Summary of coral bleaching events in Belize
2017-2019

Repopulate Reefs within Replenishment Zones of Turneffe Atoll Marine Reserve and South Water Caye Marine Reserve with Temperature Resilient Coral Varieties

MCCAP
BELIZE MARINE CONSERVATION & CLIMATE ADAPTATION PROJECT

ADAPTATION FUND

WORLD BANK GROUP

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Table of Contents

Executive Summary

The bleaching event in 2017 was remarkable for its severity, not only for Belize but for all of Mesoamerican reefs. Under MCCAP, Fragments of Hope (FoH) expanded reef restoration efforts to South Water Caye and Turneffe Atoll Marine Reserves (SWCMR, TAMR) including the use of *in situ* temperature loggers on nursery and some outplant sites (N=5, 2017-2019), but also continued to collect temperature data at seven other sites in southern Belize-two beginning 2015 and four beginning 2009 with a near shore site added in 2017. FoH has been collecting bleaching survey data in southern sites since 2008 (method from McField, 1999) and included five sites in SWCMR 2017-2019, and one site in TAMR 2017. In 2017, with additional external funding from MPA Connect, Gulf and Caribbean Fisheries Institute (GCFI) and the NOAA Coral Reef Conservation Program, FoH also assisted in surveying five sites in the Port of Honduras Marine Reserve (2017-2018) in partnership with the Toledo Institute for Development and Environment (TIDE). Bleaching data was collected nationwide in 2017 via the National Coral Reef Monitoring Network (NCRMN) whose members include co-managers for Belize's Marine Protected Areas (MPAs), The Belize Fisheries Department (BFD), the University of Belize (UB), and FoH. Not since 2008-2010 had the national bleaching data been coordinated and collected; this information was shared regionally at the 71st GCFI conference held in San Andrés, Colombia, November 2018 and again locally at the University of Belize's 12th Natural Resource Management Symposium in May 2019. FoH created a short video summarizing these results and methods used, while also highlighting the emergence of the Stony Coral Tissue Loss Disease (SCTLD) shared on social media, the FoH website and YouTube channel. While 2018 was a mild to no bleaching year for Belize, the 2019 bleaching event surpassed 2017 in severeity and was also unique in the late-year temperature spikes (October as opposed to August or Sepember) causing the bleaching event to last through January 2020 in many sites. This report details the 2017 and 2019 bleaching events in Belize and highlights the following trends directly related to acroporid restoration efforts: 1) the acroporids are no longer indicator coral species for bleaching but instead are proving most resistant and resilient to elevated temperatures, north to south in Belize, and 2) bleaching has been most severe on off shore and deeper reef sites, suggesting that near shore shallow sites now have some inherent thermal tolerance.

1.0 Project Justification

Climate change is believed by the majority of marine scientists to be the most serious threat to corals and their ecosystems today (Aronson and Precht 2006; Baird et al. 2009; Hoegh-Guldberg and Bruno 2010; Lesser 2011), with global warming causing increased severity and frequency of bleaching and coral mortality (Hoegh-Guldberg et al. 2007). Coral reefs are generally recognized as the most vulnerable of the planet's ecosystems to the impacts of climate change (Donner *et al*. 2005). An estimated 19% of the world's coral reefs have been lost and a further 35% are seriously threatened (Wilkinson and Souter 2008), and one-third of all reef-building corals are considered to be at risk of extinction (Carpenter *et al*. 2008). Some authors estimate 60% of all live corals could be lost by 2030 and state that current management practices must undergo radical changes to become effective (Hughes *et al*. 2003).

Widespread coral loss due to thermal stress and mass bleaching has already occurred (Hoegh-Guldberg *et al.* 2007) and Caribbean reefs are particularly impacted, with lower coral cover presently than at any time in geological history (Greenstein *et al.* 1998). The Caribbean as a whole has lost an average of 40% of its absolute live coral cover since the late 1970's (Gardner *et al.* 2003) and most of this is accounted for by the wide-spread loss of two Caribbean acroporids, *Acropora cervicornis* (Lamarck 1816) and *A. palmata* (Lamarck 1816), whose mass mortality is attributed to hurricanes, bleaching and disease (Aronson and Precht 2001; Bruckner 2003). These two species are the fastest growing, main reef building species in the Caribbean, previously dominating both the shallow and intermediate depths; their combined abundance has been reduced by more than 95% Caribbean-wide and they were placed on the IUCN's Red List in 2008 as Critically Endangered, one step away from Extinction in the Wild (Aronson et al. 2008).

In Belize, coral reefs were valued for their ecosystem services (shoreline protection, nursery habitat and aesthetic/tourism value) at over US$370million/year (Cooper *et al.* 2008). The national average coral cover is currently just 15%, yet both Turneffe Atoll and South Water Caye Marine Reserve are labeled as "poor" with coral cover between 5-9% (Kramer *et al.* 2015).

The most widely recognized climate change adaptation option for coral reefs is to increase coral reef health through the management of local stresses such as pollution, sedimentation, and overfishing (Buddemeier *et al*. 2004). But with ongoing work at Laughing Bird Caye National Park (LBCNP) in southern Belize since 2006, an additional option has been explored and now validated: the identification and propagation of bleaching resistant and/or resilient corals, their cultivation into second/third generation fragments, followed by transplantation to reefs where thermal stress has decimated coral cover (Carne 2008, 2011; Bowden-Kerby and Carne 2012). Restoration techniques have recently become more accepted as conservation tools in recognition of such rapid and continued reef degradation (Jaap 2000; Rinkevich 2005; Baums 2008; Baums et al. 2010; Lirman *et al*. 2010; Johnson *et al*. 2011; Young et al. 2012; Rinkevich 2014).

Belize, under the leadership of the Ministry of Forestry, Fisheries and Sustainable Development (MFFSD) with fiduciary management assistance from the Protected Areas Conservation Trust (PACT) as the National Implementing Entity (NIE) and the World Bank as Multilateral Implementing Entity (MIE), is responsible for the implementation of the Marine Conservation and Climate Change Adaptation Project (MCCAP) in the coastal areas of Belize. The Project Implementing Agency Group (PIAG) housed within the Fisheries Department and staffed by full-time and part-time consultants is responsible for the coordinating MCCAP implementation. The PIAG consists of a Project Coordinator (PC), a Senior Technical Officer (STO), staff from Fisheries Department, and fiduciary staff of PACT.

MCCAP is a five year project designed to implement a priority ecosystem-based marine conservation and climate adaptation measures to strengthen the climate resilience of the Belize Barrier Reef System and its productive marine resources. Specifically, the project will support:

i. Improvement of the reef's protection regime including an expansion and enforcement of the Marine Protected Areas (MPAs) and Replenishment (no-take) Zones in strategically selected locations to strengthen climate resilience,
ii. Promotion of sustainable alternative livelihoods for affected users of the reef, and
iii. Building local capacity and raising awareness regarding the overall health of the reef ecosystem and the climate resilience of coral reefs.

MCCAP will benefit three Marine Protected Areas (MPAs), namely, the Corozal Bay Wildlife Sanctuary (CBWS), the Turneffe Atoll Marine Reserve (TAMR), and the South Water Caye Marine Reserve (SWCMR). These MPAs are fished by fishermen mainly from 12 coastal communities, namely: 1) Consejo Village, 2) Corozal Town, 3) Copper Bank Village, 4) Chunox Village, 5) Sarteneja Village, 6) Belize City, 7) Dangriga Town, 8) Hopkins Village, 9) Sittee River Village, 10) Riversdale Village, 11) Seine Bight Village, and 12) Placencia Village.

The Belize Marine Conservation and Climate Adaptation Project (MCCAP) has developed a programme to conduct pilot investments into repopulating reefs within replenishment zones of Turneffe Atoll Marine Reserve (TAMR) and South Water Caye Marine Reserve (SWCMR) with temperature resilient coral varieties to support climate change adaptation measures that will improve the resilience of the reef. MCCAP contracted Fragments of Hope, Ltd., to implement the reef restoration activities in TAMR and SWCMR (Sub-Component 1.2.3), and by extension to expand the reef restoration programme in Belize. With financing from the Adapation Fund, these activites will also compliment other tasks under Component 1, such as field verification of spatial mapping activities via ground-truthing and carrying out stakeholder consultations (Sub-Component 1.2.1), and biological and water quality (temperature) monitoring of strategic and control sites (Sub-Component 1.2.2). Additionally Fragments of Hope will add to the project outcomes under Component 3, Raising Awareness and Building Local Capacity through Project Information Dissemination (Sub-Component 3.2.3) and Community Training Events (Sub-Component 3.2.4).

Fragments of Hope has increased live coral cover at LBCNP from just 6% to over 35% by out-planting nursery-reared acroporids from 2010-2016 in ~ one hectare of degraded reef, and is an international example of effective reef ecosystem restoration. Fragments of Hope has established replicable methodologies for mapping, genetics, outplanting and most importantly, created quantifiable success indicators for evaluating the replenishment process. This document outlines in detail the steps necessary to expand the reef repopulation success to Turneffe Atoll and South Water Caye Marine Reserve through 2020.

1.1.1 Objectives (from ToR)

The objective of this consultancy is to support the implementation and expansion of propagation and restoration practices in TAMR and SWCMR of Belize. The firm is expected to contribute to information dissemination activities of MCCAP under component 3.

1.1.2 Tasks, Activites and Outputs (from ToR)

Task 1: Initial project start-up

1. Organize briefing with PIAG staff, FD, and PACT to: (1) define the sub-project scope and activities; and (2) develop and finalize work-plan and consultation schedule.

2. Submit sub-project proposal/activities to the Department of the Environment (DOE) for environmental screening of the project.

3. Review the literature on coral reef propagation and restoration practices, review proposed MPA replenishment Zone maps/documents, and conduct initial consultations with key stakeholders to discuss the sub-project.

4. Prepare inception report, including detailed implementation plan, time-frame, and DOE report.

Task 1 **Expected Outputs**:

- **Inception report** (methodology, work plan, implementation schedule, outcome of initial consultation meetings) on how the Consultancy will be accomplished.

Task 2: Identification of reefs suitable for nurseries set-up and out-planting

5. Organize and facilitate community consultations on potential areas for nursery set-up and out-planting sites (where human activity can be managed).

