bleaching alert monitoring results from 2016, 2017, 2019 and 2021 for Cayman Crown Reef: the HRI and Pixan'Ja have been conducting BleachWatch monitoring during the 2016, 2017, 2019 and 2021 bleaching events. The impact of bleaching events on the coral reefs we have being studied has changed through time; we compared the percent of affected corals for the different years we have collected data (2016, 2017, 2019 and 2021) grouping those corals that displayed different signs of thermal stress (pale corals, partially bleached corals, and completely bleached corals) versus colonies that did not show any visible signs. To be able to develop this analysis we averaged the results for the sites we have been monitoring within Cayman Crown (2019: average from data collected in Site 1 and Site 2, 2021: average collected from the 4 sites (Site 1 and 2 from Phase I and Sites 3 and 4 from Phase II)). The data for 2016 and 2017 are absolute values of one site per each year, in 2016 44.9% of the corals were affected by bleaching (pale, partially bleached and bleached corals), in 2017 54.3 % of the corals were affected. The overall percentage of corals affected by bleaching (pale, partially bleached and bleached corals) has significantly increased in the last four years, reaching 76.8% in 2019, however, it decreased in 2021 with only 30% of the corals showing signs of affection, mostly attributed to corals being in a pale (20%) and partially bleached (10%) condition. (Fig 24). A pale condition might be that the corals are recovering from bleaching or that they have had some stress related to temperature and have only lost some of its zooxanthellae.

[4] NOAA Coral Reef Watch alert for the Caribbean: https://coralreefwatch.noaa.gov/data/5km/v3.1/current/animation/gif/baa-max_animation_30day_crb_930x580.gif

[5] NOAA Satellite Coral Bleaching Heat Stress Alert
https://coralreefwatch.noaa.gov/product/5km/index_5km_baa_max_r07d.php

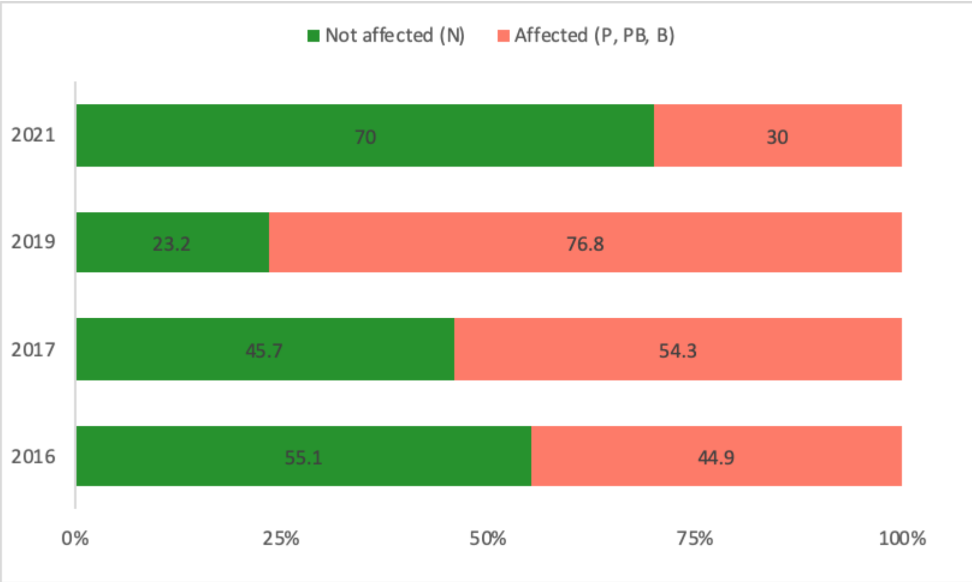

Fig 24. Bleaching impact on Cayman Crown Reef from 2016, 2017, and 2019 and 2021 (Own source).

When analyzing the results in more depth, we observed that the percentage of corals fully bleached has significantly increased since 2016 (6%), reaching 38% in 2019. During 2021, no fully bleached corals were recorded during our monitoring activities, only pale and partially bleached corals were recorded (Fig 25).

