Fragments of Hope 2021 Summary report for Research Permit renewal 0009-21

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 2021. Active reef restoration focus shifted in 2021 back to the original southern sites until funding was sourced for Northern MPAs in late 2021 but monitoring continued in most MPAs/locations listed on the Research Permit. With less funding than in previous years, and well-established, long term replenishment sites in southern Belize, the focus in 2021 was not on large outplant numbers but on increasing genetic diversity at each location. At Laughing Bird Caye National Park, LBCNP, the oldest replenishment site, there are now 29 different *Acropora palmata* genets, 20 distinct *A. cervicornis* genets, and three *A. proliferas* (hybrids). At Silk Caye there are now 14 *A. palmata* ,11 *A. cervicornis* genets and two *A. proliferas* (hybrids), and at Moho Caye there are now 10 *A. palmata* ,17 *A. cervicornis* genets and two *A. proliferas* (hybrids). Over 7,000 acroporid corals were outplanted at four southern Belize sites in 2021. The MPAs are: Laughing Bird Caye National Park (LBCNP) where 1,217 corals were outplanted in 2021, so the grand total outplanted there is 87,267; and Gladden Spit and the Silk Cayes Marine Reserve (GSSCMR) where 330 micro-fragmented elkhorn corals and 626 staghorn fragments were outplanted in 2021, so the grand total outplanted there is 14,326. The two control sites (outside of MPAs) are False Caye with 784 staghorn corals outplanted there in 2021, and Moho Caye where 4,158 corals were outplanted in 2021, making the grand total at Moho Caye 23,942, since work began there in 2015. In total, across Belize, 160,383 coral fragments have been outplanted since 2010, through December 2021. There are still four remaining table 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 the four nurseries in Northern Belize MPAs established in 2020 are now ready to harvest/outlpant.

Results from analyzed diver-based mosaics (six years at LBCNP, 2014-2020 and five years at Moho Caye 2015-2020) now reveal a pattern that suggests density of outplants

(2-38 frags/m^2) is less crucial than site and coral selection for replenishment success. At LBCNP some sites with as few as 200 staghorn fragments outplanted in an area ~ 100m^2 translated to 56% of 59% live coral cover after 10 years, but even in the fastest growing sites, annual coral cover increases of over 10% only occur ~3.5-4 years after outplanting. In northern sites where corals grow slower, these results may take two-three times longer. FoH continued using drones for shallow water reef mapping since 2019 and to better quantify total area of replenished sites. Two years of change detection at LBCNP (2019-2021) revealed 1) over 20% of a hectare of shallow reef at LBCNP is replenished acroporids and 2) natural increases doubled from 7% 2019-2020 to 14% 2020-2021, verifying that minor, non-catastrophic disturbances can aid the natural spread of acroporids, since an indirect Hurricane category 1 affected LBCNP in September 2020.

With special permission and working with MPA staff, FoH began monitoring the spread of Stony Coral Tissue Loss Disease (SCTLD) into South Water Caye Marine Reserve, received training to apply treatment, and to date (through December 2021) FoH has treated 78 corals, representing seven different species, in four sites in SWCMR, with a smaller sub-set of corals being re-treated once and/or twice. Because of the rapid spread of SCTLD, restoration focused on the acroporids as they appear to be resistant to SCTLD.

Despite initial bleaching alerts from the NOAA Coral Watch program in July 2021, bleaching was far less severe in 2021 than in 2020 or 2019, and for this reason not all temperature loggers have been switched out/uploaded yet: sample sets of temperature data from the temperature loggers collected in 2021 are included in this report. Monitoring for bleaching and disease was conducted on over 20 sites July-October 2021, with several sites being repeated November-December, primarily to track or check for spread of SCTLD, since bleaching was relatively minimal in 2021; all data has been entered into the AGRRA website database.

FoH participated virtually in multiple local and regional classrooms and talk shows, and in the ICRS 2021 and Reef Futures 2021 conferences. FoH was announced as a “First Implementer” in the UN’s Decade of Restoration, and featured on the cover of the text book entitled “Active Coral Restoration”, edited by Dr. David Vaughan, and authored a chapter on the work at LBCNP. FoH also participated in the Response & Emergency Reef Restoration Training in Belize, hosted by MAR Fund and TNC in San Pedro July 2021. FoH is also now a formal partner with SECORE, participated in their training for rearing sexual recruits in situ in Curaçao, and plans to trial this method at LBCNP in 2022. FoH hosted multiple PhD, MSc and local junior college students in subjects ranging from anthropology, coastal engineering, GIS mapping and marine biology.

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 87,000 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 will continue in SWCMR and TAMR in 2022 and in the southern sites through 2022. 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 2020, new methods for SCTLD treatment added as Annex)

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[1] 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. This same method is used to assess SCTLD on sites. 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.

In 2020 the bleaching data base was moved from UB to the AGGRA website[2]. FoH entered all bleaching data from 2017-2020, in anticipation of this website eventually generating maps for coral bleaching presence/prevalence & severity. This continued for bleaching & SCTLD in 2021. The current National Treatment Plan for SCTLD is attached as Annex I.

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

Results

Outplanted corals in 2021:

Figure 1 shows all FoH sites established nationwide on a map. Table I lists the number of corals outplanted at each site in 2021 and then with the grand totals. The total numbers of corals outplanted for 2021 is the least amount outplanted of the last three years (Table I) for several reasons. First, the number of corals in the nurseries had been reduced due to closing of several other grants/projects in 2020; without secured funding one of the risks to adding many corals is overweighted or neglected nurseries. Secondly, the emphasis was meant to be on micro fragmenting and direct outplanting however due to the SCTLD spreading though Belize only acroporids were outplanted this past year, and the preferred type/brand/model of tile saw was not available in country[3] therefore the team had to work with saws available in Belize that were both unable to cut smaller pieces, and also cut much slower than the preferred brand/model. However, the real limiting factor was weather: from January-May 2021 FoH only managed four-five field days each month due to excessively high winds, and of those days, a smaller fraction were appropriate weather for outplanting with cement. Despite these constraints, over 7,000 corals were outplanted across four sites in southern Belize, including almost 800 micro fragments. Genetic diversity was enhanced for *A. cervicornis* and *A. palmata* (Tables IIa-b) at most outplant sites in southern Belize, and FoH recently received results from the newest genetics analyses methods [4],[5] with Dr. Iliana Baums and Dr. Sheila Kitchen at Penn State. Whilst still going through the results, we now know that there are at least five *A. prolifera* genets in southern Belize, as opposed to thinking it was only two different *A. prolifera* genets previously. The genets are named for their location (e.g. south cramp caye, Jeremy, RG patch) and the *A. cervicorinis* growth rates are being compared to existing *A. cervicornis* genets using the Total Linear Extension method (Kiel, et al 2012[6]) in different nurseries (Figure 2). While none of the new genets have very different growth rates from the old genets, some have significance like the “RG patch” *A. cervicornis* which was one of the only two survivors at False Caye after the 2020 severe bleaching event at nearshore False Caye (Figs 3a-d).

Seven years of diver based mosaics at LBCNP now finally reveal a pattern: the largest yearly increase in coral cover was after ~3.5-four years on the reef: in 2018 for sites 24, 23, 20 and 21 (blue bars) and in 2015 for site 13 (outplanted in 2010, far right, Fig. 4). Figure 4a includes a table that lists outplant dates, locations and details, and this data implies the density of the outplants (2-38 frags/m^2) seems not to correlate with increases of coral cover; instead site selection and coral selection plus patience may be key to replenishment success. Previously shared FoH *A. cervicornis* growth data from Turneffe and South Water Caye Marine Reserve indicate corals sourced and growing in southern sites near Placencia have up to double the growth rates as the northern corals/sites. Therefore these types of cover cover increase results may take 6-10 years in other locations. Figure 5 illustrates the total live coral cover at each

[3] FoH recently imported the preferred saw brand/model from Florida end of 2021.
[4] https://www.nature.com/articles/s41598-020-69101-z
[5] https://www.sheilakitchen.com/uploads/5/3/0/1/53010609/stagdb_poster_final.pdf
[6] https://www.int-res.com/abstracts/esr/v19/n2/p171-176/

LBCNP sub-site 2014-2020, and Figure 6 is data from three sub sites at Moho Caye 2015-2020. All three sites at Moho were unplanted in 2015, whereas only two sites at LBCP (23 and 24) were unplanted in 2014, when the diver based mosaics began.

There are some limitations and subjectivity to using the open source software CpCE: for example categories of rubble versus dead reef, identifying CCA, and there are only vague categories of "sponge"-at least encrusting vs upright would be useful. Most of the sponge in all the mosaics are the *Clionid spp*. the brown encrusting sponge (see Figure 7 for comparing benthic community changes over time at a single unplanted site at LBCNP and the average of three unplanted sites at Moho Caye). Likewise 'gorgonian' reflect several different species. This data warrants much more thorough analysis and ideally by multiple persons to eliminate any bias. Because all increases in live coral cover are form the replenished acroporids totals are shown, and not broken down by the few different corals species on sites. Figures 15b-f are the processed diver based mosaics for the unplanted sub-site 24 at LBCNP and help to give a visual-the lasts drop (not 2016) in coral cover from 2019-2020 reflects some collapse of the large *A. palmata* colonies on this, the smallest of quantified sites (~40m^2).