6. Training event (3 days) in coral restoration skills for potential reef restoration assistance.

7. Ground-truth potential sites in TAMR and SWCMR with the participation of MPA staff.

8. Collect GPS coordinates of large Acropora stands and develop larvae dispersal map.

9. Assess genome-wide adaptive trait variance in corals

10. Prepare report on suitable sites for nursery set-up and out-planting and submit to the PIAG for review.

Task 2 **Expected Outputs**:

- Areas at TAMR and SWCMR identified as suitable for nurseries set-up and out-planting
- Maps generated showing distribution and abundance of these critical endangered coral species in the targeted MPAs.
- Monthly progress reports.
- Technical report on suitable coral nurseries and out-planting sites submitted to the PIAG.

Task 3: Establishment of coral nurseries within TAMR and SWCMR

11. Undertake the construction on nurseries within selected sites.
12. Train MPA staff and fishers to construct, install, and monitor/maintain nursery tables at sea
13 Monitor/maintain and document coral nurseries.
14 Prepare report on established coral nurseries.

Task 3 **Expected Outputs**:

- At least six coral nursery tables constructed per MPA (or as required), in accordance to findings from the ground-truthing efforts.
- Monthly progress reports (Keep record on identified challenges, limitations, threats-for coral growth)
- Technical report on established coral nurseries submitted to the PIAG for review.

Task 4: Out-planting of selected reefs

15. Undertake reef propagation in selected sites in the marine protected area of TAMR and SWCMR.

16. Conduct and facilitate training events/workshops for MPA staff, fishers, diving centres, and other MPA co-managers.

17. Conduct biodiversity analysis (as required) including potential predators.

18. Monitor and document out-planting progress (including survival rates, growth rates, colonization of the selected site by fish and invertebrates).

19. Prepare report on reef propagation in TAMR and SWCMR

Task 4 **Expected Outputs:**

- At least three restored coral sites, with resilient varieties grown in coral nurseries, within TAMR and SWCMR by the end of the project, with each site measuring 300 m^2.

- Monthly progress reports
- Technical report on coral out-planting at selected sites submitted to the PIAG for review
- MPA staff and fishermen trained to enable their routine construction, monitoring of corals within nurseries, and tracking the health status of out-planted corals as well as progress towards the building of reef resilience.
- The transfer of knowledge on successful propagation techniques and lessons learnt.
- Expansion of coral reef propagation work in Belize

Task 5: Education and dissemination

20. Contribute to the information dissemination activities of MCCAP, under component 3

21. Conduct and facilitate national consultation with stakeholders, research institutions, fishers, etc., to showcase outputs of the project

22. Regional/international dissemination of information

Task 5 **Expected Outputs:**

- Increased awareness of reef restoration and preservation with focus on climate change adaptation benefits.

1.1.3 Details on *in situ* temperature and bleaching event 2017

Monitoring restoration work (outplants and nurseries) during June-November months includes collecting growth rate data, regular removal of algae from nurseries, monitoring for spawning[1] and watching for disease and bleaching. In 2017 Belize and Mesoamerica had a particularly severe bleaching event, so this and the temperature data are discussed primarily, followed by a discussion of mortality/survivorship in the nurseries.

The first bleaching event in Belize was recorded in 1995, and the first major global bleaching event, associated with massive mortality, was in 1998. Since then, researchers have predicted bleaching events could happen every eight-10 years, three-four years, and even annually. NOAA has since developed a sea surface temperature satellite based tool, that takes into account “degree heating weeks” which predicts bleaching events based on the amount of

[1] Spawning monitoring was conducted in 2017 at LBCNP with external (not MCCAP) funding, but data collected was shared with Dr. Paris for the larvae dispersal model, discussed in earlier section. All three nursery-grown acropora taxa did spawn in August at LBCNP.

time sea temperatures are higher than the averages, since bleaching is caused not just by high temperatures (there is no set threshold temperature) but also from duration of high tempertures and light intensity, both related to weather patterns. Coral diseases are also linked with elevated sea temperatures and/or bleaching events, and these two factors (bleaching and disease) are the main reasons for the massive loss of Caribbean acroporids in recent decades, and what placed them on the IUCN Red list in 2008 as 'critically endangered', one step away from extinct in the wild. The restoration work in southern Belize began in 2006, based on observation of surviving and/or recovering acroporid populations, and bleaching monitoring began in 2007 though present. Underwater temperature loggers were installed in six different locations in southern Belize in 2009, and have been retrieved and reset each year since (with some gaps at some sites where the logger was removed or lost). Temperature data from three sites in TAMR was also collected 2009-2010, but the loggers were not replaced due to that particular project ending. The loggers can be set at timed intervals, and after bleaching events in 2008 and 2010, the National Coral Reef Monitoring Network (NCRMN) decided on one-hour intervals as a national protocol, for ease of comparing data. During those years, there was external funding from The Nature Conservancy (TNC) , World Wildlife Fund (WWF) and Protected Areas Conservation Trust (PACT) for the NCRMN to conduct coordinated bleaching surveys, using a rapid assessment protocol developed by M. McField 1999. Each site has a minimum of 200 coral colonies surveyed, and bleaching is described as Pale (P), Partially Bleached (PB) or Wholly Bleached (WB) as outlined in the AGRRA protocol. If a colony is PB, the amount of the colony bleached is recorded (e.g. 5% , 50%, etc.). If disease is present, it is recorded, and if there is recent mortality that is also recorded as percentage of the whole colony.

FoH received reports and raw data from TIDE for PHMR, BAS for LHMR and UB for TAMR for bleaching monitoring in 2017. FoH collected bleaching data from SWCMR, GSSCMR, LBCNP and three southern Belize sites outside of MPAs. Although the same swim bar methodology is used thoughout Belize (McField, 1999, Searle et al., 2014), each MPA co-manager looked at their results in different ways, so FoH standardized the data to reflect percent bleaching (only partially bleached and wholly bleached corals) per site; each site represents a minimum of 200 coral colonies evaluated. Graphs and color coded maps could then be created to compare to historical bleaching data nationwide from 2008, and to other southern Belize sites for additional years. In the color coded maps below (Figs. 2a-b) , red is <40%, orange is 30-40%, yellow is 20-30%, light green is 10-20% and dark green is < 10% corals bleached. The 2008 map were created by WWF; shapefiles and data were provided to consultant Lynette Roth by FoH, and Ms. Roth provided the 2017-2019 maps to compare with historical data. The maps show three obvious results: 2017 was a more severe bleaching event than 2008; 2017 was also more consistently severe, north to south, than in 2008.

Lessons learned from previous years is that there are more susceptible coral species to bleaching, or indicator species, and these include the fire corals (*Millapora spp*.), finger corals (*Porities spp*. See Fig. 9b) and lettuce leaf corals (*Agaricia spp*.). Acroporids had previously been considered more susceptible to bleaching; however, the good news in 2017 is that with some exceptions, most acroporids proved resilient and/or resistant to bleaching. October is typically the 'peak' or most severe bleaching month for Belize; however bleaching observations began in September 2017. Figure 1a illustrates the maximum temperature data (degrees Celsius) for several sites, over several years (note only 2017 data available for SWC), and Figure 1b is a map of maximum temperatures for 2017 only. It must be noted that the Black Bird Caye data (BBC, pink) and the Tarpon data (orange) are the most shallow sites: 0.8m wheres the others are ~ 2m, and LBC is the deepest at ~4m. Figure 1c compares the 2017 SWC temperature data (black) to Silks (green), and LBC (red), and shows almost the exact same temperatures at SWC and Silks (see also Fig. 1b for similar latitude and maximum temperatures, also similar depths). Contrast this to Figure 8d, which compares the temperaure data at Black Bird Caye (BBC in red) backreef in TAMR (0.8m) with South Water Caye back reef temperature data (in black, 2m).

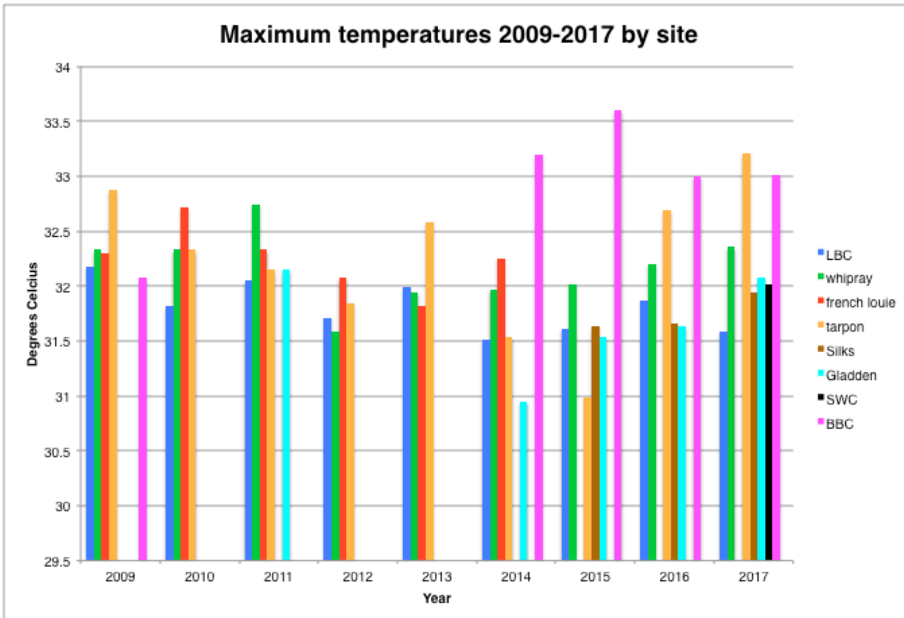

Fig. 1a. Maximum temperatures 2009-2017 for several sites: BBC=Black Bird Caye in TAMR.

