Fragments of Hope 2020 Summary report for Research Permit renewal 005-20

Repopulate reefs within replenishment zones of Turneffe Atoll Marine Reserve and South Water Caye Marine Reserve with temperature resilient coral varieties and Continued reef replenishment with the critically endangered acroporid corals in southern Belize.

Abstract

Lisa Carne and Fragments of Hope (FoH) have been conducting active reef replenishment in Southern Belize since 2006, and in Turneffe Atoll Marine Reserve (TAMR) and South Water Caye Marine Reserve (SWCMR) since 2016. This report summarizes work completed in 2020. Reef restoration focus shifted in early 2020 to Northern Belize Marine Protected Areas (MPAs) due to the presence and spread of the Stony Coral Tissue Loss Disease (SCTLD) identified there in 2019. With special permission and working with MPA staff, FoH installed one table nursery each in Hol Chan Marine Reserve (HCMR) and Bacalar Chico Marine Reserve (BCMR) in May 2020. These included trials with micro-fragmenting *Dendrogyra cylindrus*, based on successful results with this method and species in SWCMR, albeit in the absence of SCTLD, in addition to acroporid taxa that so far, are immune to SCTLD. FoH also installed two nursery tables in Caye Caulker Marine Reserve (CCMR) while conducting its annual training course in Reef Replenishment Methods in December 2020 on site, with virtual adaptations for COVID-19 restrictions (group size, and online course materials including a new knowledge review quiz). By December, SCTLD was so prevalent in CCMR that only acroporid corals were placed on those nurseries and outplanted. A donated catamaran from the Moorings made the first FoH course not conducted in Placencia safer, more affordable, and logistically easier for eight Belizean participants including four Belize Fisheries Department staff and four private (tourism) sector stakeholders. Lisa Greer, Professor of Geology at Washington and Lee University (USA) also joined the course for one day and shared her knowledge from long term studies at “Coral Gardens” located between CCMR and HCMR with an intent for future research collaborations with both HCMR and FoH. Bleaching in 2019 carried over into 2020 and for this reason, FoH did not begin outplanting until February 2020. Sea temperatures remained higher than normal throughout 2020[1] and bleaching alerts came earlier than usual; bleaching was more severe in 2020 than any other year on record for Belize. Corals (12,162 fragments and ~579 fragments during the December training) were outplanted February-May and December in nine different sites within six different Marine Protected Areas (MPAs), and in two control (non-protected sites). The

[1] https://www.washingtonpost.com/climate-environment/interactive/2021/2020-tied-for-hottest-year-on-record/

MPAs are: Laughing Bird Caye National Park (LBCNP) where 3,171 corals were outplanted in 2020, so the grand total outplanted there is 86,050; Gladden Spit and the Silk Cayes Marine Reserve (GSSCMR) where 675 micro-fragmented elkhorn corals were outplanted in 2020, so the grand total outplanted there is 13,370. In SWCMR 4,654 corals were outplanted in 2020 in sites near Tobacco and South Water Caye; and in TAMR 1,972 corals were outplanted in 2020 in sites near Calabash Caye and to new sites south of Calabash Caye. During the December training course, the surviving corals from the San Pedro Tour Operator nurseries were outplanted (~329 fragments) in HCMR and in CCMR ~250 fragments were outplanted in two sites. The two control sites (outside of MPAs) are False Caye with only 95 corals outplanted there in 2020, due to high mortality of previous outplants in the 2019 bleaching event, and Moho Caye where 1,595 corals were outplanted in 2020, making the grand total at Moho Caye 19,784, since work began there in 2015. There are four remaining nurseries in TAMR and three in SWCMR, most of which are empty having been harvested of corals (some corals remain on nurseries in each MPA), and 14 nurseries in southern Belize are still growing corals (plus four new nurseries in Northern Belize MPAs). Due to COVID-19 affecting FoH partner at University of Miami, Arthur Gleason, Ph.D., for processing the diver-based photo-mosaics data to quantify for percent coral cover changes on smaller (100-200m^2) plots, only one sub-site (24) at LBCNP was analyzed from 2019, but processing has already begun for the 2020 sub-sites (and remaining 2019 sites). Sub-site 24 (outplanted in late 2014) increased >13.5% in just one year (from 29% coral coverage in 2018 to almost 43% coral coverage in 2019), the largest single year increase for this sub-site to date. FoH added the use of drones for shallow water reef mapping in 2019 to better quantify total area of replenished sites and was able to show that > 20% of a hectare (2,190m^2) of shallow reefs at LBCNP are replenished acroporids. One year change detection using this method illustrated an increase of >200m^2 acroporid cover from natural processes at LBCNP [2]. Besides mapping replenished reefs at LBCNP and Moho Caye, FoH also mapped natural acroporid stands near Placencia and have to date classified >7,900m^2 of corals. Despite COVID, FoH still disseminated information on local TV shows for Reef Week, shared restoration results for the international Global Reek Week online in July 2020, held its AGM in August 2020 and produced a 'selfie green hero' video for German producers in September 2020[3].

[2] This calculation was pre-Hurricane Nana, but another drone ortho-mosaic was created post-Nana awaiting analysis/quanitifcation.
[3] https://fb.watch/31yWmmePiC/

Introduction/Background

The Caribbean acroporids were listed as critically endangered (one step away from extinct in the wild) on the IUCN Red List in 2008. Their loss in abundance has been estimated at over 98% in recent decades (Aronson et al. 2008). They are keystone reef species since they are the fastest-growing, main reef-building, branching corals that provide shoreline protection and habitat for hundreds of other marine species. Reef replenishment efforts with the acroporids began at LBCNP in 2006 and to date over 80,000 nursery grown corals (all three *Acropora* taxa) have been outplanted in over one hectare of shallow fringing, degraded reef at LBCNP. Using photomosaics, we have shown increases in live coral cover of over 35% in less than five years (2010-2015) at LBCNP (Carne et al. 2016). Efforts expanded to South Silk Caye (in GSSCMR) and Moho Caye (unprotected, control site) in 2015. Expansion to SWCMR and TAMR began in 2016 under MCCAP. Inclusion of an additional near shore control site (False Caye) began in 2017 under MAR Fund.

Coral replenishment efforts have become increasingly accepted as a management tool (Rinkevich 2014), but many questions still remain, which we continue to address via this program: 1) does MPA status have an effect on the success of the outplanted corals? 2) what is the desired number/density of outplants per plot/site that will achieve self-replication (increases through growth and asexual fragmentation, without adding additional corals)? 3) are there acroporid-associated biodiversity changes that accompany replenishment efforts? 4) what has contributed to the relative success at LBCNP and can the results be replicated, inside and/or outside of MPAs?

LBCNP is one of the oldest and most extensive restoration sites in the Caribbean and Western Atlantic and is widely considered the best example of true reef restoration. FoH work and funding continue in SWCMR and TAMR through 2021 and in the southern sites through June 2021. FoH is pursuring additional funding options/sources, as always.

Objective

The objectives at TAMR and SWCMR are to create at least three replenished sites in each MPA. The objectives in southern Belize are to increase coral cover by 10% at each targeted site.