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

SITES				
	ACER	**APAL**	**TOTAL 2021**	**TOTAL** **s. sites**
LBCNP	1052	165	1217	87,267
SILKS	626	330	956	14,326
MOHO	3884	274	4158	23,942
FALSE	789	0	789	5,921
subtotal	6351	769	**7120**	**131,456**
Including all other corals previously outplanted through 2020 nationwide				**160,383**

Table IIa. Number and source location of *A. cervicornis* (ACER) genets/individuals at each of three outplant locations in southern Belize: Moho, Laughing Bird and South Silk Caye.

genet source ACER	Moho	LBCNP	Silks
saddle	X	X	
lazy	X	X	X
gladden buoy		X	
gladden pillar patch		X	
tarpon	X	X	X
whipray	X	X	X
glens bank		X	
loggerhead	X	X	X
moho (genetics reveal it's APRO)	X	X	
FALSE	X	X	X
harvest	X	X	X
hatchet deep	X	X	X
mid silks	X	X	X
bl silks		X	X
near silks nursery table	X		
cramp	X	X	
crawl	X	X	X
andria	X	X	X
dale's reef	X	X	
lil bugle		X	
LBCNP		X	
Jeremy patch	X	X	
RG patch	X		X
south cramp caye	X	X	X
Total *A. cervicornis* genets	**17**	**20**	**11**

Table IIb. Number and source location of *A. palmata* (APAL) genets/individuals at each of three outplant locations in southern Belize: Moho, Laughing Bird and South Silk Caye.

genet source APAL	Moho	LBCNP	Silks
gladden buoy	X	X	
gladden pillar patch	X	X	X
gladden crest	X	X	X
loggerhead1	X	X	X
loggerhead2	X	X	X
bugle		X	
larks	X	X	
larks2	X	X /X	X
s silk caye s			X
s silk caye n			X
middle silk caye1			X
midddle silk caye2			X
nursery patch silks1			X
nursery patch silks2			X
nursery patch silks3			X
french louie	X		
Mosquito caye1		X	
mosquito caye2		X	
mosquito caye 3		X	
17 genets from 2006		X	
south cramp caye	X		
loggerhead patch	X		
BL silks patch			X/X
Total *A. palmata* genets	**10**	**29**	**14**

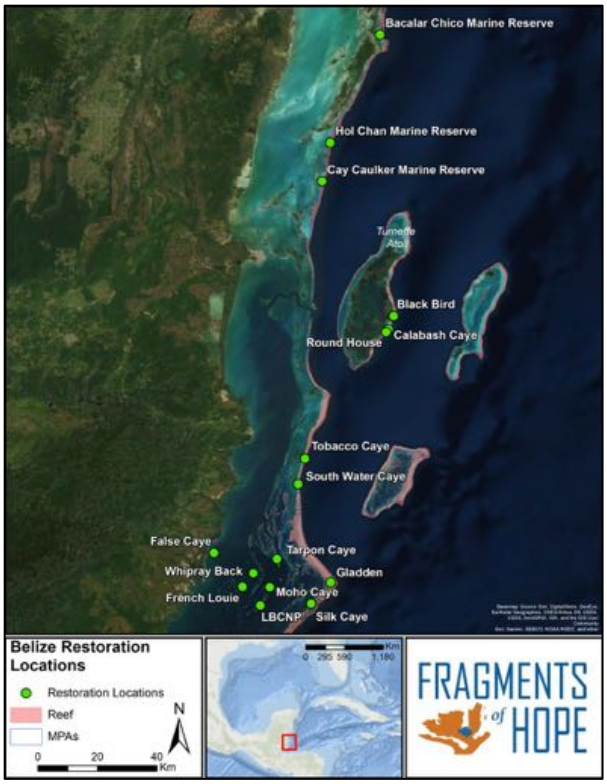


Fig. 1. Map showing FoH restoration sites through 2021 including the sites in the Northern Belize Marine Protected Areas.

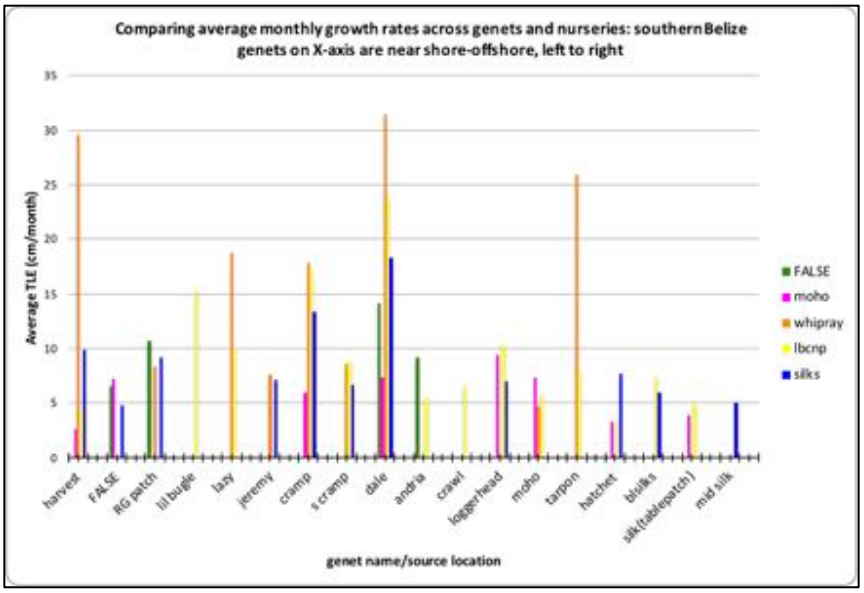


Fig. 2. The *A. cervicornis* genets are named for their home locations, and are listed from near shore to offshore, left to right, on the X axis. The nurseries (locations) are color coded in legend and the averaged TLE in cm/month (30 days) is on the Y axis.

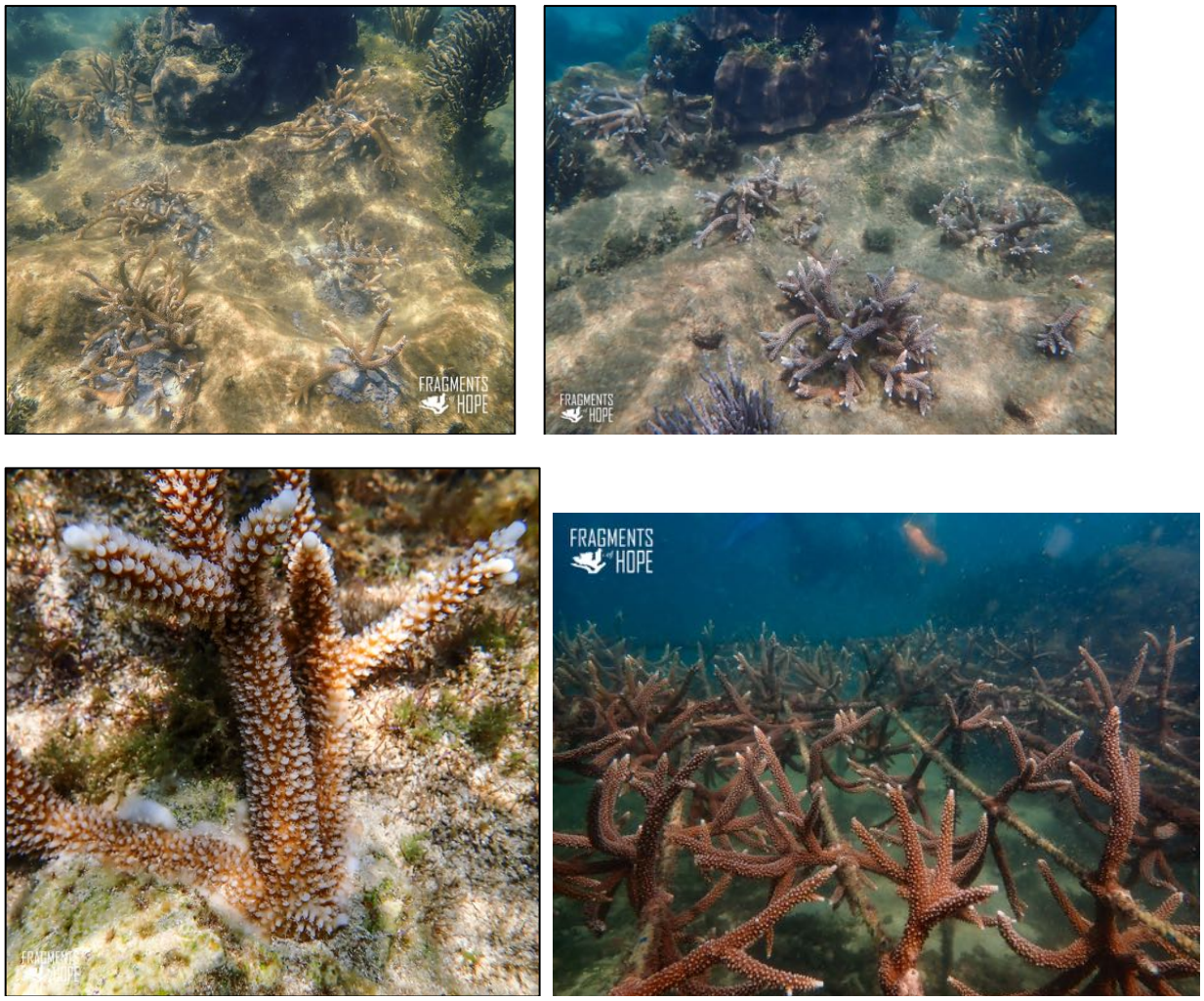
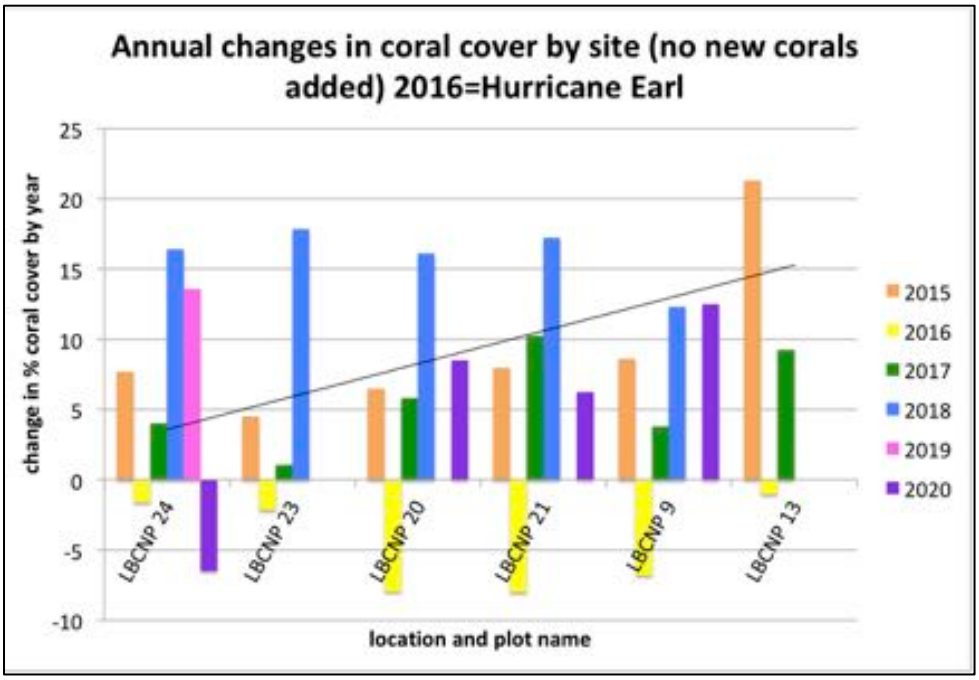


Fig. 3a-d. From top left, clockwise: (a) day 0 outplanted new *A. cervicornis* genet with cement at False Caye 17Mar21 (b) 48 days later and (c) close up of growth onto substrate/reef after 48 days (d) the "RG" genet still thriving in False Caye nurseries Dec 2021.