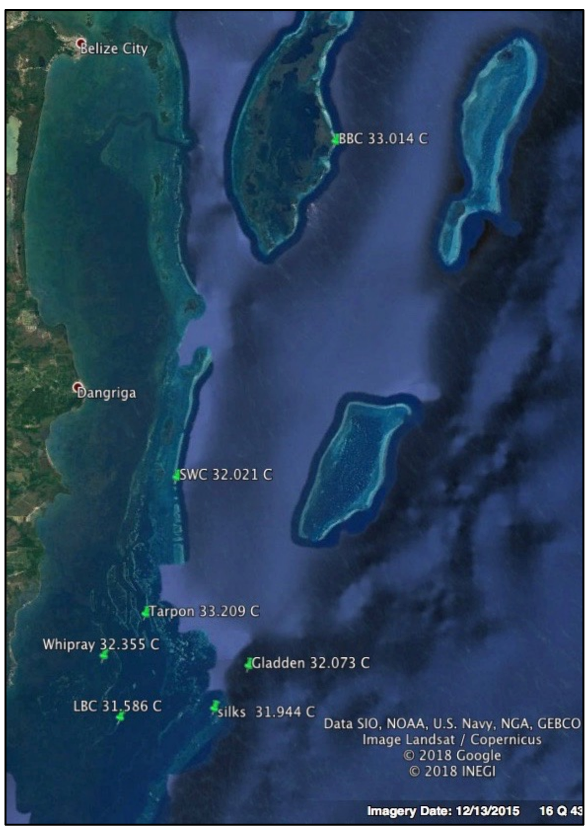

Fig. 1b. Maximum temperatures (Celsius) from north to south for 2017 only.

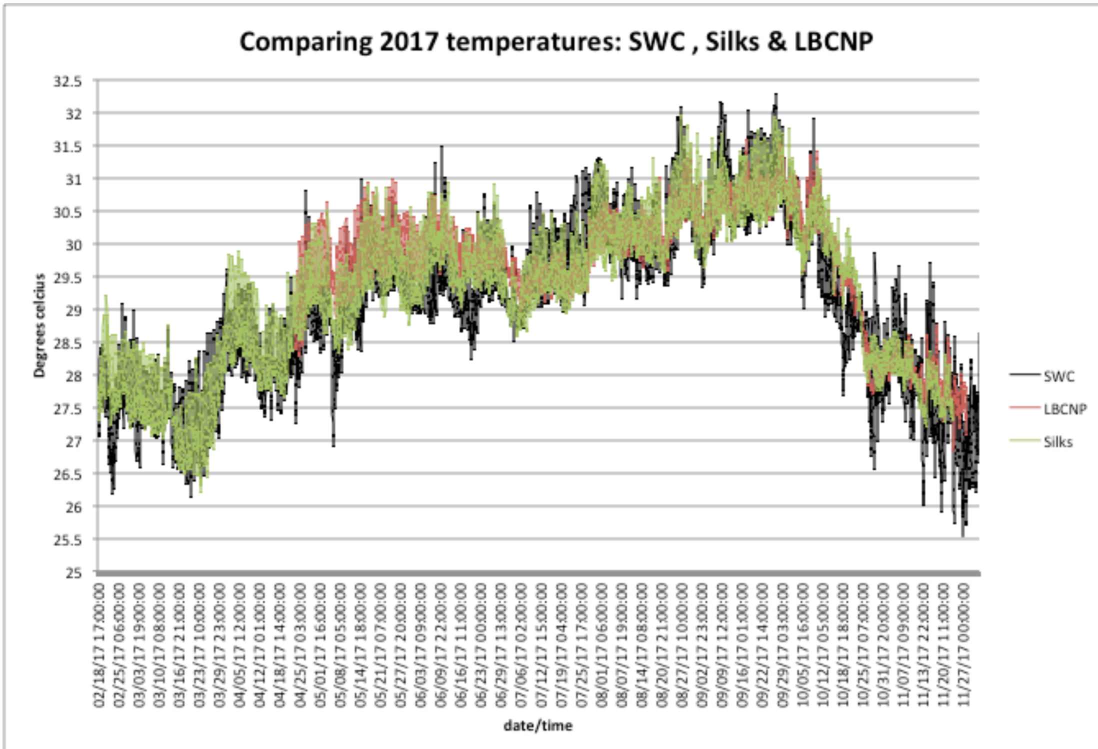

Fig. 1c. Comparing SWC (black) temperature data (C) to Silks (green) and LBCNP (red) for 2017.

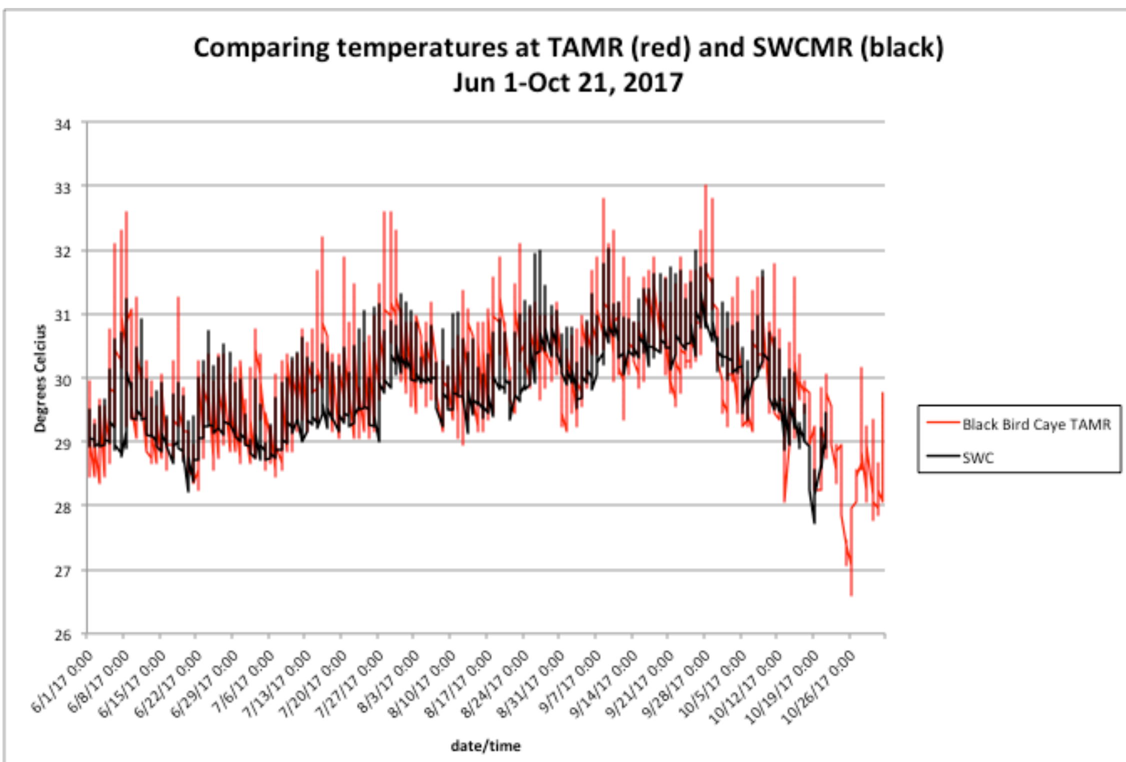

Fig. 1d. Comparing SWC (black) temperature data (C) to TAMR (Black Bird Caye, red) for 2017.

Bleaching surveys were conducted mostly in southern Belize, where there is historical bleaching data since 2008, but four sites were also surveyed in SWCMR and one in TAMR (Fig. 2a). In previous years, there has been varibility in the severity of bleaching: sometimes worse in the north, sometimes worse in the south. In 2017, bleaching was greater than 30% on all sites, north to south, but as in previous years, was more severe, in general, on the outer reef (most eastern) sites. Figure 2a shows a map of bleaching results from Ocotber 2008; compare to results in October 2017 (Fig 2b), using the same color codes: yellow =20-30%, orange= 30-40% and red=40-50% (of 200 corals surveyed in each site).

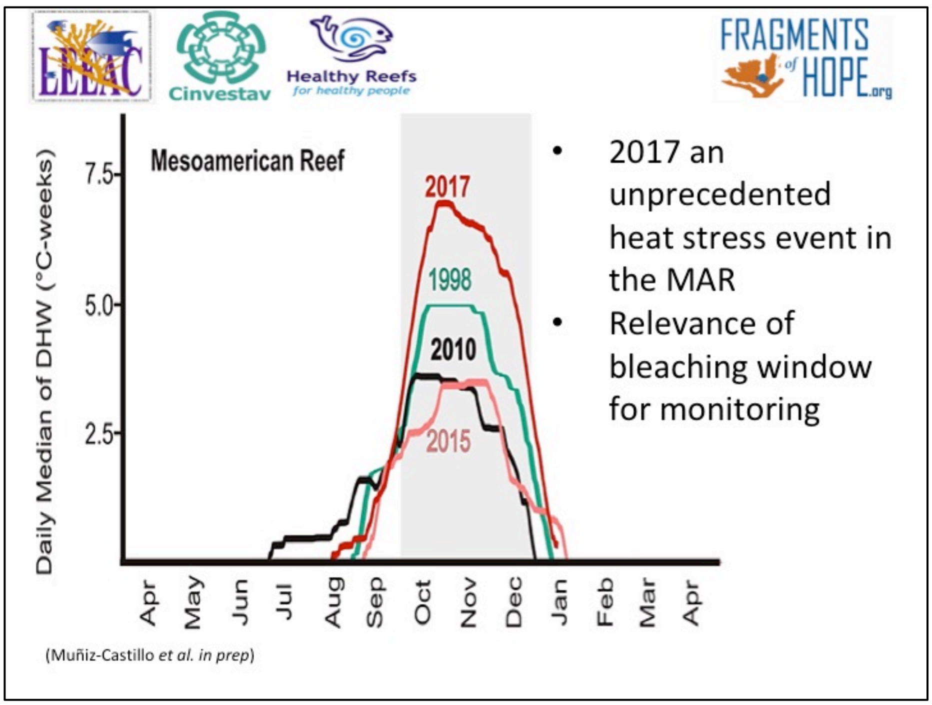

Fig. 1e. Degree Heating Weeks (DHW) mapped by years of bleaching events (1998, 2010, 2015, 2017) reflecting the recommended months for surveys, and also illustrating that 2017 was the most severe bleaching event for Mesoamerica to data. Graph/slide courtesy HRI partners in Mexico.