Methods-(remain the same as 2019)-

All of the methods for installing nurseries, monitoring nurseries (including growth rates), outplanting corals and monitoring outplanted corals are listed in the newly revised FoH Reef Replenishment Methods Training Manual, vetted by the Belize Fisheries Department. The full resolution PDF is housed here: https://drive.google.com/open?id=1ckRgmNp9j8yHNmZ6iqTE9TLo9C9QTowb.

The photomosaic technique was developed over a decade ago (Lirman et al. 2007) and has been used at sites around the world. Monitoring acroporid restoration has been one of the key applications of this technology, since it is difficult to track these species as individuals (Carne et al. 2016, Griffin et al. 2016, Gleason et al. 2007). Percent coverage of benthic organisms will be computed using the photomosaics of each site and the CPCe[4] software, which allows calculation of coral cover by species and other benthic organisms (*e.g.* sponges, crustose corraline algae) and thus can also track any changes in benthic composition over time, associated with repopulating the acroporids.

Mapping with drones: A Phantom 4Pro drone was purchased on Dr. Steve's Shill's advice and FoH was trained on how to program and fly 'missions'/ mosaics for shallow coral reef mapping with its accompanying app, DJI GS Pro. Heights are usually 200ft, with 80% overlap of images, and flight times are limited to under 20 minutes because of battery limitations. Conditions must be fairly calm, early morning or evening to avoid glare, with no rain. The software Pix4D (Dr. Schill's license) is used to process the images into a mosaic. Then the mosaics can be annotated (the corals identified, outlined and area measured) with ARC Map or Q-GIS.

Bleaching surveys are conducted using McField's (2009) Swim Bar Methodology, where at least 200 corals are surveys per site. Temperature data is collected with HoBo U-22 loggers, set for one-hour increment data collection. Both of these methods are endorsed by the National Coral Reef Monitoring Network (NCRMN) and used country-wide.

New for 2020 was the addition of a bleaching data base to the AGGRA website[5]. FoH entered all bleaching data from 2017-2020, in anticipation of this website eventually generating maps for coral bleaching presence/prevalence & severity.

Results

Outplanted corals in 2020: Table I lists the number of corals outplanted at each site in 2020 and then with the grand totals. Figure i. Shows these sites on a map. Not listed in the table are the few outplants in HCMR and CCMR as these were conducted during training.

[4] http://cnso.nova.edu/cpce/index.html
[5] https://www.agrra.org/coral-bleaching/

SITES	TAXA outplanted 2020					DCLY	TOTAL 2020	TOTAL
	ACER	APAL	APRO	MCAV	OFAV			
LBCNP	2859	312 (303 micro frags)	0	0	0		3,171	86,050
SILKS	0	675 (micro frags)		0	0		675	13,370
MOHO	979	562 (micro frags)	0	0	30 (micro frags)	25 (micro frags	1,595	19,784
FALSE	95	0	0	0	0		95	5,132
SWC	921	0	0			0	921	6,641
TOBACCO CAYE	1,583	0	2,150				3,733	11,597
BLACK BIRD CAYE	0		0				0	6,429
CALABASH CAYE (& nearby, new site)	1,972	0	0				1,972	4,260
TOTAL							**12,162**	**153,263**

Table I. Number of coral outplants by taxa, site and for 2020 with grand totals in the far right column.

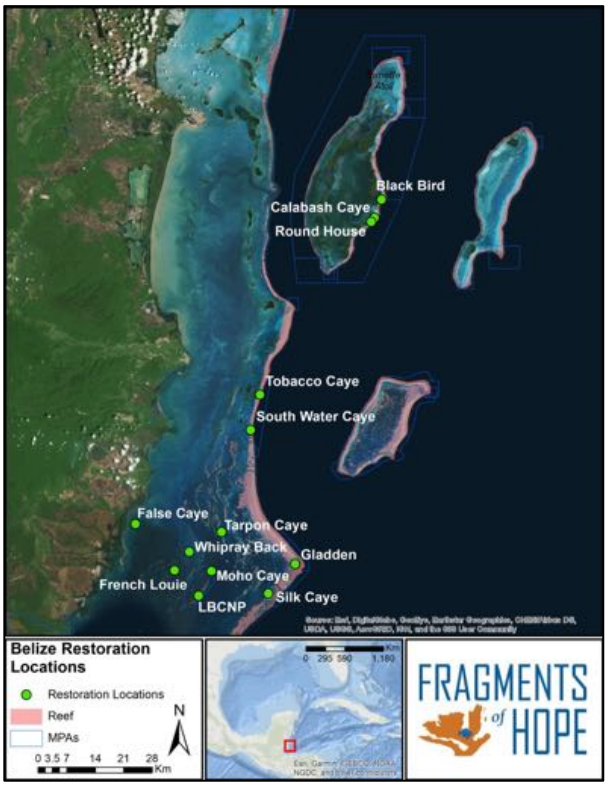


Fig. i. Map showing FoH restoration sites through 2020 with the exception of the unplanned work in the Northern Belize Marine Protected Areas.

Most of the outplanted corals at False Caye did not survive the bleaching event in 2019, and the few that did, perished in the 2020 bleaching event with two notable exceptions (two different genets of *A. cervicornis*) in the nurseries which FoH continues to propagate and monitor (Figures 1a-c). It was not just outplanted corals that bleached but many wild acroporids that had not belached in previous years bleached severely in 2020: the donor source *A. prolifera* colony also bleached near Loggerhead Caye October 2020 (Fig. 2a), wild *A. palmata* at Bugle Caye remained bleached in November 2020 (Fig. 2b). Figure 2c illustrates a natural *A. palmata* recruit at South Silk Caye in November 2020 mostly dead from bleaching in the background, versus a less than two-year micro fragment with partial bleaching (since recovered). Many of the heavily bleached south Silk Caye micro fragments recovered by December (Figs.3a-c). Many LBCNP outplants on the lee ward side bleached heavily in 2020 (Fig. 4a), versus previous years, but many outplants on the windward side did not bleached at all (Fig.4b), or only minimally and all corals on the windward side have since recovered. Some bleached corals on the lee ward suffered partial mortality for the first time since the restoration work began, but most are recovering now. Genetics from LBCNP corals have been collected and sent out for the latest genetic analyses, “SNP chip” = single nucleotide polymorphisms (Kitchen et al 2020)[6].

Although only diver-based photo-mosaic from 2019 has been processed and analyzed (Fig. 5), sub-site 24 clearly shows an increase of >10% coral coverage in one year, one of the main objectives for southern Belize (from 29.16% live coral cover in 2018 to 42.75% in 2019). Photo-mosaics are usually done in August of each year, in 2019, they were repeated in November. In 2020 sub-site 13 was repeated in October, post-Nana and during bleaching. Figures 6a-d are reduced images of the processed photo-mosaics from sub-site 24 at LBCNP in 2014 (unplanted, 2.6% coral cover), 2015, 2018 and 2019 with 42.7% live coral.

[6] https://www.nature.com/articles/s41598-020-69101-z#citeas

Fig. 1a-c. Outplanted *A. prolifera* at False Caye survived the 2019 bleaching event, but was 'whole' bleached with partial mortality in October 2020 (L) and did not survive (middle photo from December 2020); one of two A. cervcornis genets did survive at False Caye (R), photo from December 2020. Heavy macro-algae at False Caye is an indicator of high nutrients at this near-shore site.