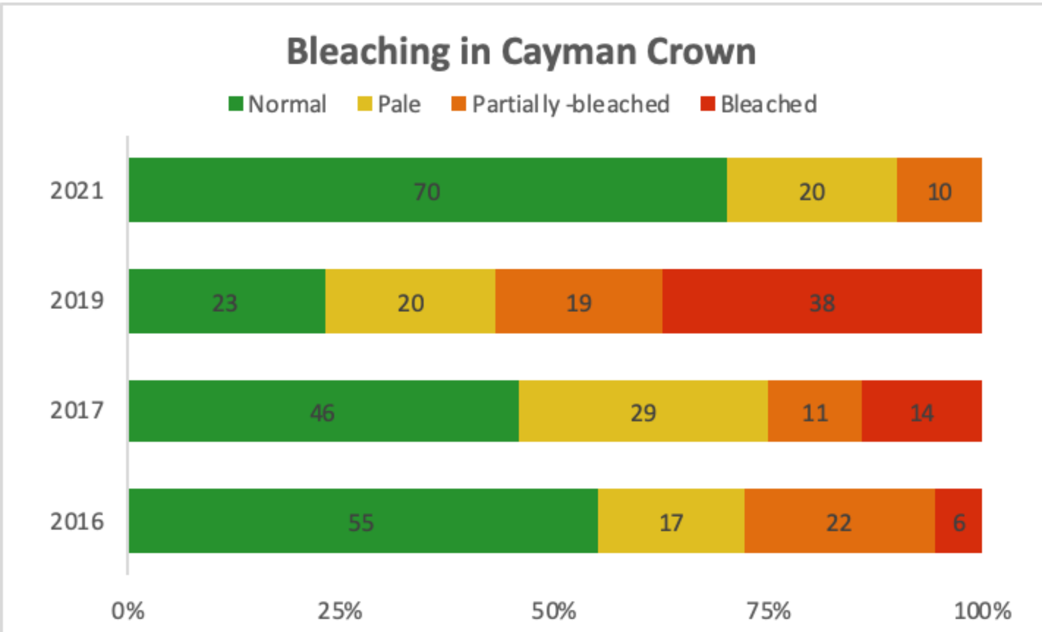

Fig 25. Comparison of bleaching alert monitoring results from 2016, 2017, 2019 and 2021 at Cayman Crown Reef (Own source).

The temperature recordings for the years surveyed are linked to the number of months of high heat that the reefs are withstanding and the bleaching events. The average temperature recorded for Site 1, during May 29th, 2019, to June 16th, 2020, was 28.77°C. There were 11 out of the 18 months the temperature was higher than 29.5°C. The average temperature recorded for Site 2, during May 29th, 2019, to June 16th, 2020, was 29.35°C and the average temperature for the second recording period from August 31st, 2021, to December 6th 2021 was 29.63°C. There were 11.5 months from the total 18 months recorded that the temperature was above 29.5°C. The data is consistent with our field observations from October 2019, when we documented strong bleaching in both sites and with the literature documenting coral bleaching as a response to prolonged warmer seas. We weren't able to go to the field to document the 2020 bleaching event so we don't have any data for this year. For 2021, for the data we were able to record, we had less months of high temperature compared to the other years recorded (documented a total of 3 months of temperature above 29.5°C, from August to October 2021).

El Niño and La Niña can both have severe impacts on coral reef ecosystems, and particularly in the Pacific. Large-scale bleaching events, however, do not necessarily occur in conjunction with major El Niño or La Niña events. In the Caribbean the largest bleaching event recorded occurred in 2005, following a mild El Niño, and was poorly connected to El Niño climate patterns (Eakin et al., 2010). Despite the limitations in knowledge of how El Niño and La Niña affect coral bleaching events, scientists are concerned that increases in SSTs globally, and potential increases in El Niño events, threaten the survival of coral reefs.