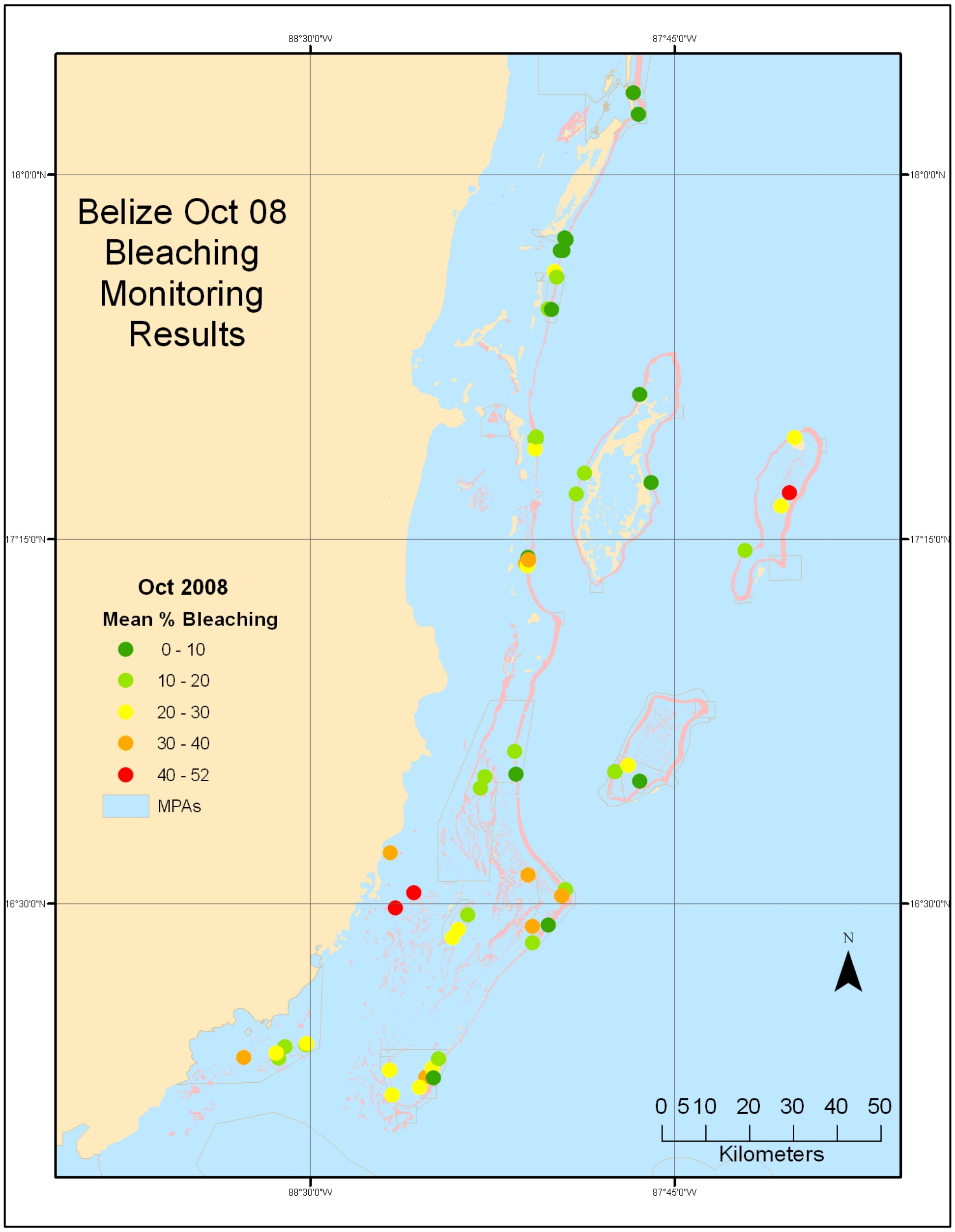

Fig. 2a. Map of bleaching severity in Belize, nationwide, October 2008. Red is <40%, orange is 30-40%, yellow is 20-30%, light green is 10-20% and dark green is < 10% corals bleached (PB and WH) of 200 surveyed. 2008 map courtesy WWF and all data from the NCRMN.

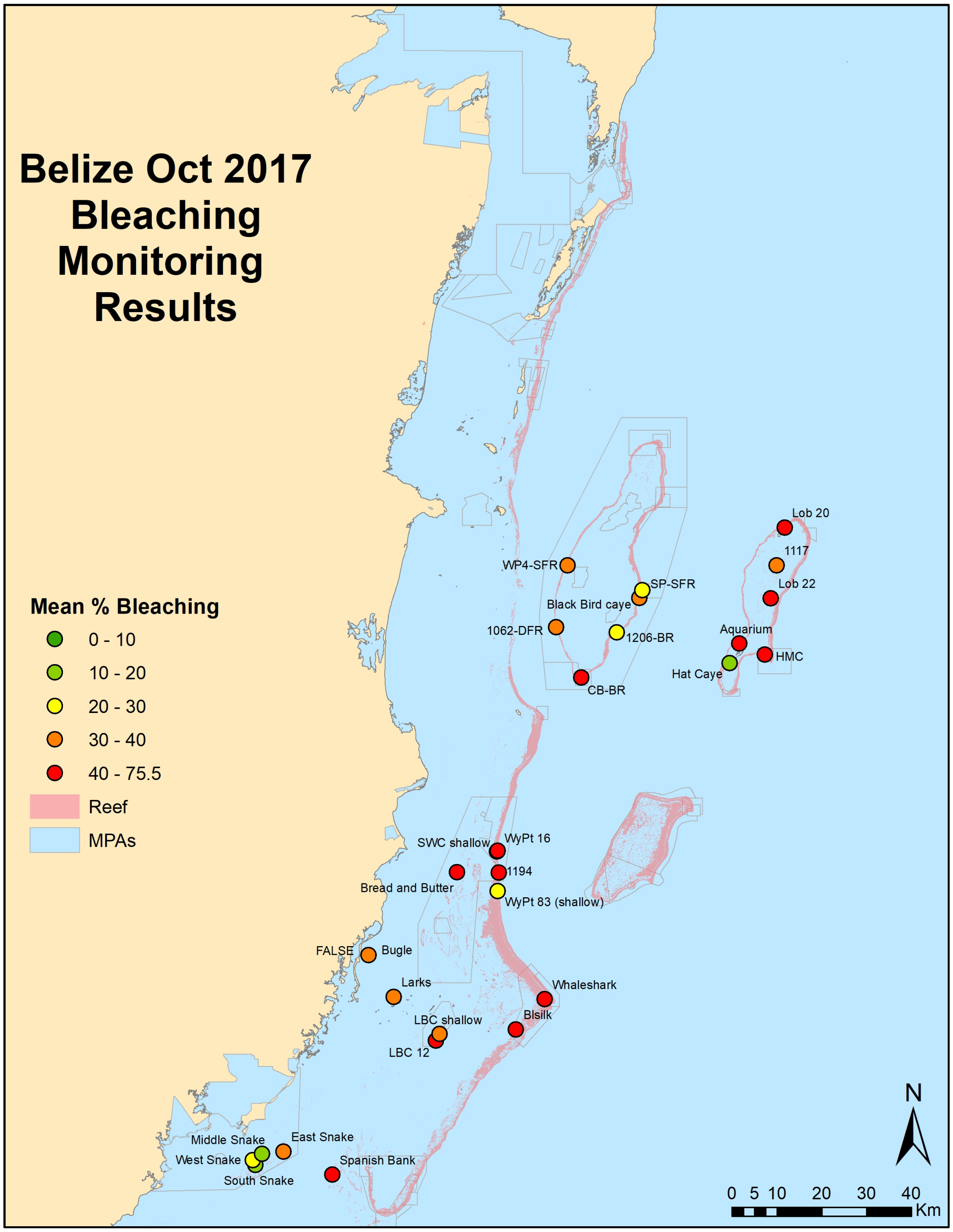

Fig. 2b. Map of bleaching severity in Belize, nationwide, October 2017. Red is <40%, orange is 30-40%, yellow is 20-30%, light green is 10-20% and dark green is < 10% corals bleached (PB and WH) of 200 surveyed. Map courtesy Lynette Roth.

Fig. 2c. Example of finger corals wholly bleached at TAMR (*P. porities*), and struggling *A. cervicornis.*

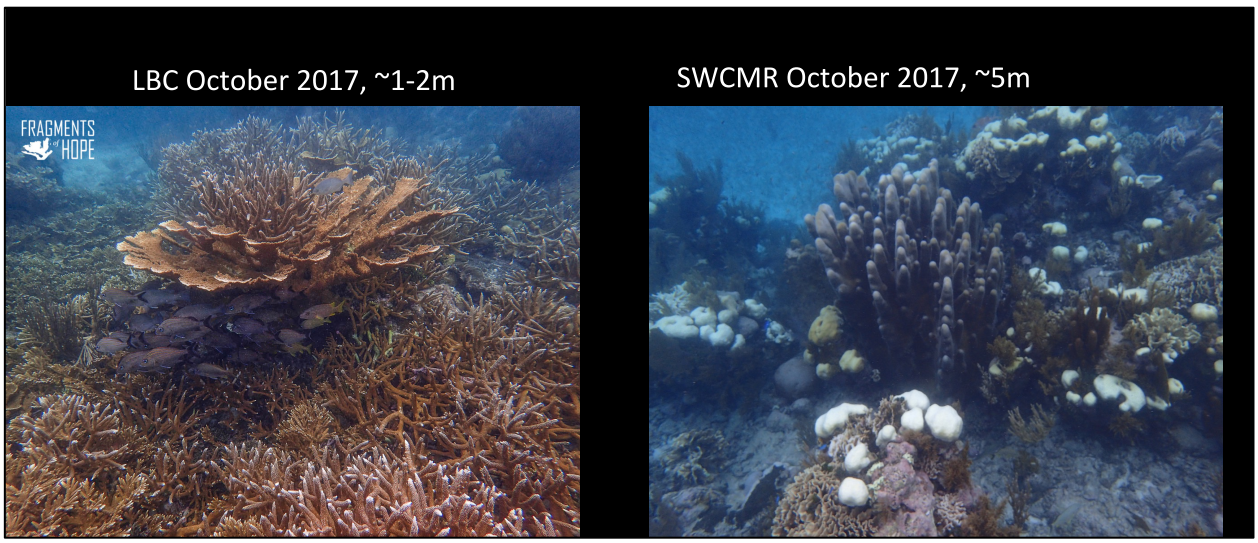

Fig. 2d. Nursery-grown acroporids outplanted at LBCNP (2m) in 2010 not bleaching versus wholly bleached *O. annularis* corals in SWCMR at 5m, both photos from October 2017.