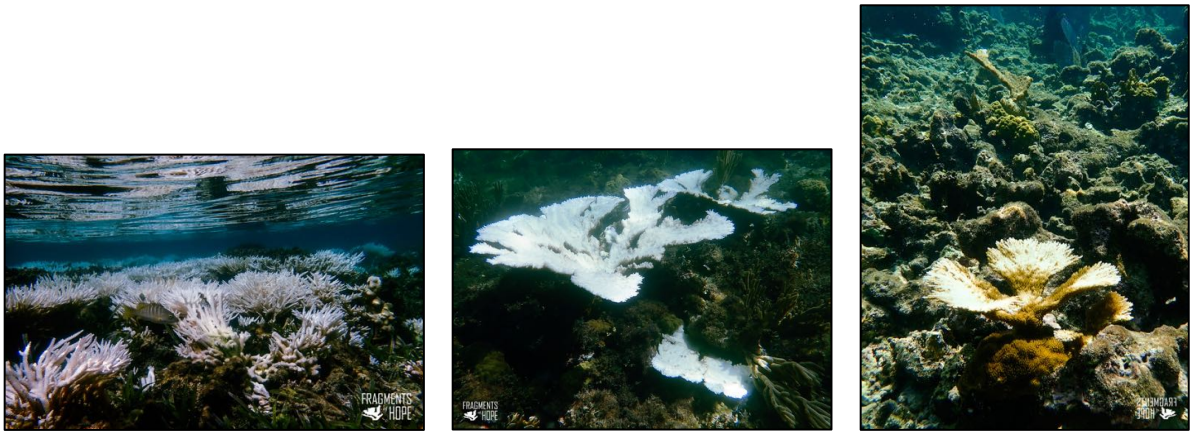


Fig. 2a-c. From left to right: wild A. prolifera near Loggerhead Caye in October 2020, wild *A. palmata* at Bugle Caye in November 2020, and wild (back ground) versus outplanted (foreground) *A. palmata* at South Silk Caye in November 2020.

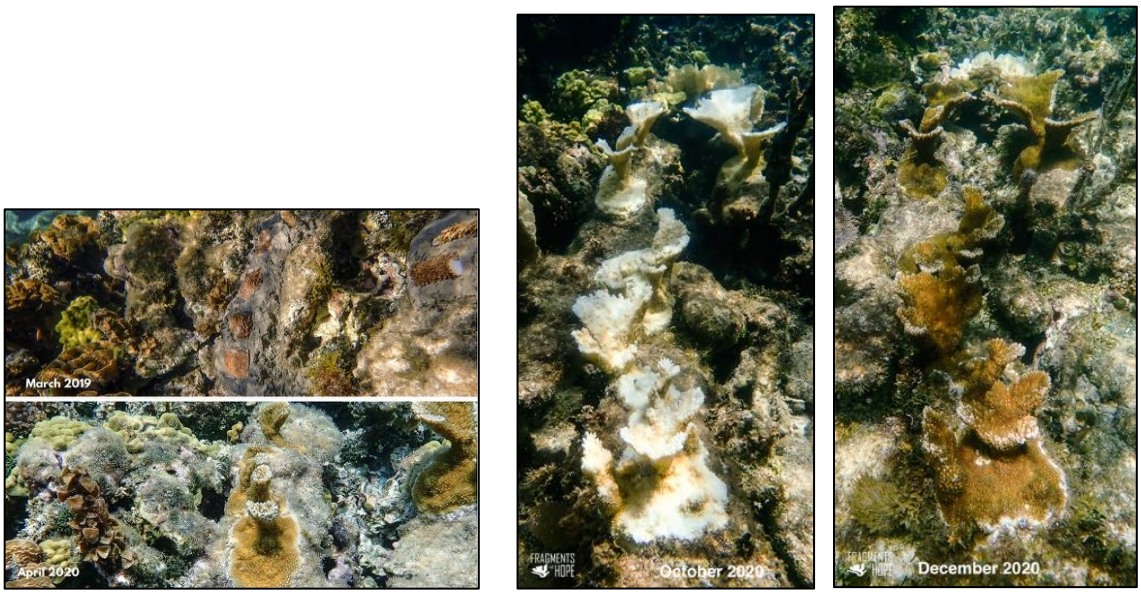
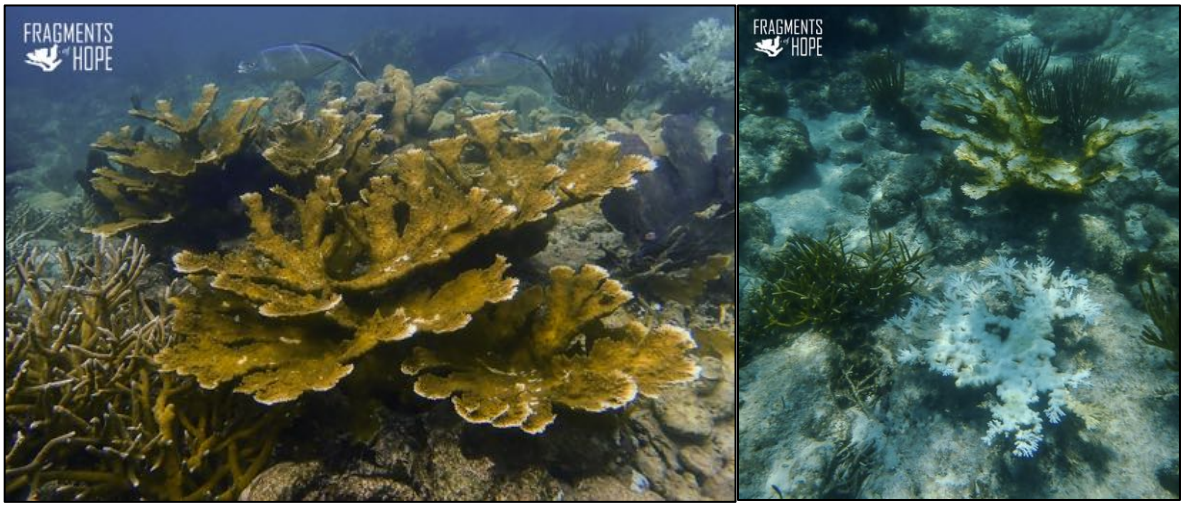


Fig. 3a-c. From left to right: time series of outplanted *A. palmata* micro fragments at S. Silk caye from day 0 of outplanting in 2019, showing 13 months growth in April and then bleaching in October and recovery by December 2020.



Figs. 4a-b. Five and half year old outplanted corals on the windward side of LBCNP did not bleach at all, photo from late October 2020 (L) versus many on the leeward side of LBCNP, photo from November 2020 (R) with different degrees of severity and recovery rates.