Figs. 4. Shown are the yearly changes in live coral cover, where data available, from six diver based mosaics plots at LBCNP. Sites on the X-axis are from youngest to oldest, left to right. No site had any corals added after initial outplanting, dates and details in Table III. Sites were surveyed post-Hurricane Earl in 2016.

Sub-site/ plot name	Area (m^2)	Out-plant date	Species & # frags out-planted	% acroporid coverage of total live coral
13	182	12-2010	633 ACER, 3 APAL, 100 APRO (or 4frag/m^2)	69.5% of 72.5% (2020)
9	110	04-2010	209 ACER (or 1.9frag/m^2)	56% of 59% (2020)
20	144	02-2014	885 ACER, 19 APAL (or 6.3frag/m^2)	63% of 65% (2020)
21	109	02-2014	906 ACER, 11 APAL, 21 APRO (or 8.6frag/m^2)	47% of 51% (2020)
23	112	11-2014	461 ACER, 7 APAL	N/A (yet)
24	40	11-2014	1138 ACER, 12 APAL (or 28frag/m^2)	33% of 36% (2020)

Fig. 4a. Details on each sub-site/plot at LBCNP including area (m^2), date outplanted, number of species/taxa outplanted and the latest available date percentage of acroporids from total live coral cover, using CpcE to annotate processed diver-based mosaics.

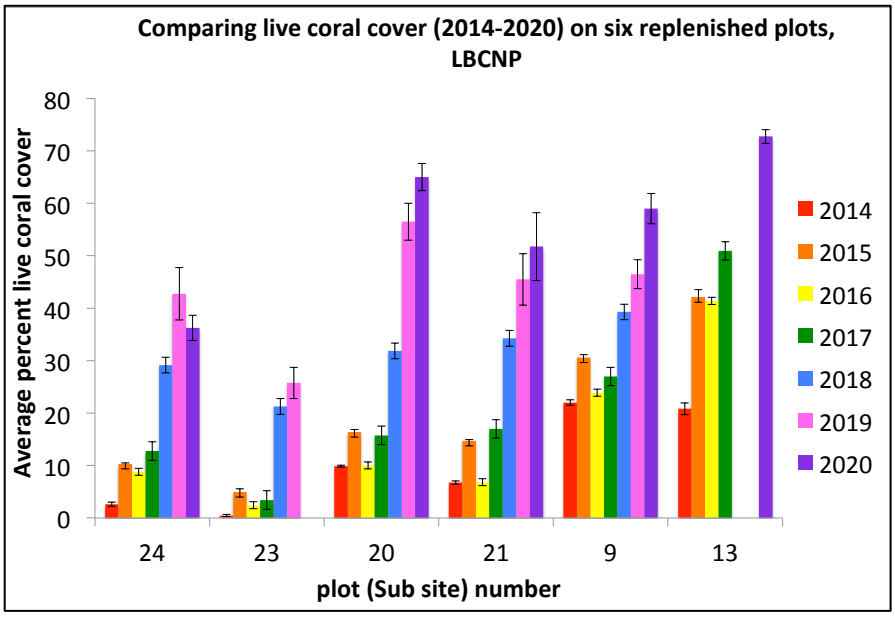
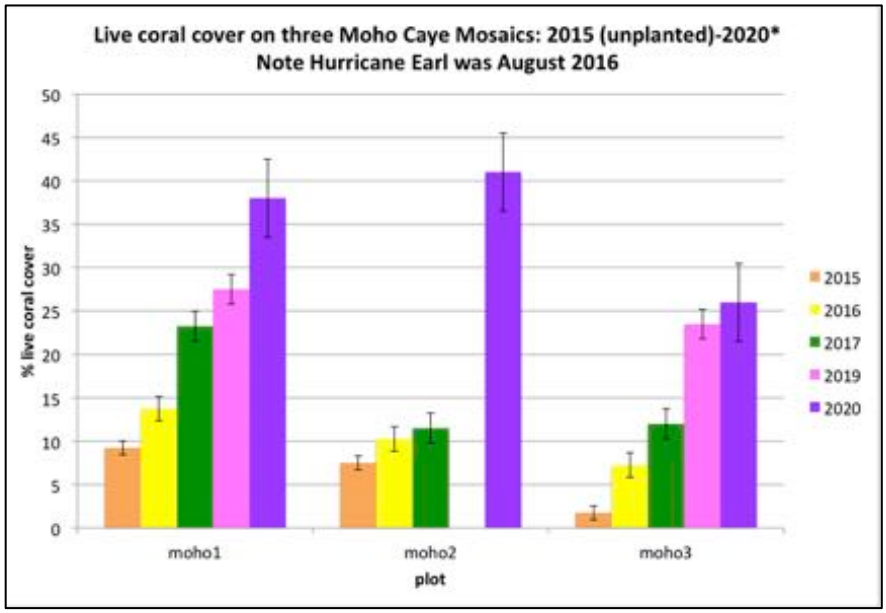


Fig. 5. The x-axis is the sub-site name at LBCNP, from left to right is newest (2014) to oldest (2010) outplant dates. The years are color coded and the y-axis is percent live coral based on CPCe analyses of processed diver-based mosaics. Only sub-site 24 has been processed and analyzed for 2019 to date (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. 6. Data from diver-based mosaics at Moho Caye 2015-2020; all three plots were unplanted in 2015 (orange).

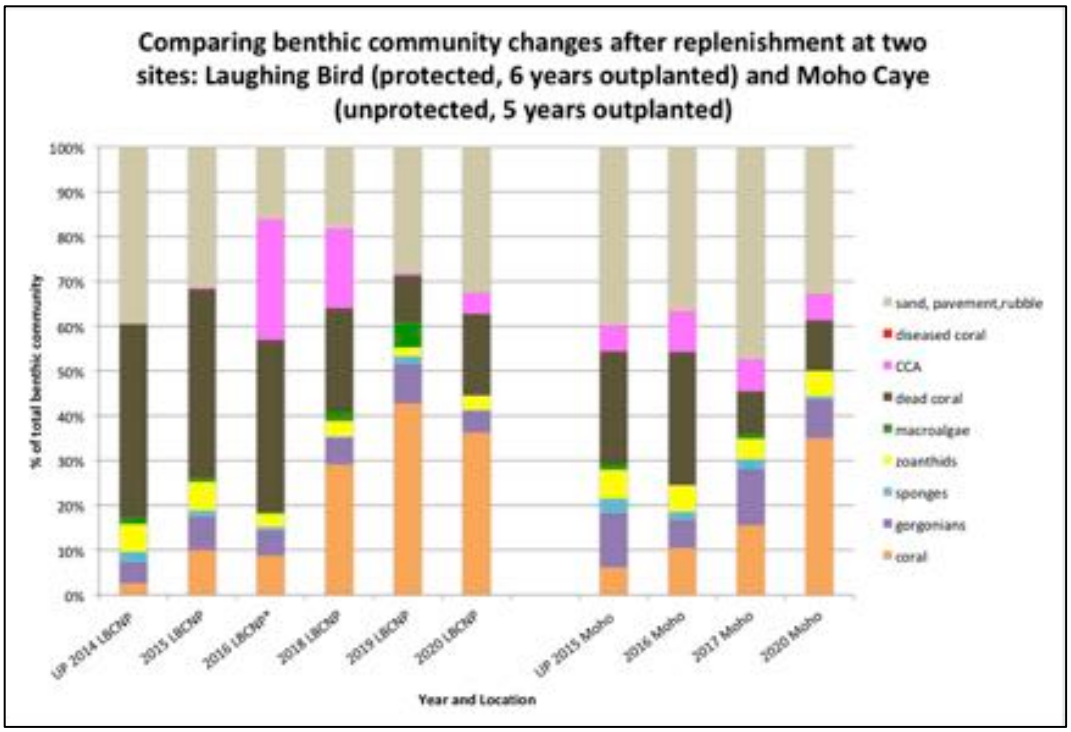


Fig. 7. Comparing changes in general benthic community categories from a single unplanted plot at LBCNP (sub-site 24 over six years) versus three unplanted plots (averaged across three plots) at unprotected Moho Caye over five years. Hurricane Earl (category 1) was in August 2016. All 2020 diver-based mosaics were conducted pre-Hurricane Nana (category 1, September 2020).

Mapping with drones and satellite imagery:

In 2021, 0.956km^2 of reef area was mapped with drones, and 171km^2 of satellite imagery was purchased. Most of this was repeated mapping (from 2019-2020) for change detection at natural and replenished acroporid stands, but also to quantify land use changes from development activities in the 'inner cayes' near Placencia (171km^2 of satellite imagery from December 2021 is same area as November 2020 satellite imagery). Additionally, Monkey River shoreline was mapped (2018-2021) as a continued in-kind contribution to the village from FoH.

Figures 8a-c show change detection 2019-2021 at two replenished sites, LBCNP and Moho Caye, and one natural acroporid stand near Loggerhead Caye. Change detection was higher 2020-2021 at both replenished sites (increases of 14% and 98% respectively, at LBCNP and Moho), likely because of the indirect Hurricane Nana, category 1 in September 2020. As the diver-based mosaics data showed at LBCNP after Hurricane Earl an indirect category 1 storm in 2016, (see Figure 5), non-catastrophic disturbances actually facilitate the asexual reproduction or spread of acroporids. At Moho Caye, there were almost 4000 staghorn fragments added by FoH in 2021, so some increase was direct intervention/replenishment, while at LBCNP the

increase is all from natural spreading. While not a direct analogy, the increase at the natural staghorn stands near Loggerhead were higher each year (41-38%) than the replenished sites, which may be a reflection of the age of the corals there as well as ease of detection by drone (dense, tall thickets).

FoH has continued to report dredging activities, a regular occurrence on and near the Placencia peninsula, and due to the drone images of illegal “mining” of sand and seagrass beds at Lazy Caye (Figs. 9a-b) in early 2021, a stop order (Fig. 9c) was issued the same day and delivered by SEA staff the following day[8]. In order to have a comprehensive picture of land use change in the inner cayes, the 171km^2 of purchased, tasked satellite World View3 imagery from December 2021 was annotated with dredge and fill shapefiles made from drone mosaics. Figure 10a illustrates this for 2021, with the total land within the 171 km^2 area only ~ 1.7 km^2 (or < 0.1% of the area), and of that land, approximately 8% has been altered (0.13 km^2). The only change 2020-2021 was identified at Larks Caye range.

Figure 10b shows the results of using eCognition[9] on the 171km^2 of purchased, tasked satellite World View3 imagery from November 2020 to identify and quantify marine habitats. The task and the software are in-kind from Steve Schill, lead scientist at the Nature Conservancy (TNC), insular Caribbean. The task was completed mid 2021 and the product should be considered a draft, as Dr. Schill has committed to 1) refine the results with habitat shapefiles created from drone orthomosaics to continue to ‘train’ refine the AI software, 2) decrease the amount/number of benthic classes and 3) covert to m^2 versus hectares, when he finds the time.