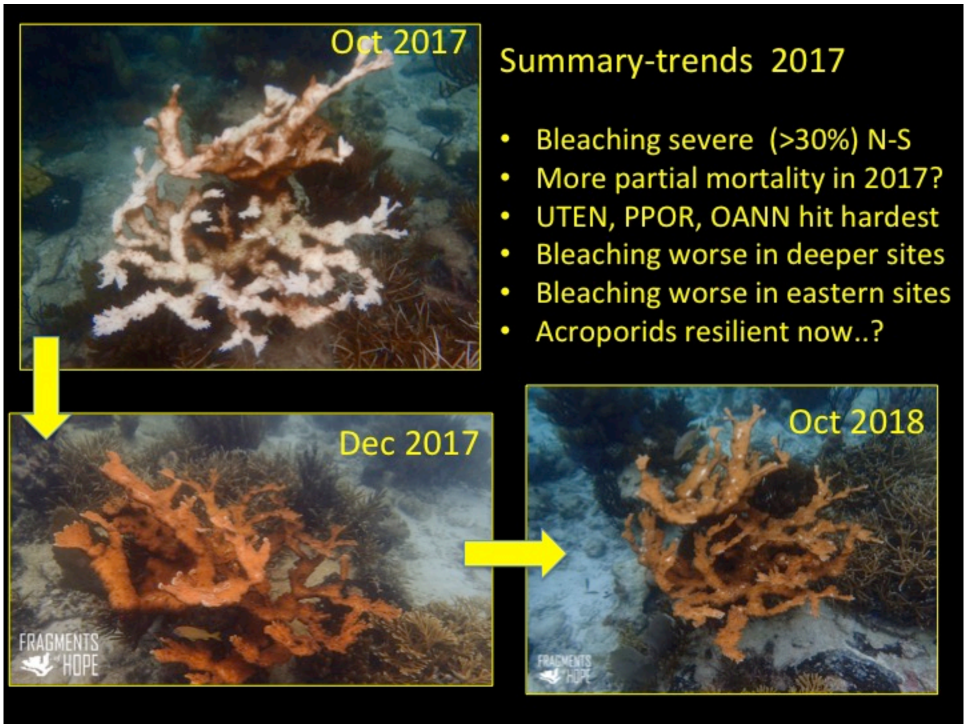

Fig. 2e. Example of resilient tranplanted acroporids at LBCNP; although they fully bleached (WH) in October 2017, they also fully recovered by December 2017 with no mortality.

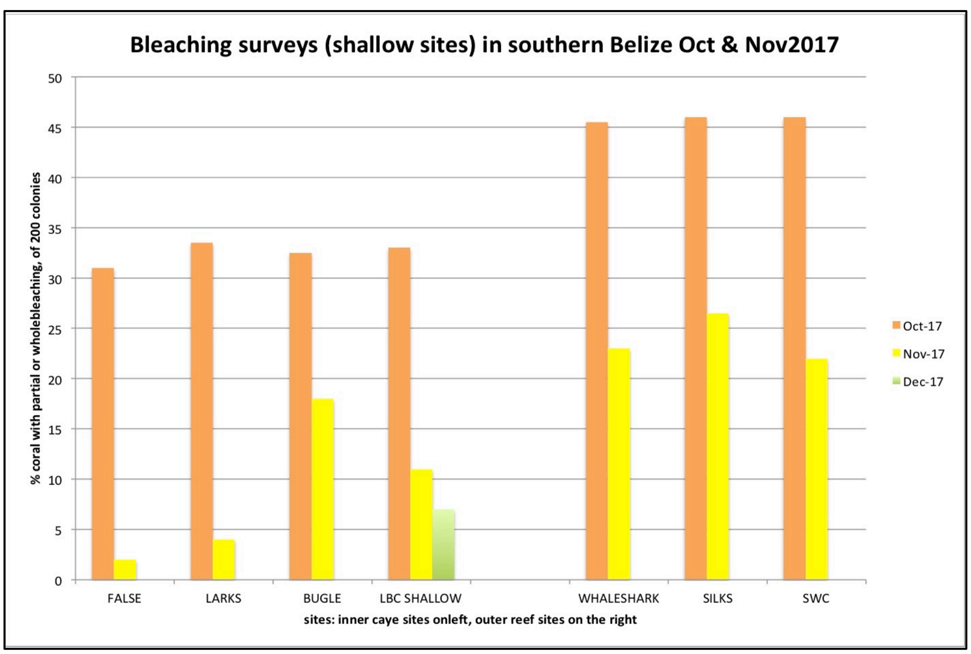

Fig. 2f. Results from bleaching surveys conducted in October and November 2017, with the outer reef (eastern sites) on the right.

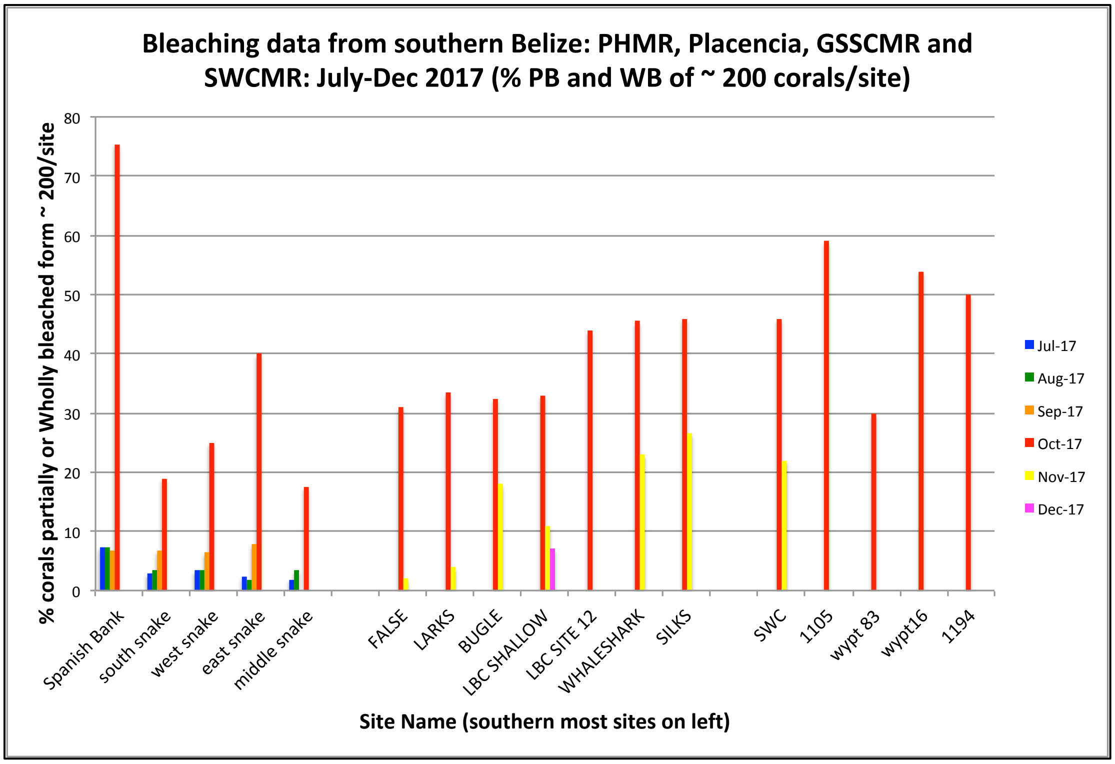

Fig. 2g. Results of several months of bleaching surveys in 2017 from PHMR (far right) up to Ocotber, and with some follow up surveys (Nov and Dec) at sites near Placencia. Values are percent of 200 corals surveyed that had partial or whole bleaching.

While not every site could be revisited[2], those that were, showed a marked recovery in November 2017 (Fig. 2f-g). This data also emphasizes the need to conduct timely bleaching surveys.

There was partial mortality observed on many *A. tenuifolia* colonies, and on a few outlanted *A. palmata* colonies at LBCNP, even if they recovered from bleaching. However, the mortality rates for the *A. palmata* in the nurseries were much higher (Table I) than expected, and the rapid loss suggests a disease event, more so then bleaching. Although it can be difficult to distinguish between disease and bleaching, in general, disease has a distinct, sharp line at the live versus recently dead tissue, versus bleaching which has more patchy, undefined edges (Fig 3a, from BBT1). Also, bleaching typically would occur on all/most replicates of the same genet, whereas disease may only affect a few (Fig. 3b, from BBT2); also supporting a hypothesis about a vector (i.e. fish) that transfers disease.

[2] Bleaching surveys were funded externally by MAR Fund.

There was variability in survivorship by nursery location (Figs. 4a-b), to some degree fragment size, and genet. Corals sourced from and placed in Black Bird Caye sites have higher survival and growth rates than the corals sourced from and placed at Calabash Caye: the final (sixth) nursery was placed in a third, new location (Round House reef). While FoH had much higher survival rates for *A. palmata* in the southern sites, in previous years, those corals had not experienced the severe temperatures of 2017. The trial SWC *A. palmata* micro-fragments outplanted directly on the shalow fore reef had far better survival rates than those in the nurseries. Because of this, FoH has switched to directly ouplanting micro fragmented *A. palmata*, bypassing nursery time for this species. Some trials with other species have also begun; the use of nurseries is now more a back up in the case of poor weather preventing direct outplanting.

Table I: Elkhorn suvivorship in the nurseries after 2017 bleaching event:

Nursery	method	Total number	% surviorship
TBC Table1	cookies	22	32
TBC Table 2	cookies	25	8
TBC Table 2	Micro-frags	83	16
SWC Table 1	cookies	36	14
SWC Table 2	cookies	15	0
SWC Table 2	Micro-frags	88 and 90	1 and 58
CC table 1	cookies	29	51
CC table 1	Micro-frags	188	27
BB table 1	cookies	20	55
BB table 2	Micro-frags	184	66

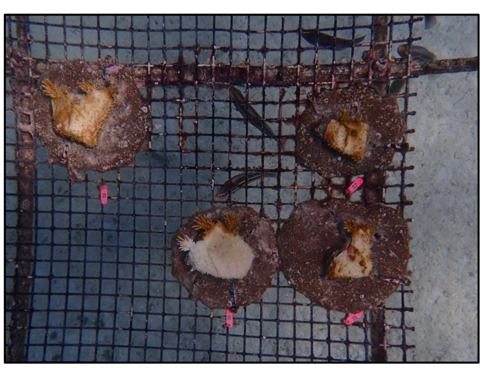

Fig. 3a. The coral in the middle looks diseased whereas the three around it look partially bleached.