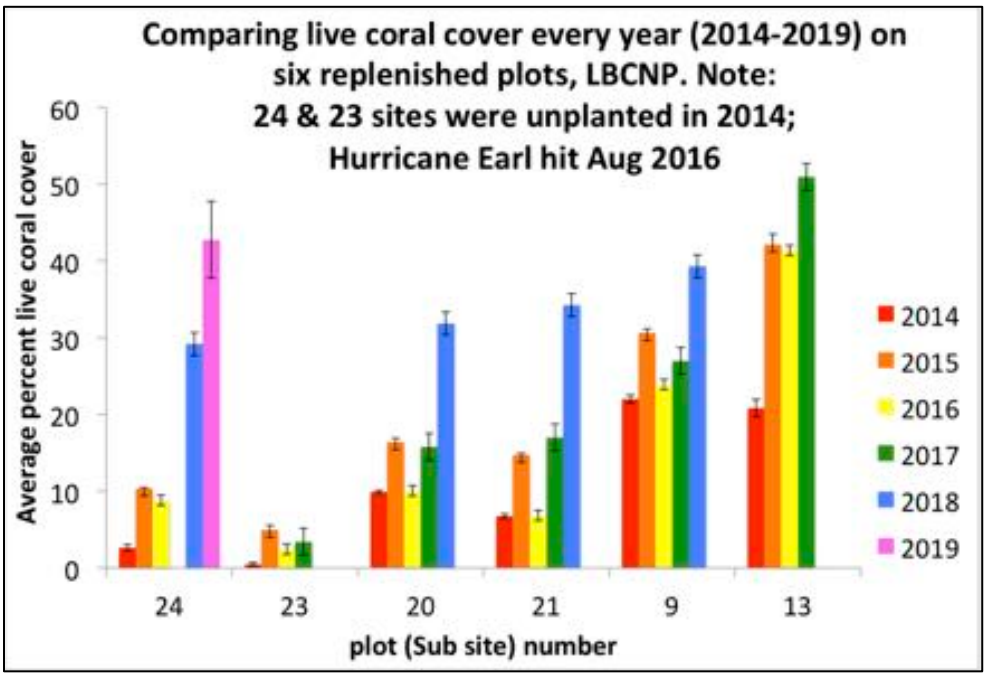
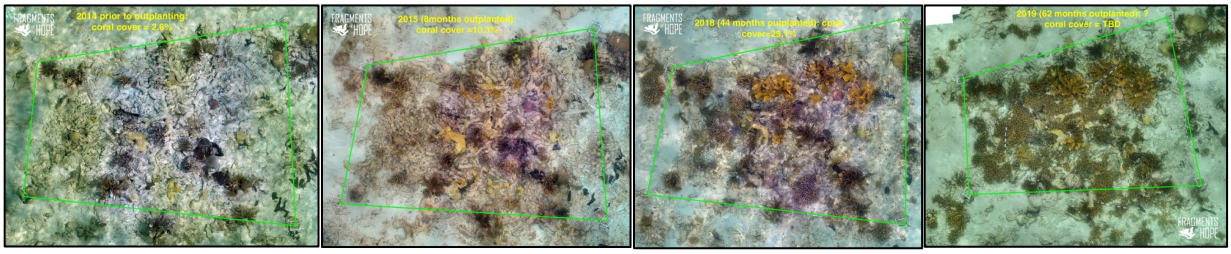


Fig. 5. The x-axis is the sub-site name at LBCNP, from left to right is newest (2014) to oldest (2010) outplant dates. The years are color coded and the y-axis is percent live coral based on CPCe analyses of processed diver-based mosaics. Only sub-site 24 has been processed and analyzed for 2019 to date (in pink) but the increase of naturally spreading coral cover on this replenished plot was almost 13.5% in one year (2018-2019), surpassing the objective of 10% increases in one year. No corals are added to the sub-sites used for photo-mosaics.



Figs. 6a-d. From left to right: processed diver-based mosaics of sub-site 24 at LBCNP prior to outplanting in 2014, 2015, 2018 and 2019, showing visually the increase from 2.6% live coral cover to 42.7% in five years (2014-2019). The perimeter of the ~50m^2 plot is outlined. No additional corals were added after initial outplanting in November 2014.

Mapping with drones:

Figure 7a illustrates sub-site 13 at LBCNP, outplanted in December 2010. The border lines for the diver-based mosaics are illustrated (~180m^2). The image was taken late October 2020, post-Nana and during bleaching event; one large *A. palmata* to the right of the sub-site flipped in Hurricane Nana and bleached, but on the whole, this outplanted site was not bleaching. But what the photo really shows is that diver-based mosaics alone do not capture the extent of the replenished reef cover: the six sub-sites at LBCNP total < 700m^2, whereas the new method of using drones for shallow reef coral cover quantification allow a much greater coverage ~ one hectare (Figure 7c). Figure 7b illustrates the quantification of the replenished acroporids at LBCNP from the 2019 ortho-mosaic color coded by taxa: orange =ACER 1938m^2, red=APAL 250m^2, yellow=APRO 52m^2 totaling 2,190m^2 of acroporids. The left image in Figure 7c shows all acroporids combined in orange, with available shallow reef substrate in red representing star corals and dead coral structure, but not rubble (10,273 m^2). Using these figures, over 21% of a hectare of shallow reef at LBCNP is replenished acroporids (2019). Figure 7c also shows one year change detection at LBCNP where the toal acroporid coverage increased to 2,397m^2 (pre-Nana[7], ortho-mosaics conducted in August 2020), and increase of 9% in acroporid cover by *natural processes* (although some outplanting did occur at LBCNP between drone flights, most were micro-fragments which are not detected by the drone).

FoH also began mapping natural acroporid stands in 2019 through 2020 and classified in total, > 7,900m2 of reef at replenished sites LBNCP & Moho, and five natural acroporid stands near Placencia. Examples in Figure 8a show yearly change detection (2019-2020) at a natural acroporid stand (predominantly *A. cervicornis* but all three acropora taxa are present) of almost 29% increase at site near Loggerhead Caye near Placencia. A drone ortho-mosaic was created and annotated for this site in October 2020 (Figure 8b) post-Hurricane nana and during the bleaching event. While the *A. palmata* and *A. prolifera* coverage was reduced due to and/or both mechanical damage and mortality from bleaching, the *A. cervicornis* coverage increased, as can happen with relatively minor disturbance events, as the acroporids are adapted to spread asexually via high wave energy events. But these numbers will need to be revisited/ground-truthed to verify recovery post-bleaching in 2020. See also Figure2a for standard underwater image of bleaching *A. prolifera* at this Loggerhead Caye stand.

[7] A follow up drone flight/ortho-mosaics was made in October 2020 post-Nana and during bleaching, but has not yet been analyzed/quantified.

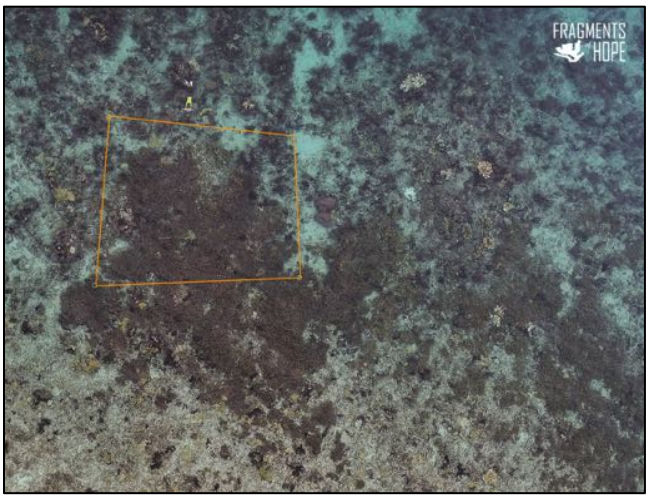


Fig. 7a. Image captured from drone illustrating a diver conducting a photo-mosaic on sub-site 13 in October 2020. The sub-site plot is outlined (~180m^2), showing clearly replenished coal coverage extends far beyond the perimeter of sub-site 13.