Drone work in Monkey River began in partnership with Tim Hawthorne and the Citizen Science GIS group in 2018. Figures 11a-b show the shoreline changes outlined 2018-2021 and 2020-2021, respectively. After the geotubes were installed, between 2018 and 2019 the sediment accumulated, and the beach grew behind the geotubes. Subsequent losses are attributed by the villagers to hurricane Nana (September 2020). Storms usually increase the cross-shore transport and deposit sand offshore. This sediment may make its way back onshore during less energetic periods. Monkey River villagers have requested this annual drone flight continue to be repeated, FoH has completed all of the work in Monkey River 2018-2021 with private donations.

[8] Note that threats have been made to FoH team members by the recipient of the stop order up to > six months after the stop order was delivered by SEA; these threats have been reported discreetly to the local authorities and SEA.

[9] https://www.geospatial.trimble.com/products-and-solutions/trimble-ecognition

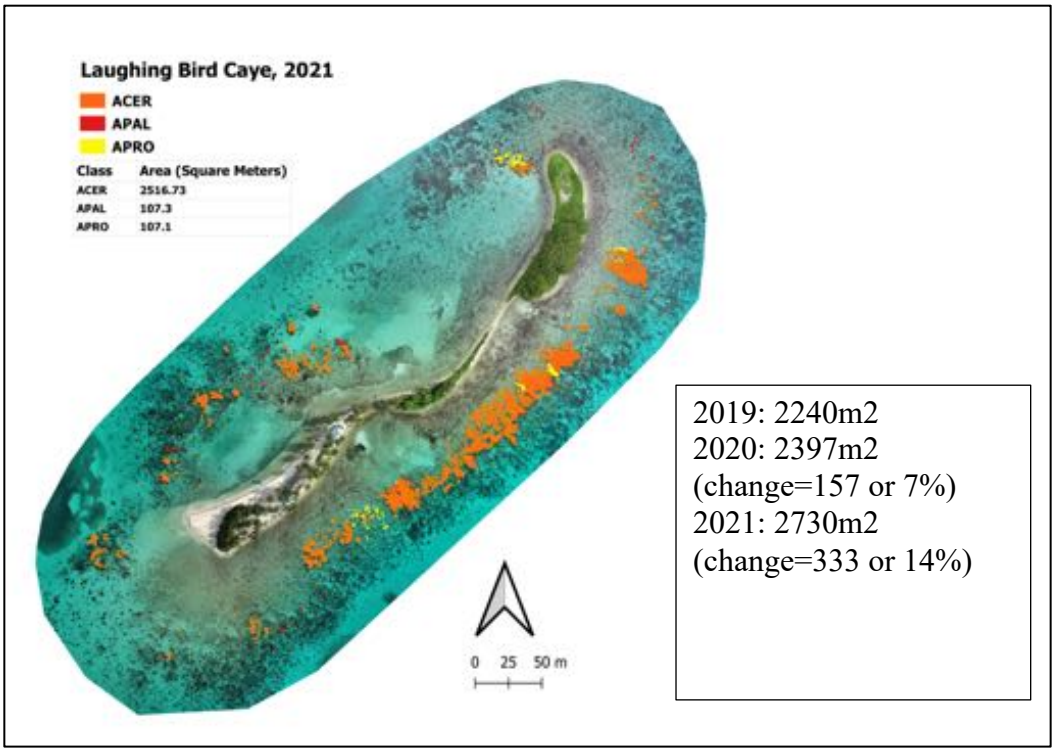
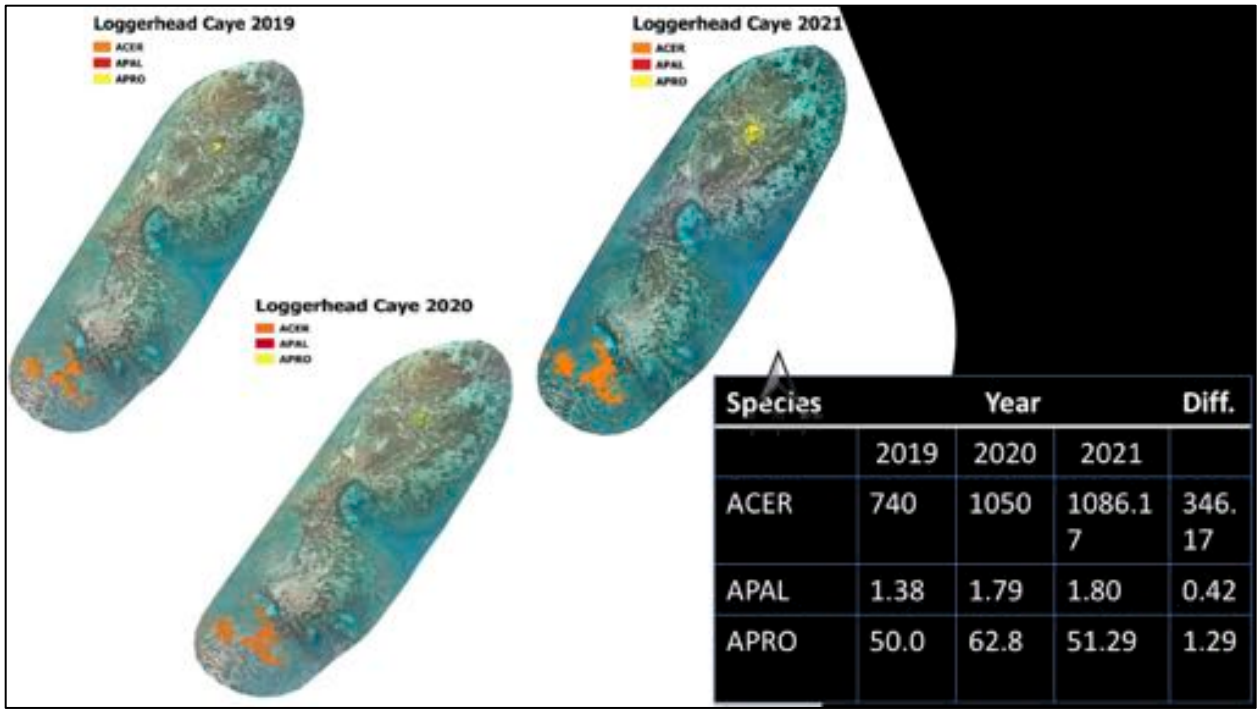


Fig. 8a. Change detection at LBCNP has been completed for all acroporid cover 2019-2021: 2019: 2240m2, 2020: 2347m2 (change=157 or 7%), 2021: 2730m2 (change=333 or 14%)

Figs. 8b. Change detection for Moho Caye 2019-2021. Only the staghorn is directly visible at Moho Caye, not the hundreds of elkhorn micro fragments ouptlanted.



Species	Year			Diff.
	2019	2020	2021	
ACER	740	1050	1086.17	346.17
APAL	1.38	1.79	1.80	0.42
APRO	50.0	62.8	51.29	1.29

Fig. 8c. 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, 2019-2021. This is not a replenishment site, all existing and increased coverage of acroporids is natural.

Figs. 9a-c. Drone images showing illegal mining (although by hand) of sand and seagrass at Lazy Caye 15Feb2021 (L and middle) and copy of the Stop Order letter issued same day and delivered the following day on site by SEA staff (R).

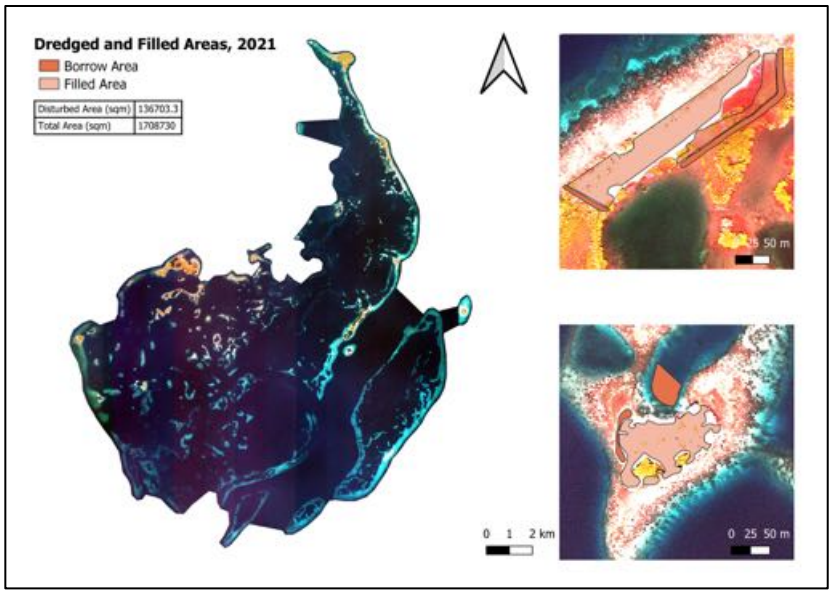


Fig. 10a. Tasked, satellite imagery acquired in December 2021 annotated with GIS to calculate and use changes. Of the 171 km^2 area, only ~ 1.7km^2 is land (<0.1%) and of that land, ~ 8% has been altered in or before 2021(0.13km^2).

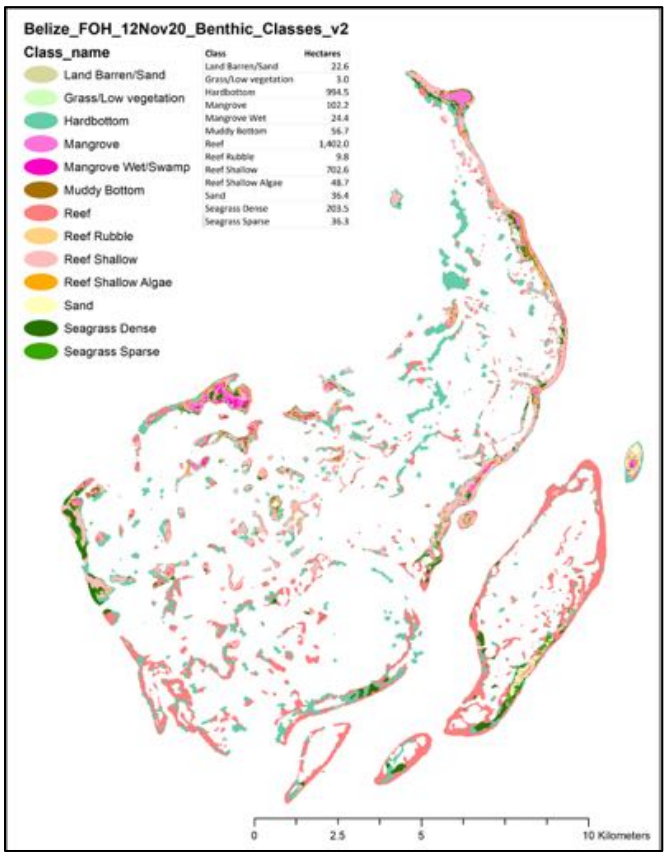


Fig. 10b. Tasked, satellite imagery acquired in November 2020 was annotated with eCognition software by Dr. Steve Schill (TNC) in mid-2021.