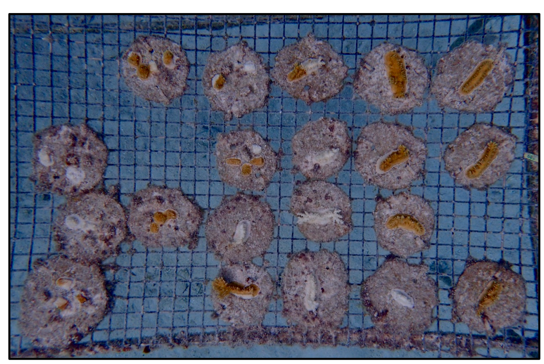

Fig. 3b. Random mortality pattern on same genet suggests rapid disease, perhaps transferred by a fish (vector). Note defintive line (s) on some corals.

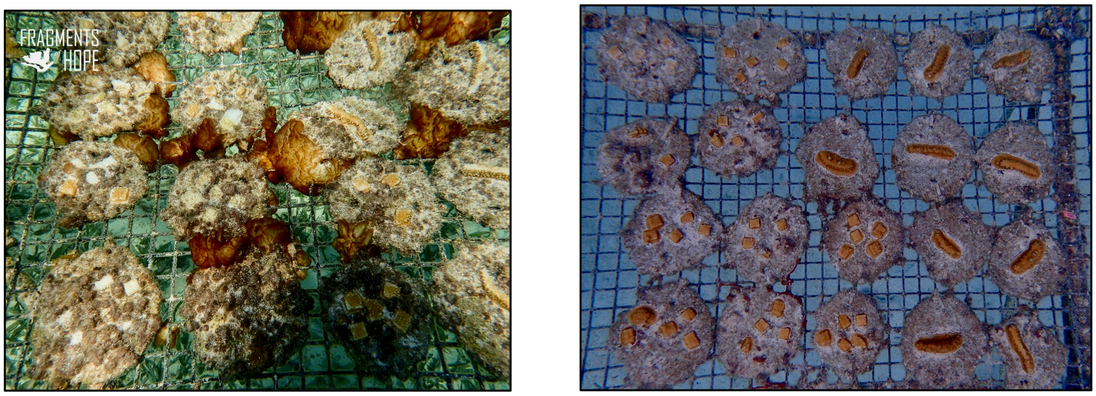

Fig. 4a-b. Poor survivorship at CCT2 (photo from September 2017) versus BBT2 (December 2017).

Staghorn: In general, very few staghorn were affected by either bleaching or disease, compared to *A. palmata* (Fig 5a).

Fig. 5a. Corals thriving on the most shallow nursery (~0.5m), TBC1, photo from December 2, 2017.

1.1.4 Details on *in situ* temperature and lack of bleaching event 2018

Temperature Figure 6a compares the 2017 temperature (black) at SWCT1, (depth is ~ 2m and the nursery table is in the back reef, but in a channel that often has current) to the 2018 temperatures (blue). In August-September 2017, temperatures were extremely high, reaching up to 32 degrees Celcius, explaining the severe bleaching and disease observed in 2017. However, in May 2018, temperatures were briefly higher than in 2017, which also may explain the amounts of disease and mortality observed in 2018, despite limited to no bleaching in 2018. Figure 6b is temperature data from TBCT1, located right below the surface, directly behind the reef crest, 2017[3]-2018. While temperatures over all were lower than at SWCT1, likely due to the high wave energy depsite the shallow depth of the table nursery, the same trends are observed at TBC1: in 2017 temperatures were higher in July-August 2017 than in 2018, but in 2018 temperatures were higher April-June in 2018 than in 2017. Temperature data was also collected from the TAMR nurseries (CCT2 and BBCT1, with a logger set Nov2018 on Table 6, a different site south of Calabash Caye, Round House reef); see full temperature summaries under the 2019 section.

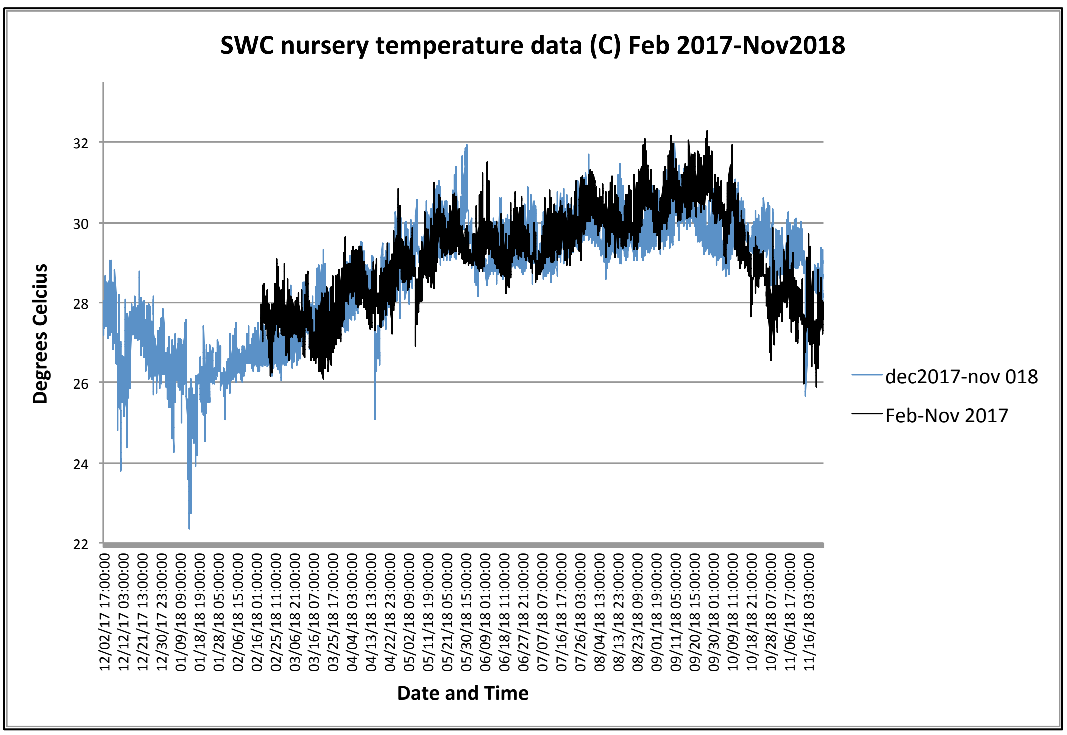

Fig. 6a. Comparing temperature data (degrees Celcius, on the y-axis) at SWCT1 2017-2018, the black lines are 2017 and the blue lines are 2018. Dates and time are on the X-axis. Temperature data is collected every hour.

[3] The temp logger used in 2017 on TBCT1 ran out of battery and thus quit logging around the end of August 2017. It was replaced with a new temperature logger.

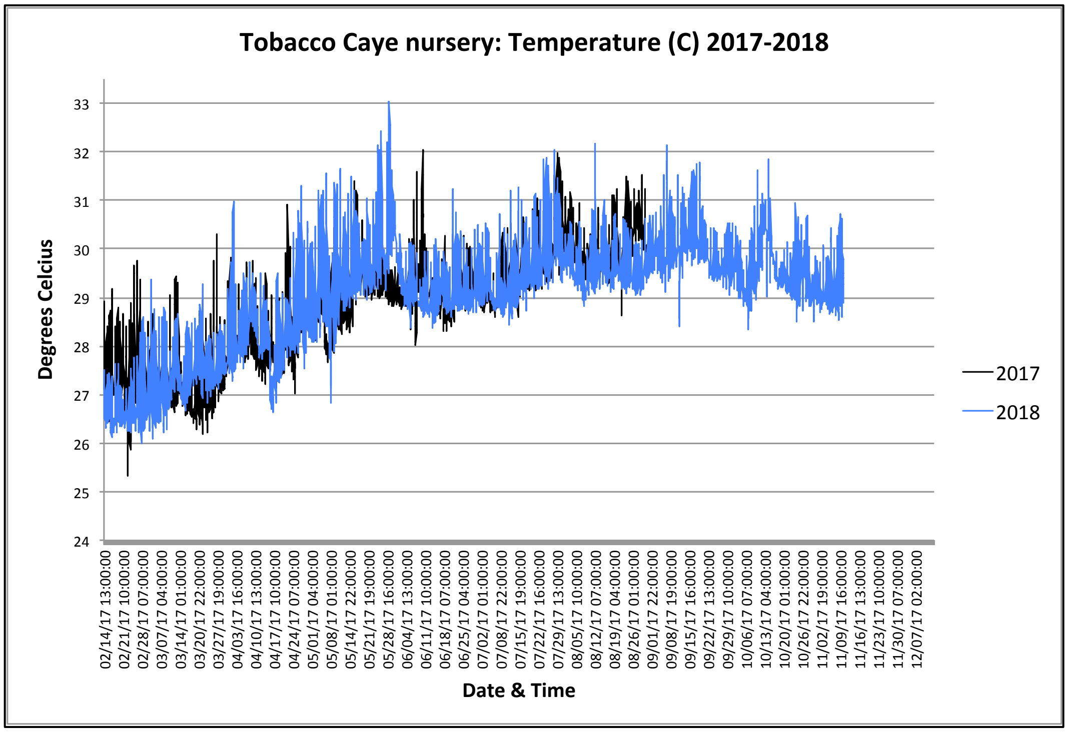

Fig. 6b. Comparing temperature data (degrees Celcius, on the y-axis) at TBCT1 2017-2018, the black lines are 2017 and the blue lines are 2018. Dates and time are on the X-axis. Temperature data is collected every hour.

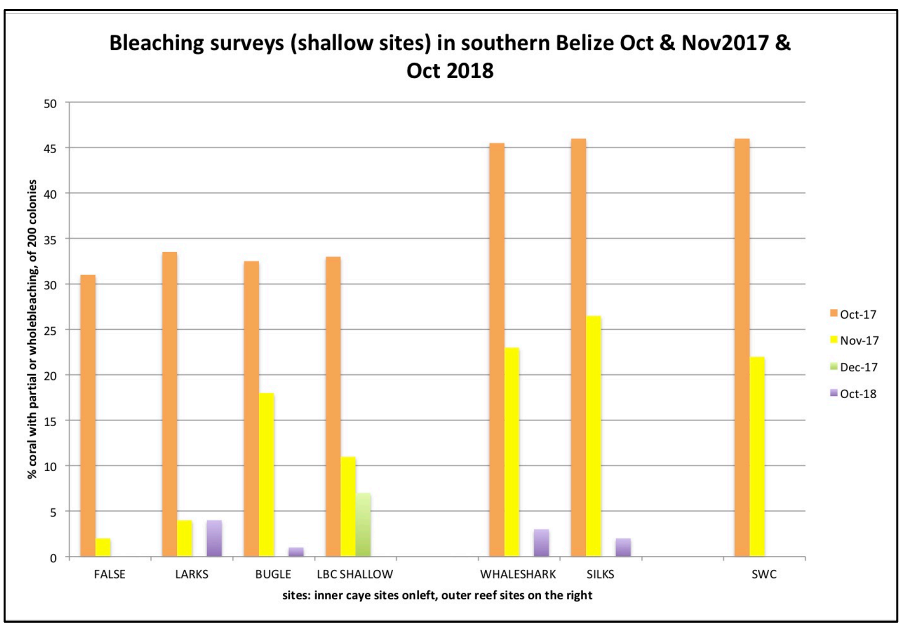

Fig. 6c. Results of bleaching surveys conducted in Ocotber 2018 compared to 2017. Each site has at least 200 corals surveyed and the Y-axis is the percentage of those that had either partial or whole bleaching.