Fig. 7b. The three acropora taxa color coded (orange =ACER 1938m^2, red=APAL 250m^2, yellow=APRO 52m^2) versus the image on the left in Fig. 7c which combines all three acroporid taxa in one color, orange: Object-based classification of coral features based on an orthophoto mosaic (2cm RGB) acquired with a DJI Phantom 4 Pro flying at 300ft on July 31, 2019.

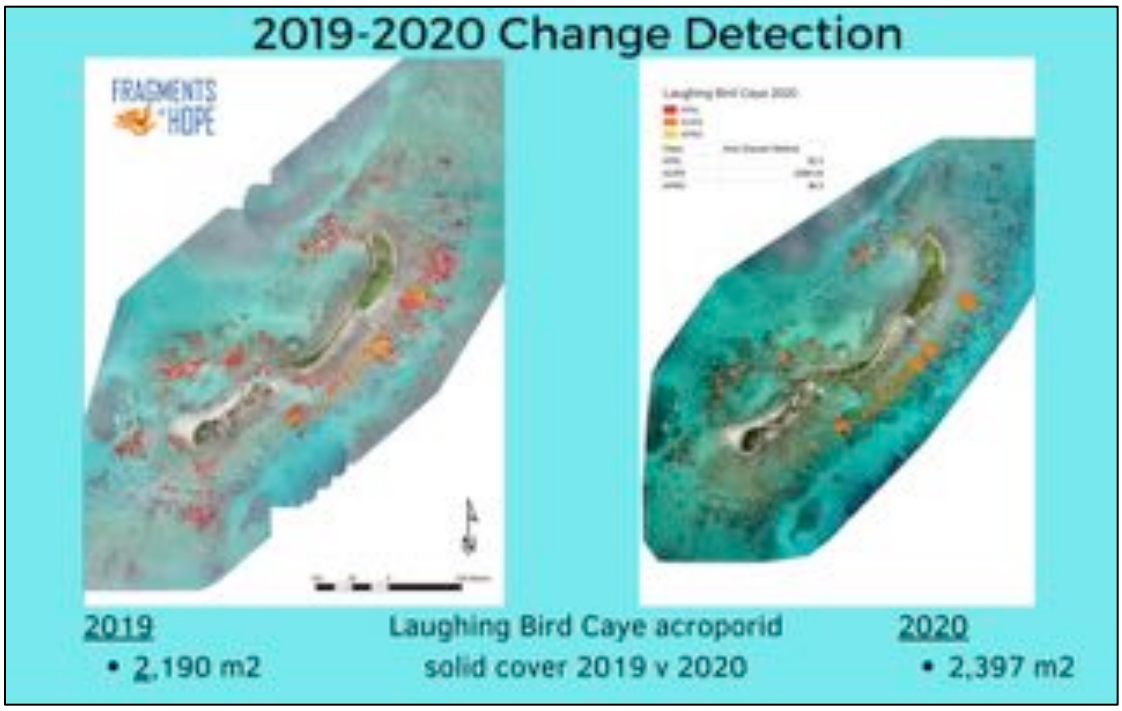
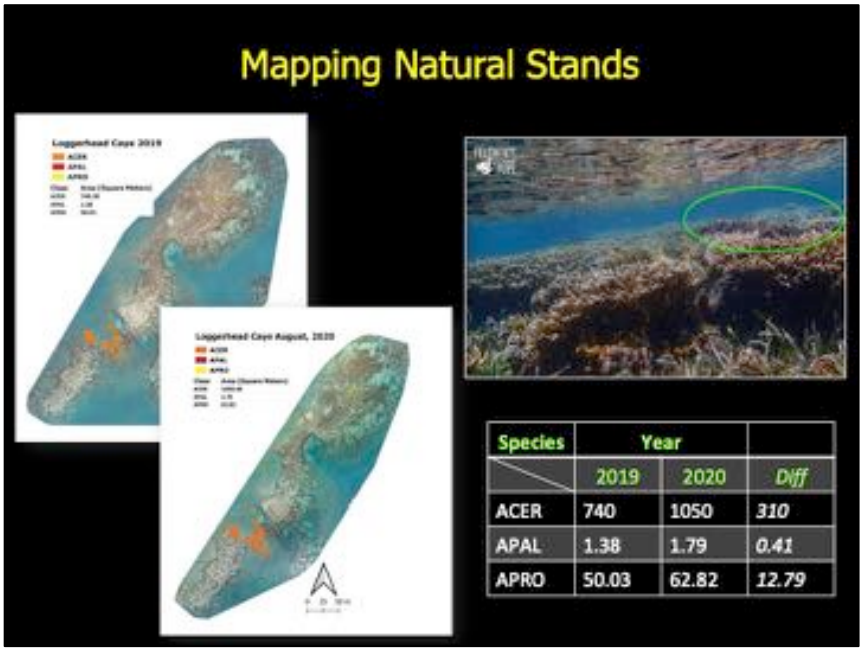


Fig. 7c. Example of one year (August 2019-2020) change detection in replenished acroporid cover at LBCNP using ortho-mosaics made with drones and quantified with Q-GIS. There was an increase of acroporid cover by 207m2, which is attributed to natural spread & reproduction, not direct outplanting, during this time frame.



Figs. 8a. An example of one year change detection using ortho-mosaics made with drones, and quantified with Q-GIS, from a natural acroporid stand near Loggerhead Caye, near Placencia. The table in the figure shows changes in acroporid taxa coverage in m^2, pre-Hurricane nana and pre-bleaching

event in 2020. This is not a replenishment site, all existing and increased coverage of acroporids is natural.

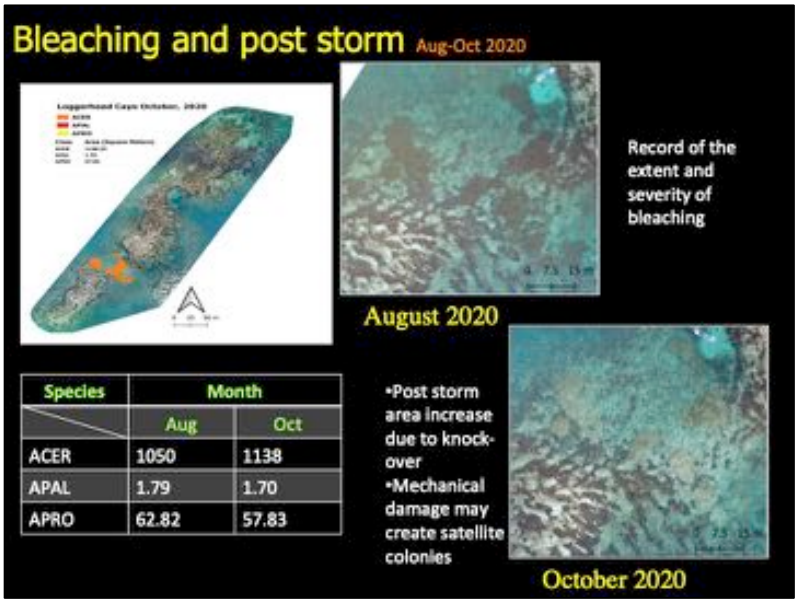


Fig. 8b. Example of using the drone ortho-mosaics to calculate changes after storms, and/or bleaching events. The change in acroporid cover was quantified shown in table as m^2, but the bleaching extent was not yet quantified at this site (not a regularly visited bleaching survey site).