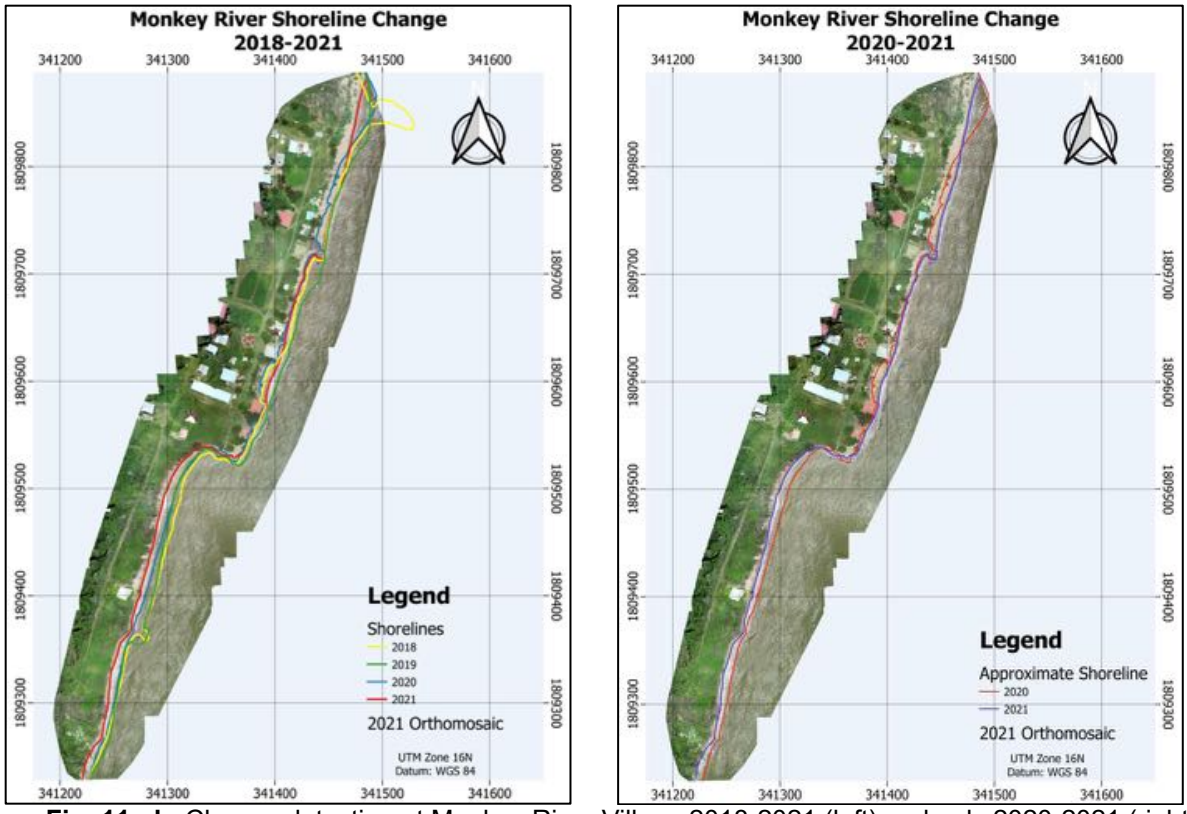


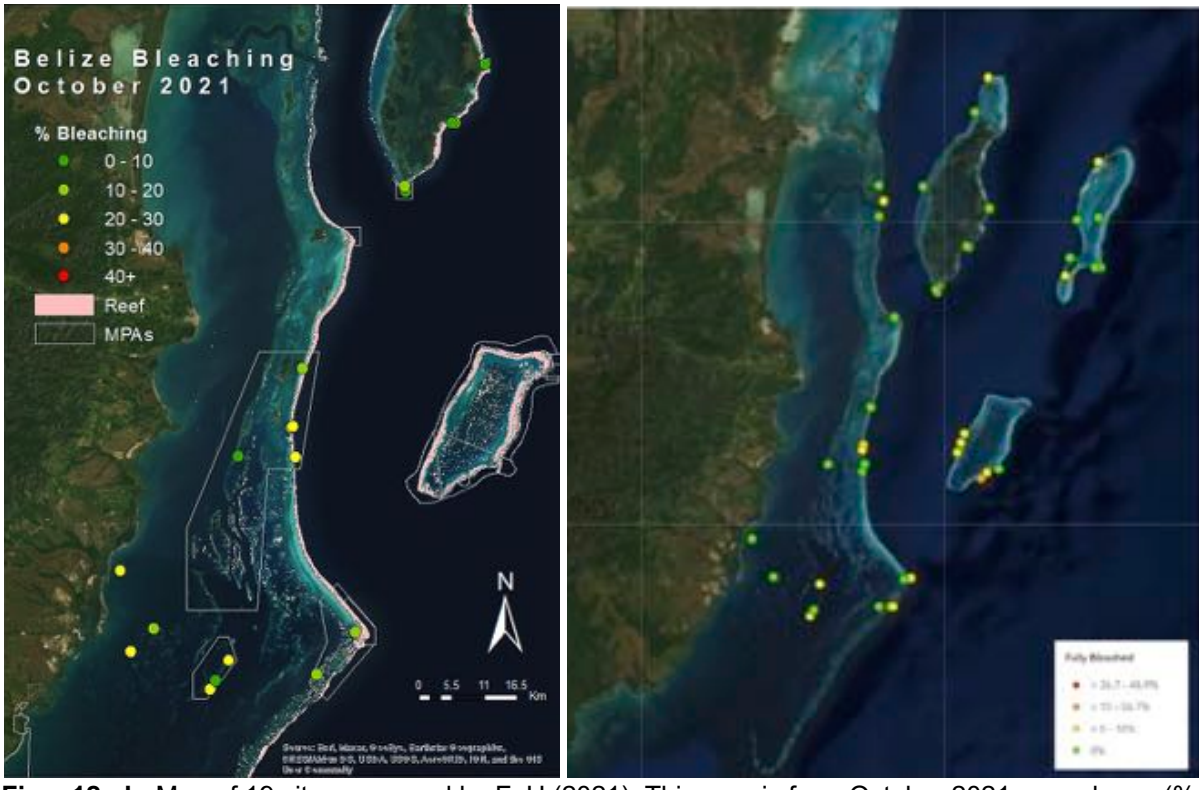
Fig. 11a-b. Change detection at Monkey River Village 2018-2021 (left) and only 2020-2021 (right).

Bleaching and Temperature Data

Some inner caye sites near Placencia have been monitored for bleaching for over a decade (Fig. 12d), with outer reef and SWCMR sites added in 2017 (Fig. 12c), and in 2021 FoH monitored an additional six sites in TAMR in October (Fig. 12a). Figure 12b is a map of all the bleaching data sites entered to the AGRRA website from Belize in 2021; UB and BAS entered their own data, and FoH entered WCS data from Glover's Reef. This map (12b, unlabeled) is shared by Particia Kramer who manages the AGRRA database and reflects reports of whole (fully) bleached corals only at each site, with different percentages and color codes than those used by FoH (map in 12a). The FoH site map (12a) is reflecting prevalence of bleaching at each site (no Pale colonies included), or percent of 200 corals surveyed that have partially or fully bleached corals. Likewise the bar graph data in Figures 12c-d do not include pale corals, only partially and wholly bleached corals, as a percentage of all corals (~200) surveyed per site. All of these data correlate with the in situ sea temperature data shared in Figures 13a-d: 2021 had the 'mildest' temperatures and thus relatively mildest bleaching event in recent years. Notably

not more mild than 2018, 2013 or 2009, and even in the shorter temperature data sets from False and South Water Caye, a slightly increasing trendline is evident (Figs. 13c-d).

There are temperature loggers at each site pictured on the map in Figure 1, however the logger at Tobacco Caye was taken in 2021, the batteries died in the logger at Black Bird Caye in TAMR and the MPA managers have responsibility/data for the loggers in CCMR, HCMR and BCMR. In addition to the two sites with temperature data (False and SWC) shown, FoH has retrieved the data from LBCNP, Calabash and Whipray Caye. This raw data is shared on the external hard drive. The rest will be retrieved in early 2021. The differences between the temperature data shown in Figures 13a-b and 13c-d is the software used: Excel versus “R”. FoH does not have “R” and these graphs (and in 2020) were completed by Colleen Bove, who collaborated with FoH and Justin Baumann when they were both at UNC completing their PhD’s. Now Dr. Bove is a Postdoctoral Associate Lecturer at Boston University but continues to facilitate FoH with their temperature data. All temperature data are collected in one hour increments.



Figs. 12a-b. Map of 19 sites surveyed by FoH (2021). This map is from October 2021; prevalence (% corals bleaching of ~200 surveyed per site) are color coded. This also reflects the relatively ‘mild’ severity of bleaching as no sites had over 30% bleached corals (left). On the right is all data from Belize (FoH entered but did not collect Glovers Reef data; UB and BAS submitted their own data) showing only Wholly bleached corals (not many) in Belize in 2021. Map on right shared from Patricia Kramer, from the AGRRA website/database.