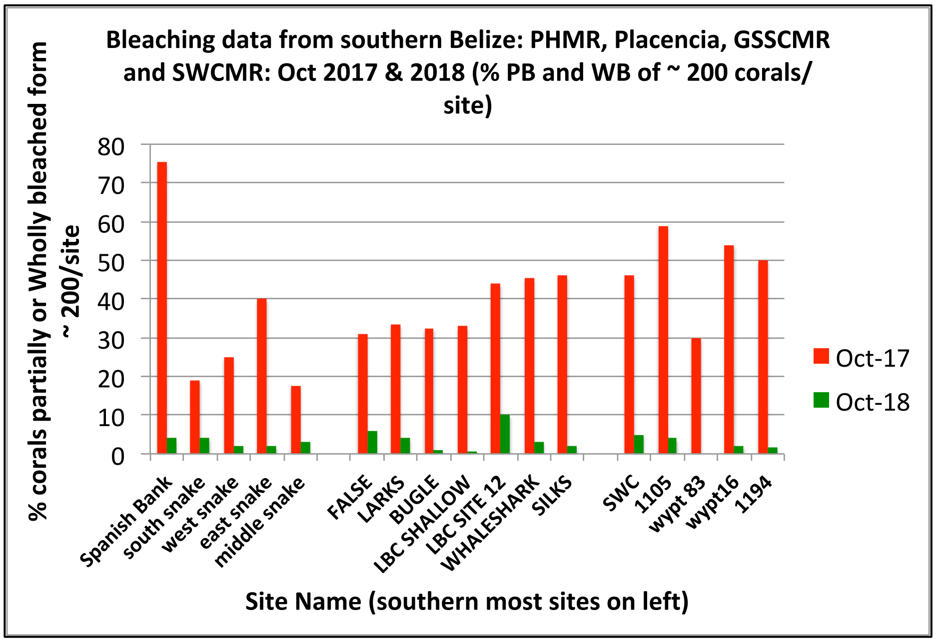

Fig. 6d. Results of October 2017 and 2018 bleaching surveys for southern Belize sites (PHMR on left, Placencia sites in the middle, SWCMR sites far right). Values are percent of 200 corals surveyed that had partial or whole bleaching.

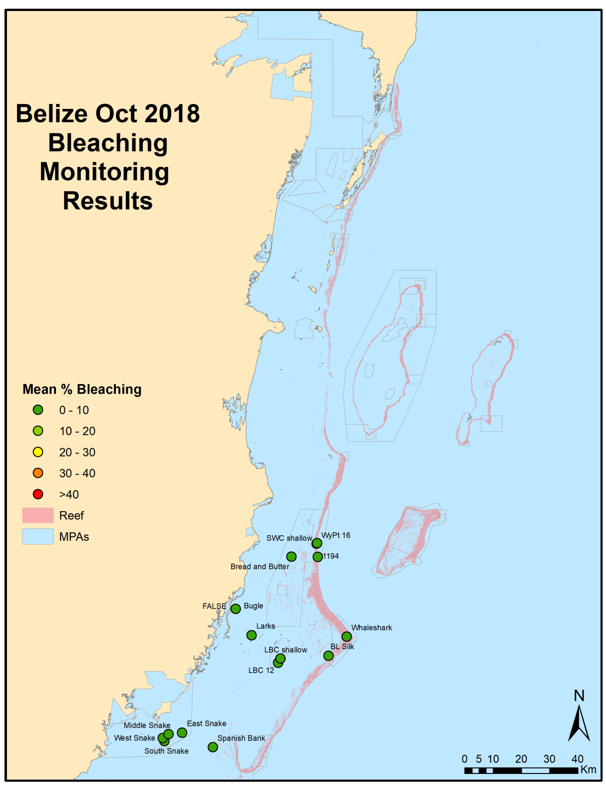

Fig. 6e. Map of bleaching severity in southern Belize, October 2018. Red is <40%, orange is 30-40%, yellow is 20-30%, light green is 10-20% and dark green is < 10% corals bleached (PB and WH) of 200 surveyed. Map courtesy Lynette Roth.

Fragments of Hope Bleaching workshop, Placencia October 27 & 28, 2018

FoH held a two-day training work shop in Placencia, October 2018, for stakeholders from PHMR, SWCMR and TAMR (Figures 7a-b). Day one was on shore, with overviews of coral species identification, swimbar methodology, defining levels of bleaching, how to quickly estimate % of colony with old or new mortality, and review of known diseases including the emergent Stony Coral Tissue Loss Disease, as yet unreported in Belize. Day two was in the field, practicing the swimbar methodology and species ID, and calculating percent mortality for colonies, at LBCNP due to participants' requests (some had never been there). FoH had conducted similar training for tour guides in Placencia in 2008, and used updated training materials from then, plus materials sourced from Florida and AGRRA, courtesy Dr. Patricia Kramer.

Figs. 7a-b. Photos from field day of bleaching training workshop at LBCNP October 29, 2018.

Fragments of Hope GCFI Video

Fragments of Hope created a short educational video titled "Coral Bleaching Monitoring in Belize 2017-2018" that highlights the history of bleaching events in Belize, monitoring methods and results, new disease outbreaks and recommendations of coral bleaching monitoring.

https://drive.google.com/open?id=1qehDy1O8yBW4VkNu0HfZ8vUi2ldx00h5

1.1.5 Details on *in situ* temperature and bleaching event 2019

Stony Coral Tissue Loss Disease (SCTLD) was reported in northern Belize (Bacalar Chico Marine Reserve) in June 2019. FoH co-hosted a three-day regional meeting with Mar Fund in Belize City October 2019, where a full day was spent learning about SCTLD from regional partners and planning for its spread through out Belize. Two of the three days were the second Biennial meeting of the Mesoamerican Reef Restoration Network. Much of the discussions revolved around threats incuding disease and bleaching events, and there was much local news coverage. However, unlike 2017-2018, nationwide data were not available and shared below is only bleaching data that FoH collected in southern Belize.

FoH has *in situ* temperature loggers at all of the sites shown in the map in Figure 8a. These multi-year results (where available) are shown and discussed in order of north to south as far as Tarpon Caye, located inside South Water Caye Marine Reserve and one of FoH's oldest nursery sites (2009) with the longest *in-situ* temperature data set. For reports detailing *in situ* temperature data and bleaching results south of Tarpon Caye, see approved WWF Technical reports housed on the FoH website[4]. All temperature loggers (Hobo U22-001[5]) were placed on the back reef coral nurseries, depths 1-2.5m (the most shallow one is Tobacco Caye, Figs. 8e and 12b). The deepest one in this data set is Round House reef, the last nursery installed at TAMR, so only one year of temperature data is available from this site (Figs. 8d and 11f). One logger data set is from the shallow fore reef, ~2m, an outplant site , SWCplot1 (Figs. 8g, 12d-e). This is also a site with bleaching survey data since 2017 (labled "SWC" in Fig. 9). This site is not shown on the map (Fig8a).

Temperatures were highest at all sites in 2019 compared to other years. The difference from other years also was high temperature peaks lasting through October compared to usual peaks in August/early September. These dates are circled in Figures 8b-c and i-j but is obvious in each graph. Black Bird Caye had the highest temperatures in this data set discussed, but near shore False Caye in southern Belize (Fig. 8a), not discussed in this report, had the highest temperatures of all sites in 2019. Because the temperature remained high so late in the year, the bleaching was not only severe but lasted through December 2019 and recovery only began for

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[4] http://fragmentsofhope.org/technical-reports/
[5] https://www.hobodataloggers.com.au/hobo-u22-001-water-temperature-pro-v2-data-logger

some sites in January-February 2020 (Fig. 9a). The same trends were observed in 2019: the most severe bleaching occurred on off shore sites, and deeper sites. The graph in Figure 9a shows sites on the X-axis in order of near-shore to off-shore, with sites near Placencia on the left and sites in SWCMR on the right. The only deeper (12-17m) sites are “LBC site 12” near Placencia and “wypt16” and “1194” in SWCMR. These deeper sites had higher bleaching in November than October, which until 2019 was always the ‘peak’ month for bleaching in Belize. Figures 12c and 12g illustrate the severe bleaching observed on the deeper fore reefs in SWCMR. If bleaching surveys were only conducted in early October, some more resilient sites would not have reflected the severerity of the event in 2019 (Fig. 9b).

Below Figures 8b-j show the *in situ* temperature data, and Figures 9a-b are the bleaching survey results from southern Belize sites. Although no bleaching survey data were collected from TAMR (by FoH) in 2019, two site vists were made in November 2019 and Figures 10a-h are from Black Bird Caye, and Figures 11a-f are from Calabash Caye. The trends remained the same in 2019 as observed in recent years. Despite the severity and long lasting bleaching event, the acroporids proved most resilient, with very few genets/individuals bleaching and if they did, they recovered quickly compared to other species. None of the directly outplanted *Acropora palmata* bleached (Figs. 10g, 11c-d, 12e) compared to species like *Orbicella annularis* and *Agaracia tenuifoila* that often fully (wholly) bleached. While some of the *A. cervicornis*, both outplanted and natural, had partial bleaching at Black Bird Caye, there was no mortality and picture pairs in Figures 10a-f from Novermber 2019 and July 2020 show full recovery. Black Bird Caye had the highest temperatures of the three sites in TAMR (Fig. 8d) and far higher than SWC (Fig.8h).