Bleaching and Temperature Data

Sites near Placencia have been monitored for bleaching for over a decade, and the near shore sites did have worse bleaching results in 2020, than in any previous year with the exception of two sites (Bugle and Larks, Fig. 9a), however 2020 sea temperatures dropped dramatically, quickly, in early-mid October (see Figures 9e-g), allowing relatively 'normal' recovery of corals by December 2020 (see Figures 3a-c) despite the severe bleaching (Figure 9c). Figure 9c includes data from Port Honduras Marine Reserve (PHMR) as FoH assisted TIDE, along with all other southern sites comparing October 2017 through October 2020. All sites are labeled in the map in Figure 10a.

FoH has large sets of *in situ* temperature data-in some sites up to ten years, which makes it difficult to illustrate all the data at once. Figure 9b is NOAA data, courtesy Dr. Mark Eakin, through October 2020 and illustrate both sea surface temperatures from satellite data (top lines) with 2020 in black, and Degree Heating Weeks (DHW)[8] on the lower part of the figure, with 2020 also in black; this data is from the virtual monitoring station at Glover's Reef and shows the ten hottest years in Belize, not just the last ten years.

[8] https://coralreefwatch.noaa.gov/satellite/methodology/methodology.php#dhw

Figures 9e-g are a sample of some of FoH temperature data from multiple sites comparing different years and/or different locations. FoH has temperature loggers in each nursery and many outplant site locations. The prevalent trend across all sites, is the higher temperatures throughout most of 2020, then the sudden drop in early-mid October, compared with 2019 that had an unusually late temperature peak in October and caused bleaching to last many months longer than in the 2020 bleaching event. Each graph/map is captioned with details.

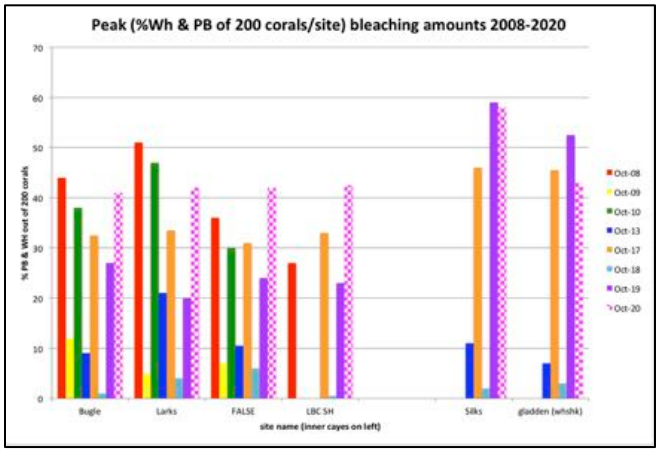


Fig. 9a. Comparing bleaching rates in October 2008-October 2020 (where data available) at multiple sites (X-axis) in southern Belize. All are sites are shallow (1-5m), From left to right is near-shore to offshore, see labeled sites on map in Fig. 10a. The percentage of bleaching (Y-axis) is based on 200 corals per site surveyed.

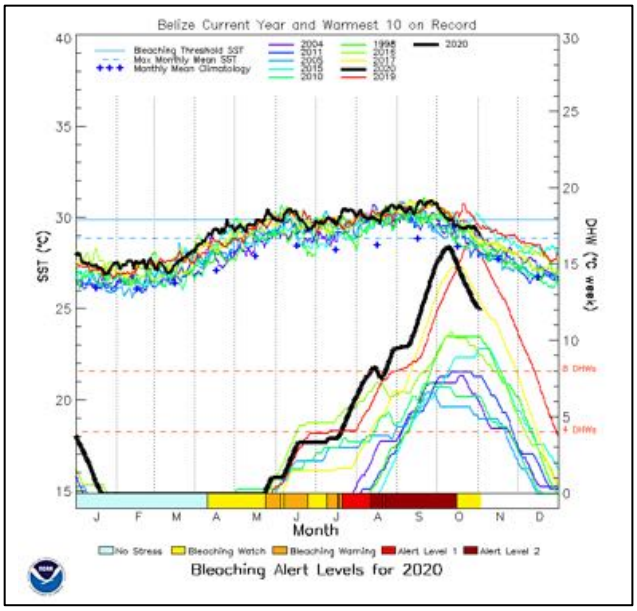
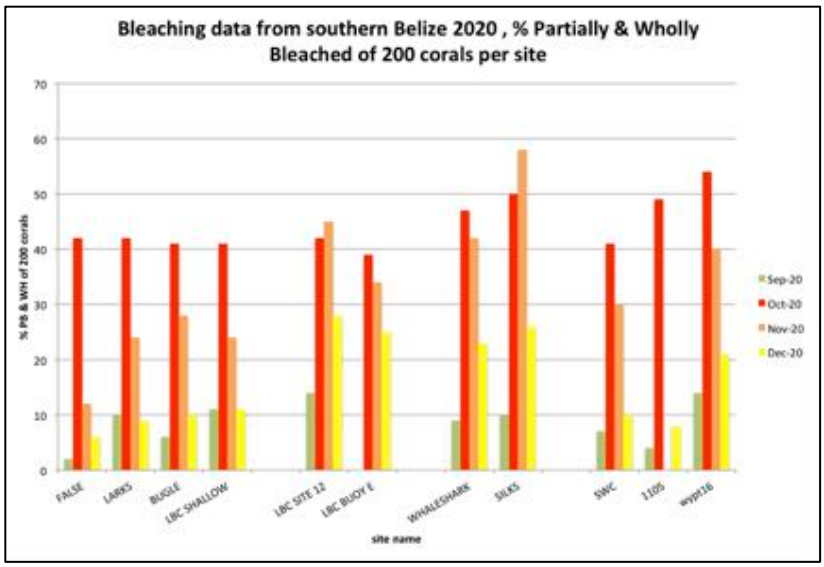
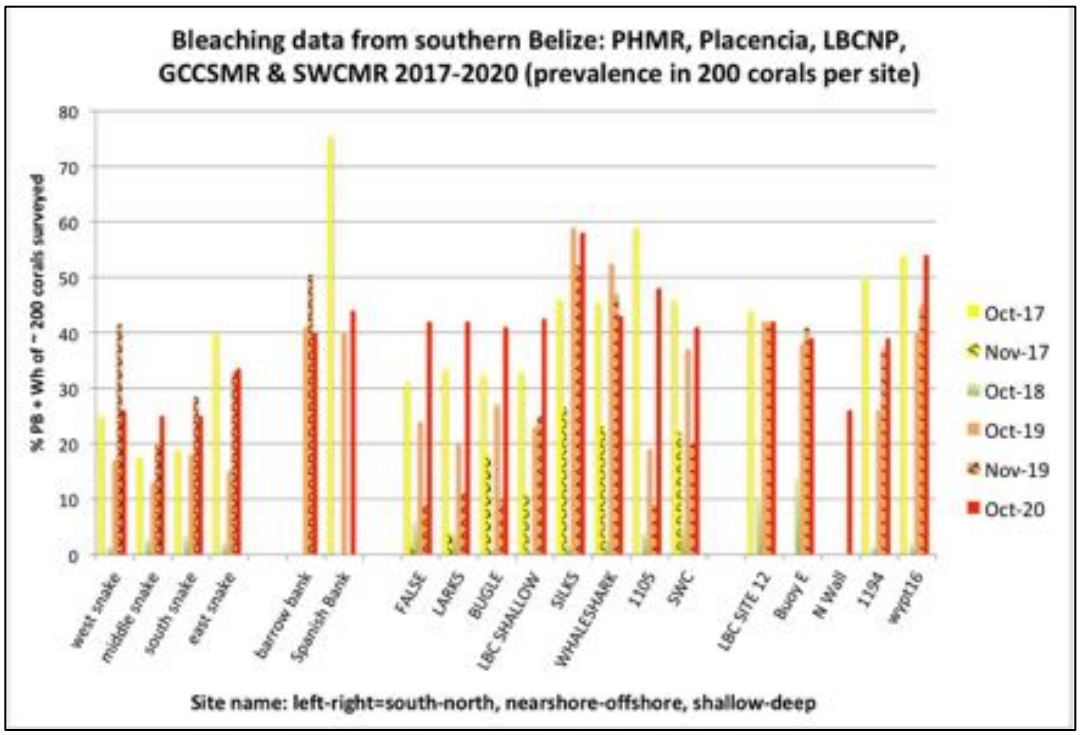