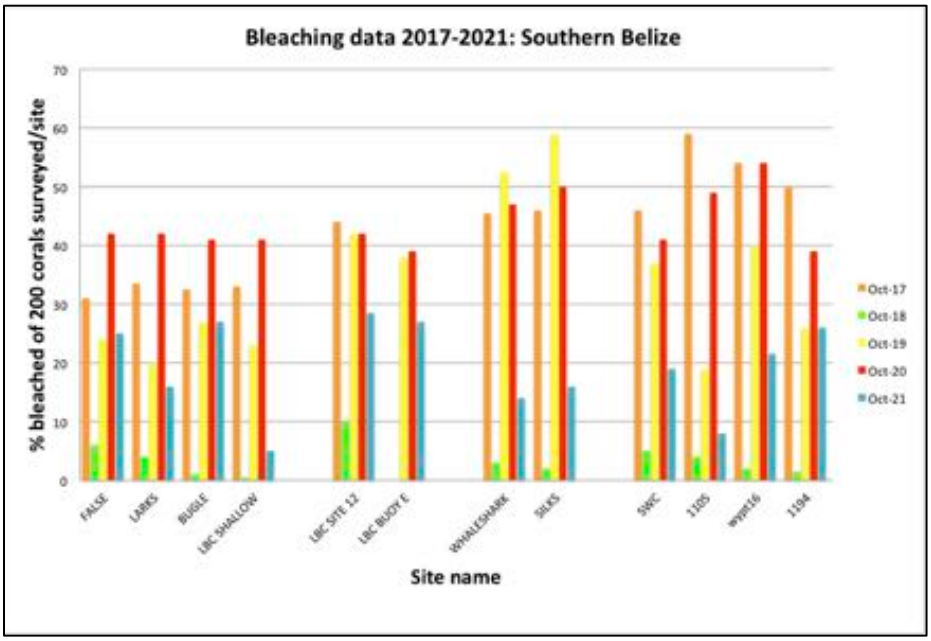


Fig. 12c. Comparing bleaching rates in October 2017-October 2021 (where data available) at multiple sites (X-axis) in southern Belize. From left to right is near-shore to offshore. The percentage of bleaching (Y-axis) is based on 200 corals per site surveyed and only includes partially and wholly bleached corals.

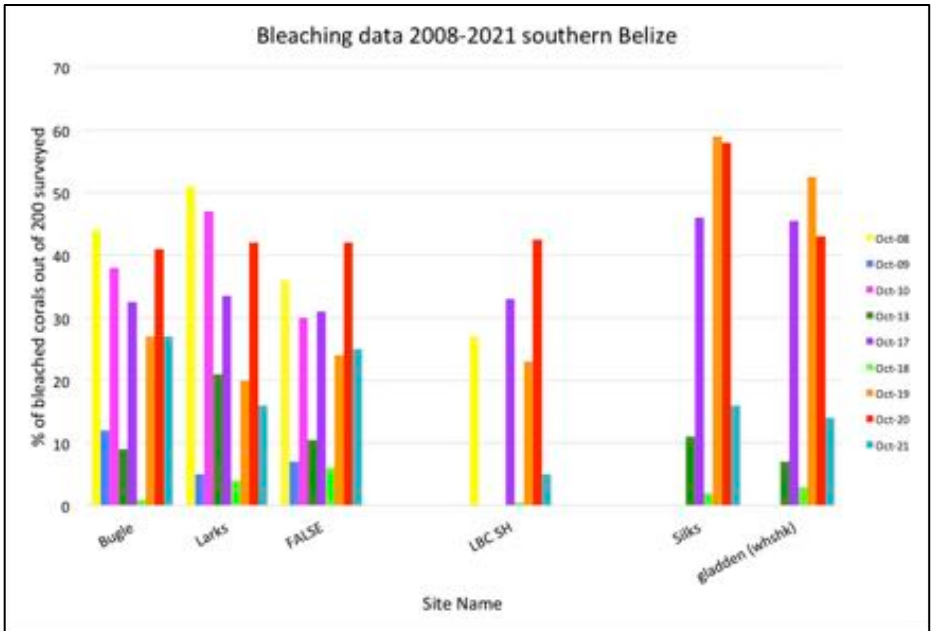


Fig. 12d. October bleaching data 2008-2021 in southern sites (where available) illustrates that 2021 was a relatively minor bleaching event in Belize, yet still more severe than 2009, 2013 and 2018, other less severe bleaching years in Belize.

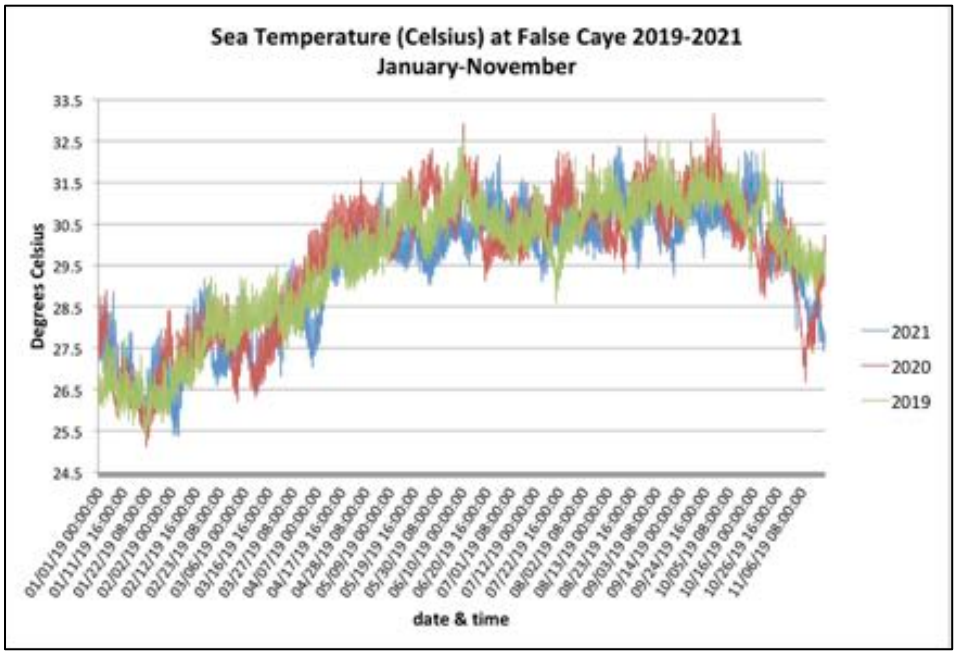


Fig. 13a. Temperature data at near shore False Caye January-November 2019-2021 reflects relatively lower temperatures in 2021 (blue), although there were some spikes evident in July (when Belize had bleaching alerts from NOAA's coral watch) and late October.

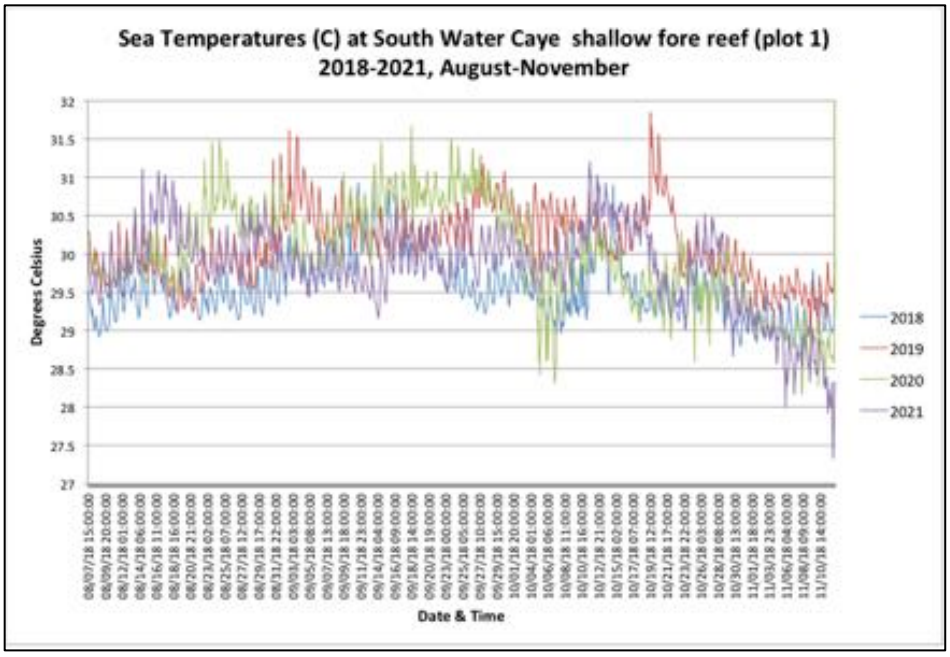


Fig. 13b. In situ temperature data from the shallow (~5m) fore reef at South Water Caye, August-November, 2018-2021 which corresponds to "SWC" or "SWC shallow" in graphs and maps; this is an outplant site (SWC plot 1 in MCCAP and SCTLD reports).

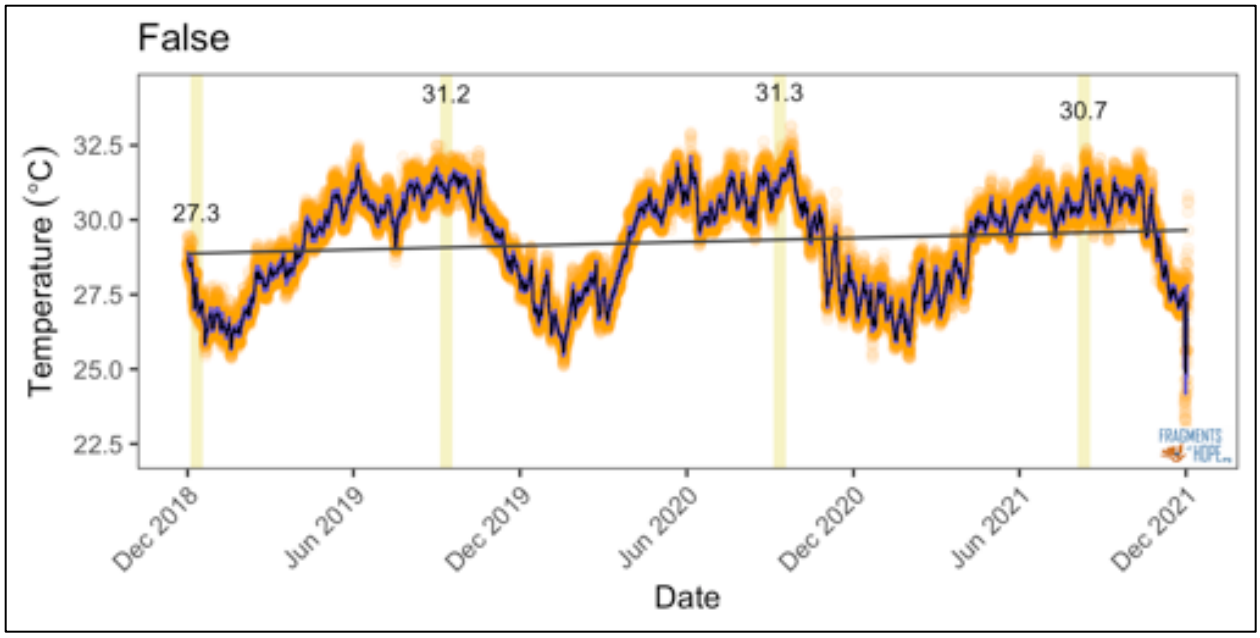


Fig. 13c. False Caye in situ temperature data from December 2018-December 2021. The orange circles are the individual observations, the blue/purple ribbon is the 95% CI, and the black line is the mean. Trend line also in black. The numbers above the vertical lines are the yearly means.