In the MAR a recent publication has linked El Niño to heat stress when evaluating the Degree Heating Weeks in the region, but heat stress is not solely related to the warm-phase, El Niño, since warm thermal anomalies are present somewhere in both positive and negative ENSO phases (Muñiz-Castillo et al., 2019). As a result, the study observed that La Niña sometimes leads to coral bleaching in some locations, and warming global ocean temperatures have caused La Niña years now to be warmer than they were during El Niño events three decades ago (Muñiz-Castillo et al., 2019). Also, the change in the heat stress regime since 2003 and the long-term trend observed could be linked to other low-frequency patterns such as the recent Atlantic Multidecadal Oscillation (AMO) warm signal and anthropogenic climate change (Muñiz-Castillo et al., 2019). Both the AMO and climate change have been recognized as important drivers in recent heat stress in the Caribbean. For the Cayman Crown reef we still need longer data sets regarding temperature on the reef and bleaching events to better understand its relationship to ENSO events.

4.4 Passive acoustic monitoring for fish noise mapping

Regarding the passive acoustic monitoring for fish noise mapping, after receiving a quote for the equipment, we were informed that the developers discontinued the production of the LHC Cyclops underwater acoustic recorder HD camera we wanted to buy, due to the COVID19 pandemic. An alternative equipment was purchased after MAR Fund approval, the Hydrophone SNAP from loggerhead electronics (a simpler hydrophone that has no camera). We selected this equipment because it's being used in other Mesoamerican Reef countries like Mexico, this will allow data comparison.

The installation of the equipment was done during the field expedition of December 2021. The hydrophone installation was not done during the august field expedition given that the fish aggregations (mostly groupers and snappers) we are expecting to document are known to take place during the months of December, January, February and March; leaving the equipment underwater is always a risk (e.g., potential damage or loss, as well the inability to find it again) that we prefer to take during the time of the year we have higher chances of documenting the species of interest for this project. The hydrophone was installed in one of the reef areas where we have seen different fish aggregate in past trips (jacks, Atlantic spadefish, snappers, and ocean triggerfish) and have also seen a few groupers with colorations of possible spawning; this specific site is not one of the four study sites we are monitoring but it is close to one of the sites. The hydrophone was installed near a coral reef wall at 18.5 m deep, we named the site Sassy wrasse. A third trip was made to the Cayman crown reef with funds from HRI and Beluga Smile from the 3rd to the 8th of February 2022; one of the activities we were able to do during this trip was to retrieve the hydrophone, download the information and reinstall it on the Sassy Wrasse site. The analysis of the recording is still underway.

5. Conclusions

- The reef health for the sites surveyed in 2019 (Site 1 and 2) have lowered their reef health index for 2021 from fair to poor condition (Site 1) and from poor to critical condition (Site 2). The results indicate that this is mainly due to the critical condition of herbivorous and commercial fish biomass on both sites and the increase in macroalgae cover (critical condition). Despite the observed decrease in the health of these three indicators, the coral cover in most of the study sites is still outstanding with very good and good conditions.
- The average ocean pH registered on the site surveyed in Cayman Crown (Site 1) was of 8.32, which is congruent with the average pH levels (a pH of 8.2-8.5) whish calcifying organisms such as corals tend to calcify best at we can say that the pH for this site is adequate.
- The temperature recordings for the years surveyed are linked to the number of months of high heat that the reefs are withstanding and the bleaching events recorded. The average temperature recorded for Site 1 was 28.77°C. There were 11 out of the 18 months the temperature was higher than 29.5°C. The average temperature recorded for Site 2 for both recording periods was 29.49°C and there were 11.5 months from the total 18 months recorded that the temperature was above 29.5°C.
- For SCTLD in the Cayman Crown reef, we monitored a total of 7 sites, 200 coral colonies per site in 2021. In the sites monitored there is no presence of the disease. However, monitoring needs to carry on as the disease continues to spread in the MAR and the Caribbean region.
- Bleaching data indicate that thermal stress impact on the study sites corals' (percentage of pale, partially bleached and bleached corals) increased from 2016 (44.9%), to 2017 (54.3%) and 2019 (76.8%); however, the latest data collected during 2021 show a less severe impact (30%). Data from temperature sensors installed in 2019 are congruent with the visible observations in the field, showing that during 2021 corals were exposed to temperatures greater than 29.5 C for less time than during 2019 to 2020.
- It is of great importance to continue the monitoring of biological and key variables to improve our understanding and document capabilities regarding the health of Cayman Crown reef, its evolutionary processes and its resilience capacity.

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