Fig. 9b. Data (satellite se surface and DHW) from NOAA illustrating the ten hottest years for Belize, with 2020 in black and surpassing all other years in temperature until early-mid October 2020.



Figs. 9c. Bleaching data for 2020 only (September-December) at FoH regular monitoring sites in southern Belize (from left to right on x-axis is near shore to offshore, LBC site12, LBC Buoy E and wypt 16 are fore reef sites~ 14m deep, all others are 1-5m).



Figs. 9d. Bleaching data October 2017-October 2020 including PHMR sites (see map in Figure 10a for site locations).

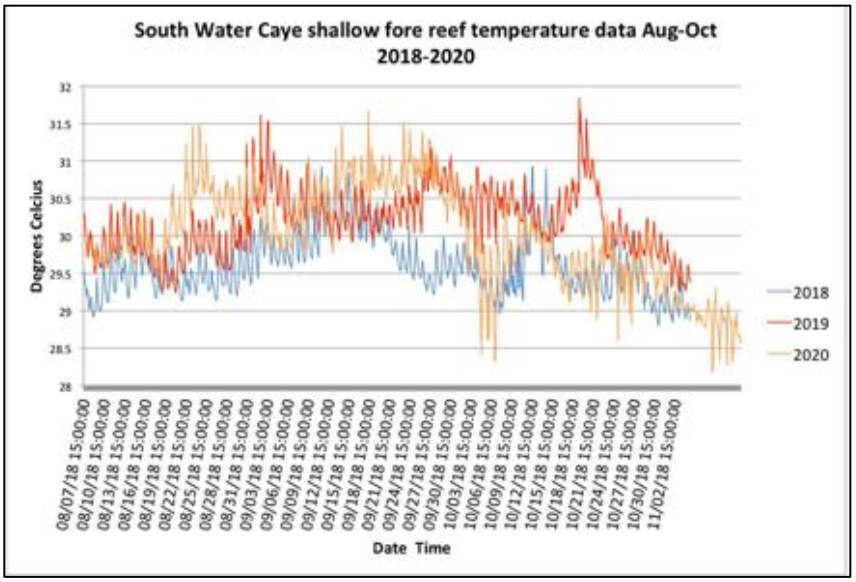


Fig. 9e. In situ temperature data from the shallow (~5m) fore reef at South Water Caye, which corresponds to "SWC" or "SWC shallow" in graphs and maps; this is an outplant site (SWC plot 1 in MCCAP reports).

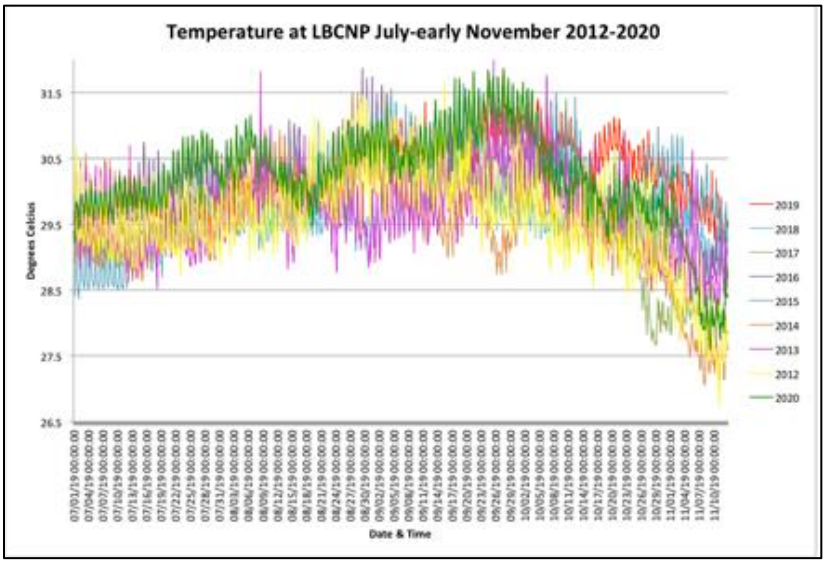


Fig. 9f. LBCNP is a site where > 10 years of temperature data exist; here only 2012-2020 is shown and 2020 is in bright green, showing the elevated temperatures throughout the year versus previous years until October. The logger is located on the west side of LBCNP ~ 5m.