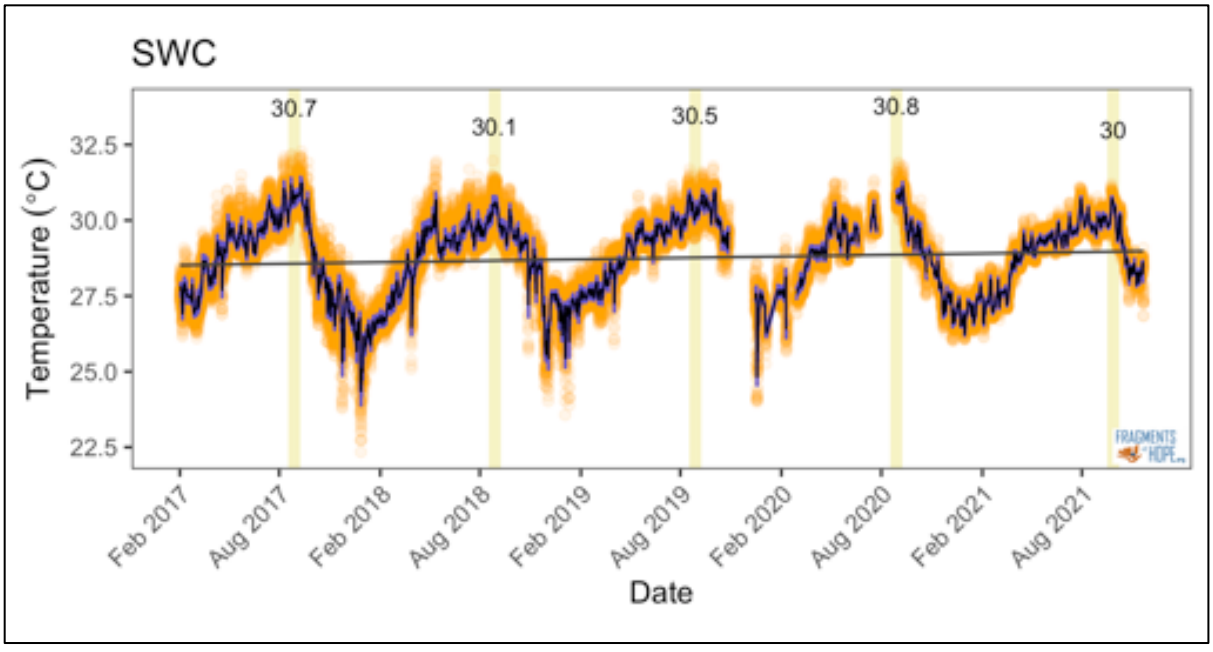


Fig. 13d. South Water Caye (SWC) in situ temperature data from February-August only, 2017-2021. The orange circles are the individual observations, the blue/purple ribbon is the 95% CI, and the black line is the mean. Trend line also in black. The numbers above the vertical lines are the yearly means.

SCTLD in 2021

Following the trial application of CoreRx and antibiotic, the National Coral Reef Monitoring Network (NCRMN) of Belize received approval to scale up treatment efforts. The project has purchased 20kg of CoreRx and the necessary ratio of antibiotic and treatment material is stored at the Belize Fisheries Department. The national plan has been updated with a treatment guideline that details site and colony selection, treatment mixing and application, thresholds for treatment as well as reporting (Annex I). Because SCTLD was reported in SWCMR mid-2021, a training session was completed on September 28th, 2021 in South Water Caye Marine Reserve that has prepared 11 participants from the Belize Fisheries Department (BFD) and Fragments of Hope (FoH) to treat affected corals in the Southern Reefs of Belize (Figs. 14a-d, 15a). A second training workshop was held 11 & 12 November 2021 near Belize City with eight participants from four Marine Protected Areas co-management NGOs, the University of Belize (UB) and the Coastal Zone Management Authority and Institute (CZMAI) see Figures 15c-d. As of December 2021, a total of 53 corals have been treated in northern Belize at Goff's Caye, and a total of 72 corals have been treated at four sites in South Water Caye Marine Reserve (SWMCR). A smaller sub-set of corals in each location has been re-treated (2nd application) based on date(s) of first treatments and weather.

Although the number of corals with second or third treatment was small in 2021, primarily due to only receiving treatment in November, then poor weather and holidays in December 2021, follow up rapid assessment (200 corals) surveys were done on several sites and the data from one fore reef site (30-50ft) at SWC (Wypt 16) across four months is shown in Figure 16a. The prevalence of SCTLD at this site progressed from 2.5% to 15% July-November 2021.

Figure 16b and Table III are data shared by Patricia Kramer from the AGRRA.org database for 2021; 70 detailed surveys were submitted in 2021, 36 by FoH. Figure 16b is a map of the submitted surveys showing presence (red), absence (green), possible (yellow) or pending confirmation (purple) of SCTLD reports. NOTE: the map does not include the northern MPAs (BCMR, HCMR and CCMR) where SCTLD was first reported and we know SCTLD to still be present in these MPAs. Fig 16c is the map of all SCTLD reports since 2019, country wide. Table III details the health of over 10,000 corals surveyed in Belize by species.

Figs. 14a-b. Participants at the 28 Sep2021 SCTLD treatment training at Tobacco Caye in South Water Caye Marine Reserve.

Figs. 14c-d. Examples of tagged, treated corals from the 28 Sept 2021 SCTLD treatment training in SWCMR.

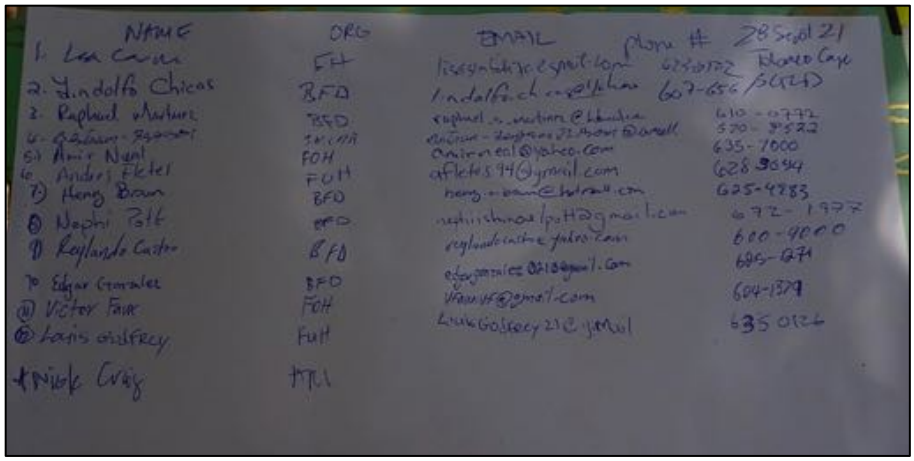


Fig. 15a. Attendance sheet for the 28 Sept2021 SCTLD treatment training with BFD and FoH participants.

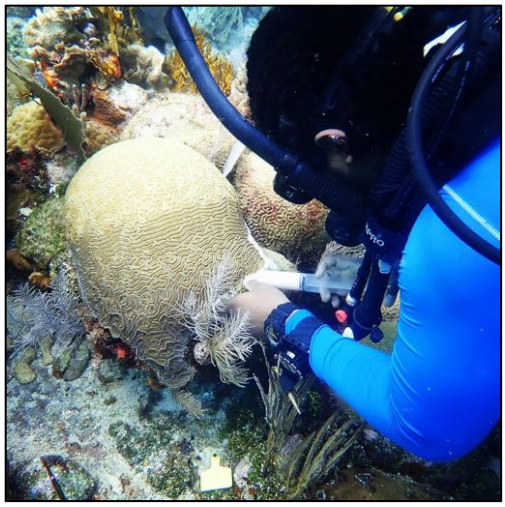
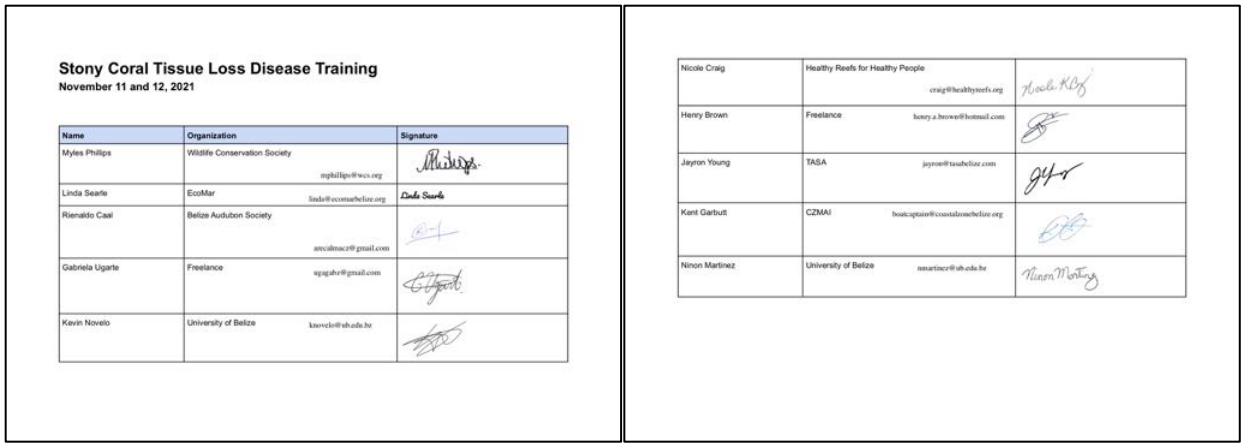


Fig. 15b. Photo from the November training workshop at Goff's Caye.



Stony Coral Tissue Loss Disease Training
November 11 and 12, 2021

Name	Organization	Signature
Myles Phillips	Wildlife Conservation Society mphillips@wcs.org	
Linda Searle	EcoMar linda@ecomarbelize.org	Linda Searle
Rienaldo Caal	Belize Audubon Society arecalmacr@gmail.com	
Gabriela Ugarte	Freelance sgugabr@gmail.com	
Kevin Novelo	University of Belize knovelo@ub.edu.bz	

Nicole Craig	Healthy Reefs for Healthy People craig@healthyreefs.org	
Henry Brown	Freelance henry.a.brown@hotmail.com	
Jayron Young	TASA jayron@tasabelize.com	
Kent Garbutt	CZMAI boatcaptain@coastalzonebelize.org	
Ninon Martinez	University of Belize nmartinez@ub.edu.bz	

Figs. 15c-d. Attendance sheet for training held at Goff's Caye in Northern Belize 11 and 12 November 2021.

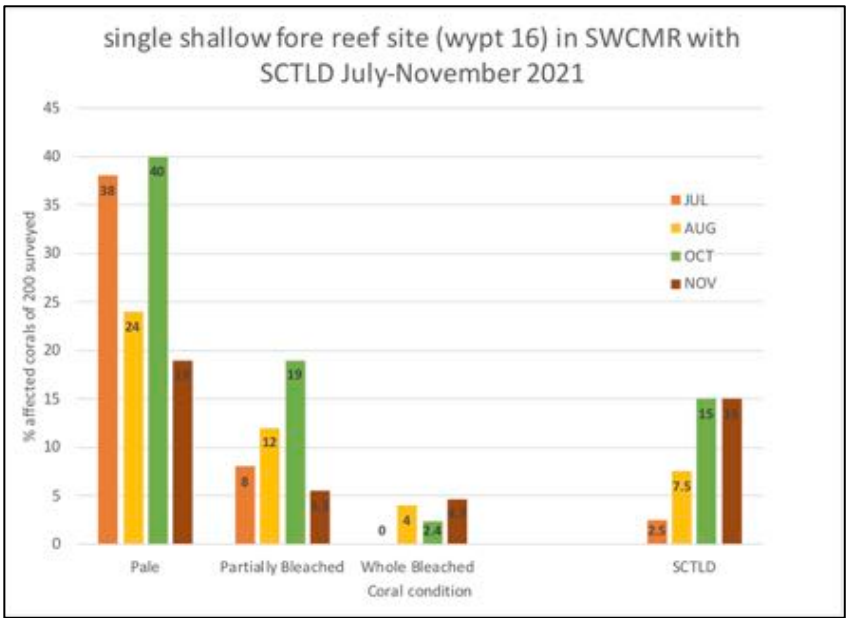


Fig. 16a. Example of follow up (July- November 2021) SCTLD (and bleaching) survey data at single shallow (30-50ft) fore reef site (WyPt 16) in South Water Caye Marine Reserve-using the rapid swim bar drop method, 200 corals per site.

Fig. 16b-c. Presence of SCTLD in Belize in 2021 (left). Map is courtesy Patricia Kramer from aggra.org site/database. Purple is submissions under review, yellow is maybe SCTLD, red is present and green is absent. Note these data are from 2021 and the map does not include BCMR, HCMR or CCMR, where we know SCTLD to still be present. The map on the right shows all SCTLD reports since 2019.

Table III. Coral colony summary from AGRRA data base detailed surveys entered in 2021: A total of 70 detailed surveys including 10,411 coral colonies were submitted (SCTLD and bleaching), 36 surveys were completed by FoH and the eight completed by WCS were entered by FoH.

Coral Species	# of Healthy Colonies	# of Colonies with Only SCTLD	# of Colonies with other Disease(s)	# of Fully Bleached Colonies	# of Partially Bleached Colonies	# of Pale Colonies	# of Colonies with SCTLD + Fully Bleached	# of Colonies with SCTLD + Partially Bleached	# of Colonies with SCTLD + Paling	# of Recently Fully Dead Colonies	Total
ACER	108	0	3	3	5	18	0	0	0	0	137
APAL	105	0	0	0	10	13	0	0	0	0	128
APRO	19	0	0	0	0	1	0	0	0	0	20
AAGA	923	52	0	7	47	88	0	0	0	0	1117
ALAM	12	6	0	0	19	36	0	0	0	0	73
ATEN	251	0	0	4	106	110	0	0	0	0	471
CNAT	147	21	0	7	18	81	0	0	0	1	275
DCYL	12	5	0	0	0	2	0	0	0	0	19
DSTO	45	4	0	0	8	8	0	1	1	0	67
DLAB	117	23	2	1	9	106	0	1	0	0	259
EFAS	50	1	0	1	9	32	0	0	0	0	93
MAUR	23	0	0	0	1	28	0	0	0	0	52
MDEC	70	0	0	3	5	5	0	0	0	0	83
MARE	5	0	0	0	0	1	0	0	0	0	6
MIAC	13	0	0	0	2	2	0	0	0	0	17
MMEA	67	53	0	6	9	67	0	0	0	4	206
MCAV	2	0	0	0	0	0	0	0	0	0	2
MANG	436	32	0	4	14	170	0	1	1	0	658
MLAM	47	1	0	0	5	17	0	0	0	0	70
OANN	548	28	2	7	44	167	0	0	0	0	796
OFAV	242	11	0	2	25	134	0	0	0	0	414
OFRA	250	82	1	2	88	44	0	0	0	0	467
PAST	1315	6	0	2	49	288	0	0	0	0	1660
PDIV	6	0	0	1	0	0	0	0	0	0	7
PPOR	354	2	0	4	58	93	0	0	0	0	511
PCLI	31	1	0	0	8	35	0	0	0	0	75
PSTR	412	76	1	2	32	354	0	1	1	2	881
SSID	460	26	18	125	276	667	0	2	4	0	1578
SINT	123	0	3	4	41	96	0	0	0	0	267
Total	6193	430	30	185	888	2663	0	6	9	7	10411

Discussion, Recommendations and Future Plans

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. With UNEP funding the replenishment work will continue in the northern MPAs in 2022. Much of Belize still has large healthy acropora stands, and since less than 10% of a large stand can easily be transplanted to identified replenishment plots, nurseries are really only now needed for demonstration purposes and growth rate comparisons. Each replenishment plot should have ~four-six different genets of each species[11] to ensure sexual reproduction and adaptation capabilities.

The long term data shared from both diver-based photomosaics and the change detection data using drone ortho-mosaics for LBCNP and natural stands, illustrates well the importance of site and coral selections for 'rewilding' these populations versus simply putting out as much corals as possible-with minimal efforts and patience, given the right sites and corals, nature can rebound. FoH should work with the NCRMN to create national acroporid restoration strategy, and work with government to create a MOU since many new groups are attempting restoration

[11] https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/eap.1978

projects. Future plans include trialing the SECORE methodology of capturing and rearing coral larvae, and continued training workshops for Belizeans.

Drone use will continue yearly to detect and quantify changes in coral cover over a larger scale than diver-based mosaics, on both natural and replenished stand/sites. A key future indicator is at what size/age the elkhorn micro fragments will be detected by the drone orthomosaics. Figure 17 is the lessons learned slide shared at the virtual REEF Future conference in 2021. FoH continues to explore methods to link shallow restoration efforts with shore line protection.

Regarding dredging/mangrove removal/developments on the Placencia peninsula and near by cayes, FoH plans to create a map of all sites reported since 2018, and hopes to work with government to create maps of approved projects in the Stann Creek District, and a user friendly reporting form for citizen reports.

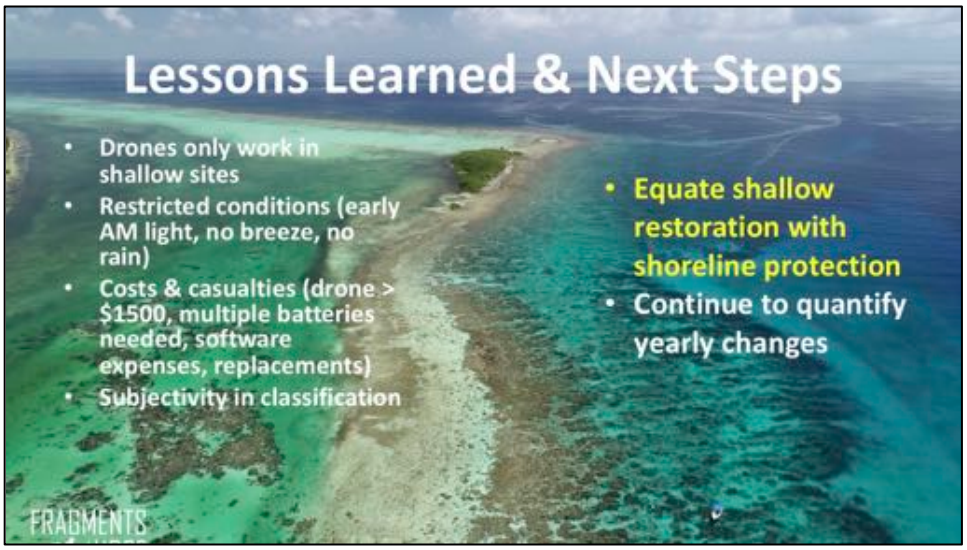


Fig. 17. Lessons learned from drone work, shared at REEF Futures in 2021.

For SCTLD, FoH will continue to partner with relevant organizations and departments for treatment, and to explore the idea of involving the private sector for aid in reporting and possible treating SCTLD. Bleaching surveys will continue each year.

By the end of 2022, FoH hopes to create a type of map with all collaborations, projects and products or results.

Bibliography

Aronson R, Bruckner A, Moore J, Precht B, Weil E (2008) *Acropora cervicornis*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>

Baums, I. B., A. C. Baker, S. W. Davies, A. G. Grottoli, C. D. Kenkel, S. A. Kitchen,I. B. Kuffner, T. C. LaJeunesse, M. V. Matz, M. W. Miller, J. E. Parkinson, and A. A. Shantz.2019. Considerations for maximizing the adaptive potential of restored coral populations in the western Atlantic. Ecological Applications 29(8):e01978. 10.1002/eap.1978

Carne L, Kaufman L, Scavo K (2016) Measuring success for Caribbean acroporid restoration: key results from ten years of work in southern Belize, Proceedings of the 13th International Coral Reef Symposium, Honolulu, HI, 19th - 24th June, 2016: pp. 342-358.

Kitchen, S.A., Von Kuster, G., Kuntz, K.L.V. *et al.* STAGdb: a 30K SNP genotyping array and Science Gateway for *Acropora* corals and their dinoflagellate symbionts. *Sci Rep* **10,** 12488 (2020). https://doi.org/10.1038/s41598-020-69101-z

Griffin S, Moore T, Nemeth M, Gleason ACR Gintert B (2016) Using photo mosaics to monitor Acropora cervicornis thickets created by outplanting nursery-grown corals. Proceedings of the 13th International Coral Reef Symposium, Honolulu, HI, 19th - 24th June, 2016: pp. 315-328.

Gleason ACR, Lirman D, Williams DE, Gracias NR, Gintert BE, Madjidi H, Reid RP, Boynton GC, Negahdaripour S, Miller MW, Kramer P (2007) Documenting hurricane impacts on coral reefs using two dimensional video-mosaic technology. Marine Ecology 28: 254-258.

Lirman D, Gracias NR, Gintert BE, Gleason ACR, Reid RP, Negahdaripour S, Kramer P (2007) Development and application of a video-mosaic survey technology to document the status of coral reef communities. Environmental Monitoring and Assessment 125: 59-73.

Rinkevich B (2014) Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? Current Opinion in Environmental Sustainability (7): 28-36