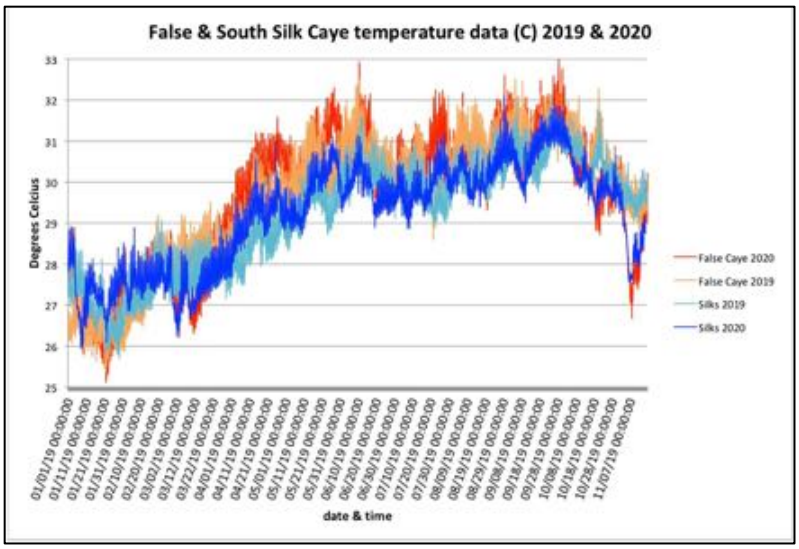
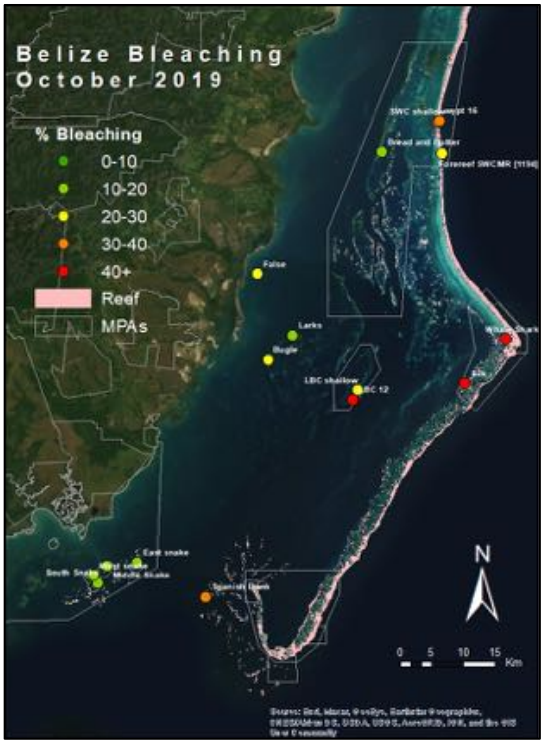
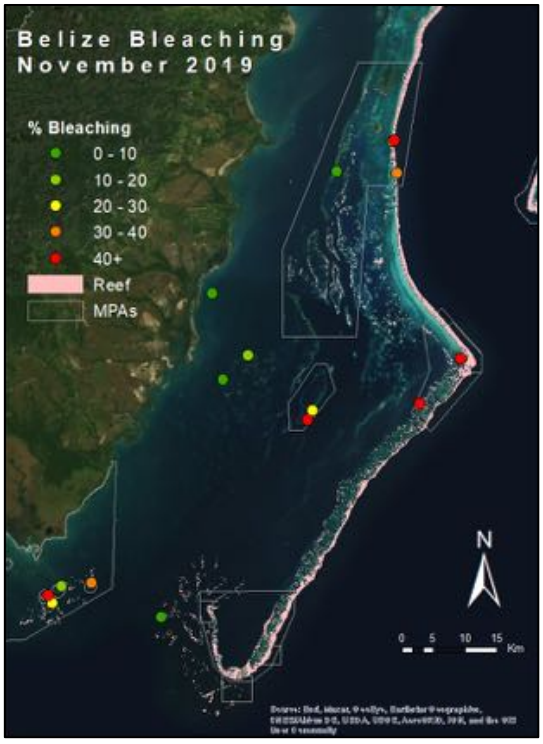


Fig. 9g. This graph compares temperature data for two years (2019 and 2020) at two extreme locations, Silks on the outer reef (light and dark blue line) and False Caye near shore (orange and red lines). The locations are shown on the map in Fig. 10a and also, the corals took longer to recover at Silks (offshore) than at False (near shore) despite both sites having initially equally high bleaching prevalence in 2020 (Fig.9c). However the acroporid outplant mortality at False Caye far exceeded that at Silks Cayes, which was minimal, in both years.





Figs. 10a-b. Maps of sites surveyed (2017-2020) with labels on the left. These maps are October and November 2019, showing the peak bleaching came later for many sites than usual (October) in 2019; prevalence (% corals bleaching of ~200 surveyed per site) are color coded. This also reflects severity of bleaching as no “pale” colonies are included.

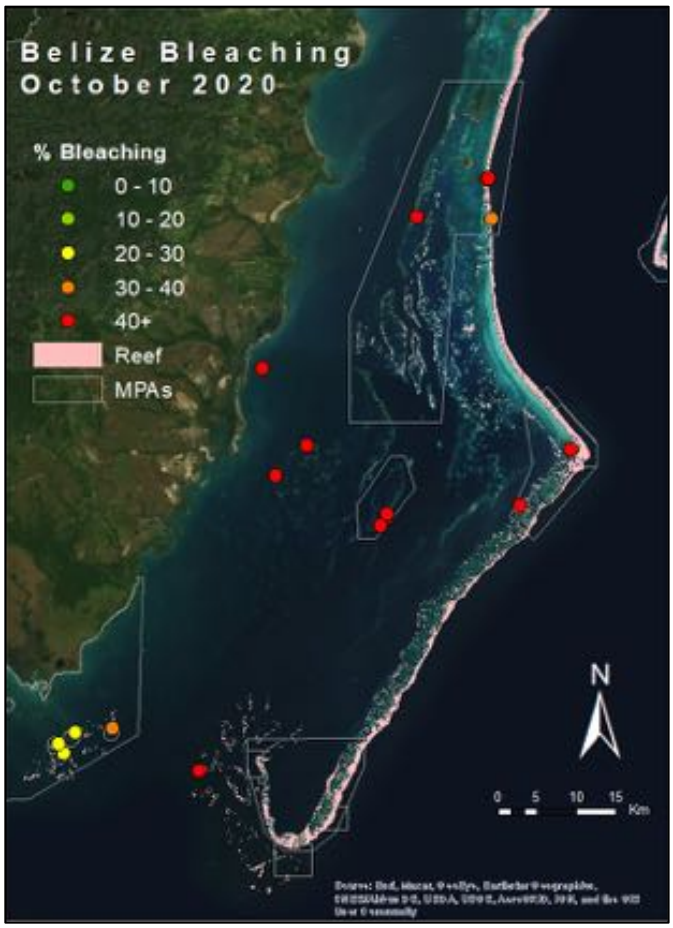


Fig. 10c. In 2020 the peak bleaching was in October (normal peak time) but, 2020 stood out as the worst beaching event in Belize to date. Prevalence (% corals bleaching of ~200 surveyed per site) are color coded. This also reflects severity of bleaching as no “pale” colonies are included.

Discussion and Conclusion

Fortunately the acroporids remain unaffected by SCTLD, therefore mapping existing wild stands throughout Belize should be a national priority to identify as many different temperature tolerant individuals for each taxa, for propagation and replenishment activities. The severity of the 2020 bleaching event further narrowed FoH data on resistant and resilient individual acroporid colonies, as well as sites in general. For example, near shore sites in PHMR did not bleach as severely as off shore sites, and near shore sites in Placencia area recovered more rapidly than offshore sites.

The data shared from both diver-based photomosaics (where available through 2019) and the change detection data using drone ortho-mosaics for LBCNP and natural stands, illustrates well the previously observed trend that the longer the corals are on site, the faster they can grow and spread out, thus the need for long term monitoring and data sets for reef replenishment work.

Recommendations

Based on the anonymous Reef Replenishment Methods in Belize course evaluation forms (2015-2020), more training of local coastal community members is still needed. Reef restoration has spread globally since FoH first began in 2006, stakeholder meetings have identified no less than 14 additional sites in Belize that desire reef replenishment. Lisa Carne and FoH have had an excellent relationship with the Belize Fisheries Department (BFD) since 2006, and established multiple regional and international collaborations with research institutions (e.g. Smithsonian Institute, MOTE Marine Laboratory), universities (Boston University, University of Miami, Penn State, University of North Carolina, University of South Florida, etc.), local and regional NGO's involved in reef restoration in the Caribbean (Jamaica, Colombia, St Barth's, etc.) and local and international funders. FoH recommends that BFD consider us the leaders in reef restoration that others do, not only in Belize, but regionally.

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