Neither outplanted (Figs. 12a, d) nor nursery *A. cervicornis* bleached in SWCMR. Figure 12b is the most shallow nursery site at Tobbaco Caye that experienced temperatures above 31°C from 29 August -20 October 2019 and above 32°C 22 September-6 October 2019. The photo (Fig 12b) from 15 November 2019 shows thriving acroporids.

While no SCTLD was observed, Black Band disease (Figs. 10h and 12g) was present on all sites and has been linked to higher sea temperatures.

Figure 13a is sea surface satellite temperature data from NOAA’s Coral Reef Watch program. There is a virtual station at Glover’s Reef and the data shown are the hottest ten years of their 35 year record, by color. Red is 2019 and clearly higher than other years, but thick blackline is 2020 data to date and higher still. Degree Heating Weeks (DHWs) are illustrated on the right of the figure again showing 2017 and now 2019 were the most severe bleaching events for Belize. DWHs are defined as follows. Corals experience thermal stress, the main cause of bleaching, when sea surface temperatures exceed 1°C (1.8°F) above the maximum summertime mean. This stress worsens as the heat anomaly persists. Degree Heating Week (DHW) shows how much heat stress has accumulated in an area over the past 12 weeks (3 months) by adding up any temperature exceeding the bleaching threshold during that time period. When DHW reaches 4°C-weeks (7.2°F-weeks), significant coral bleaching is likely, especially in more sensitive species. When DHW is 8°C-weeks (14.4°F-weeks) or higher, widespread bleaching and mortality from thermal stress may occur.

Figure 13b is the entire (1985-2019) sea surface satellite temperature data set from NOAA's virtual station at Glover's Reef in Belize. The DHWs are shown on the bottom of the figure with color codes to reflect the bleaching alerts based on DHWs. Figures 13a-b provided by Dr. Mark Eakin, NOAA by request.

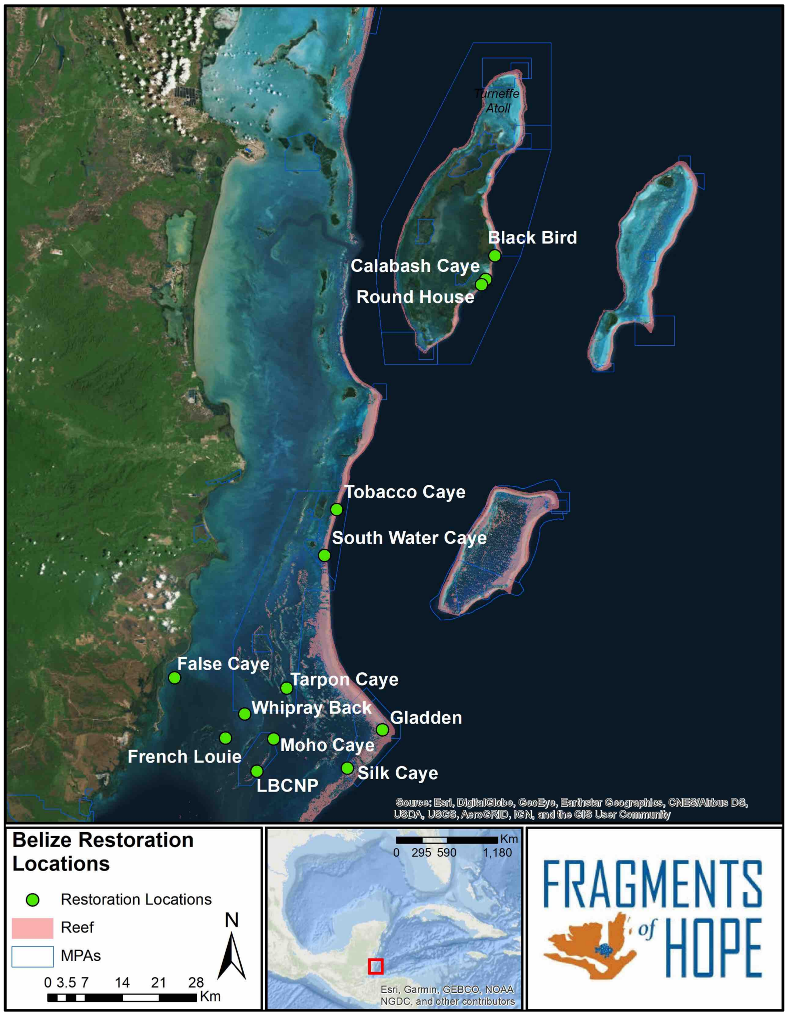


Fig. 8a. Map of FoH coral nurseries and temperature loggers through out Belize. All loggers are on the shallow nursery tables (0.5-2m) and one new logger, not shown, is on the shallow fore reef, a replenished plot, at South Water Caye.

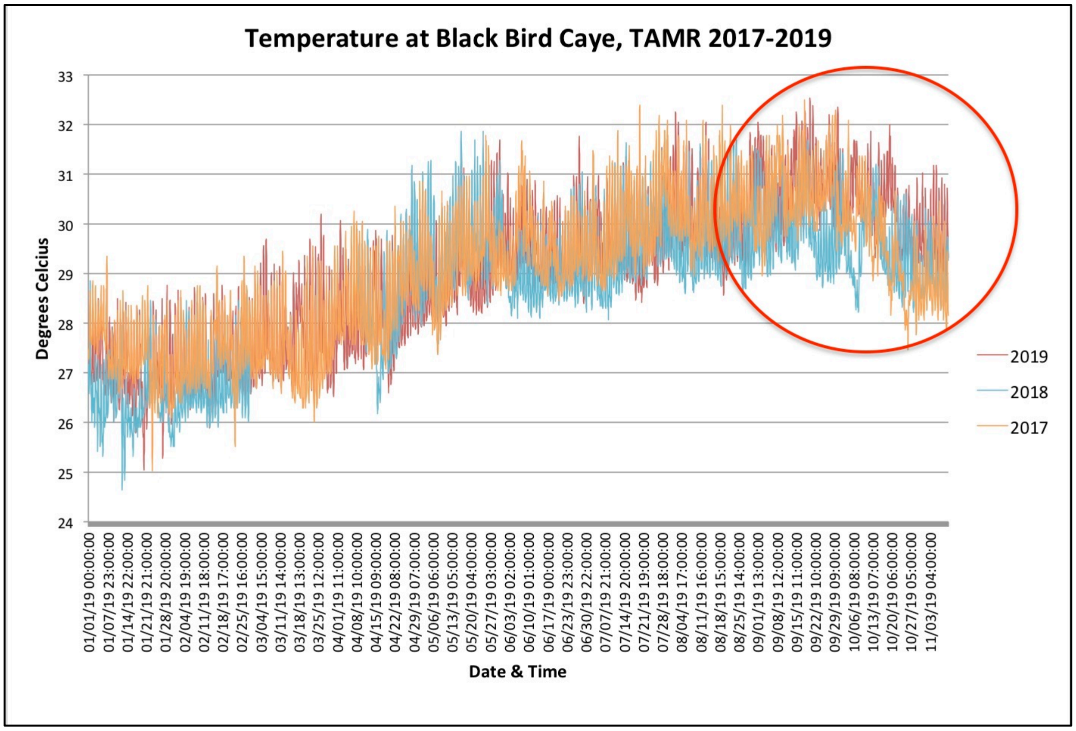


Fig. 8b. Three years (2017-2019) of *in situ* temperature data at Black Bird Caye, Turneffe Atoll Marine Reserve (TAMR). Data is collected hourly, in degrees Celsius. Years are color coded (2019=red, 2018=blue, 2017=orange).

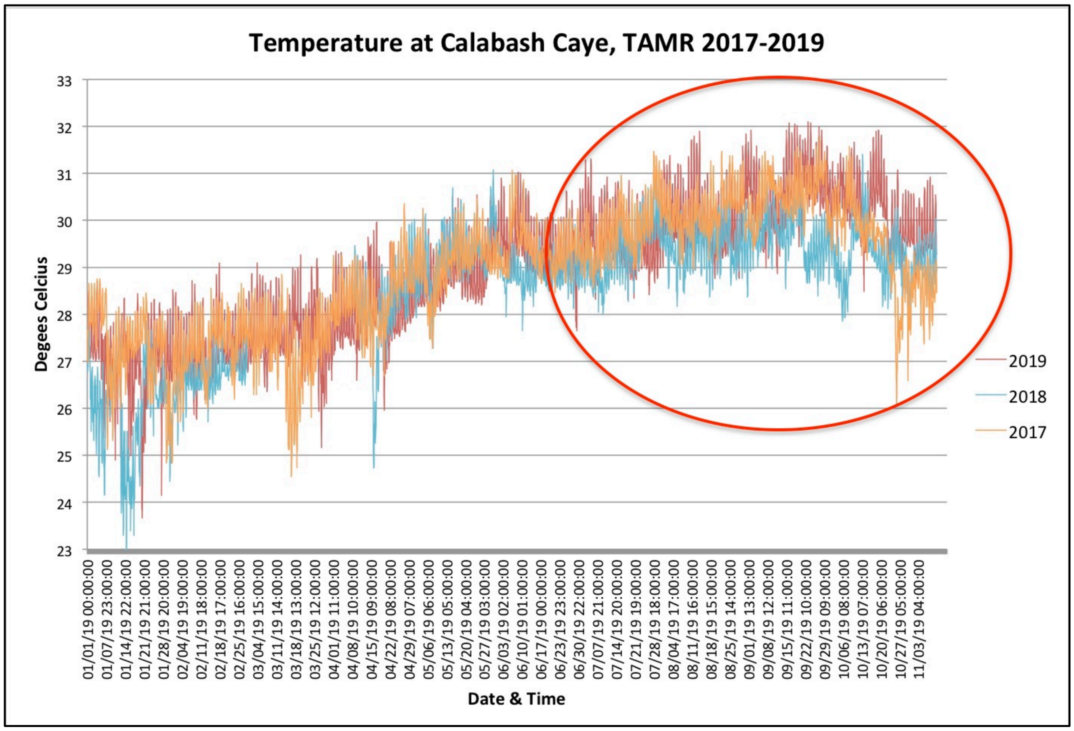


Fig. 8c. Three years (2017-2019) of *in situ* temperature data at Calabash Caye, Turneffe Atoll Marine Reserve (TAMR). Data is collected hourly, in degrees Celsius. Years are color coded (2019=red, 2018=blue, 2017=orange).

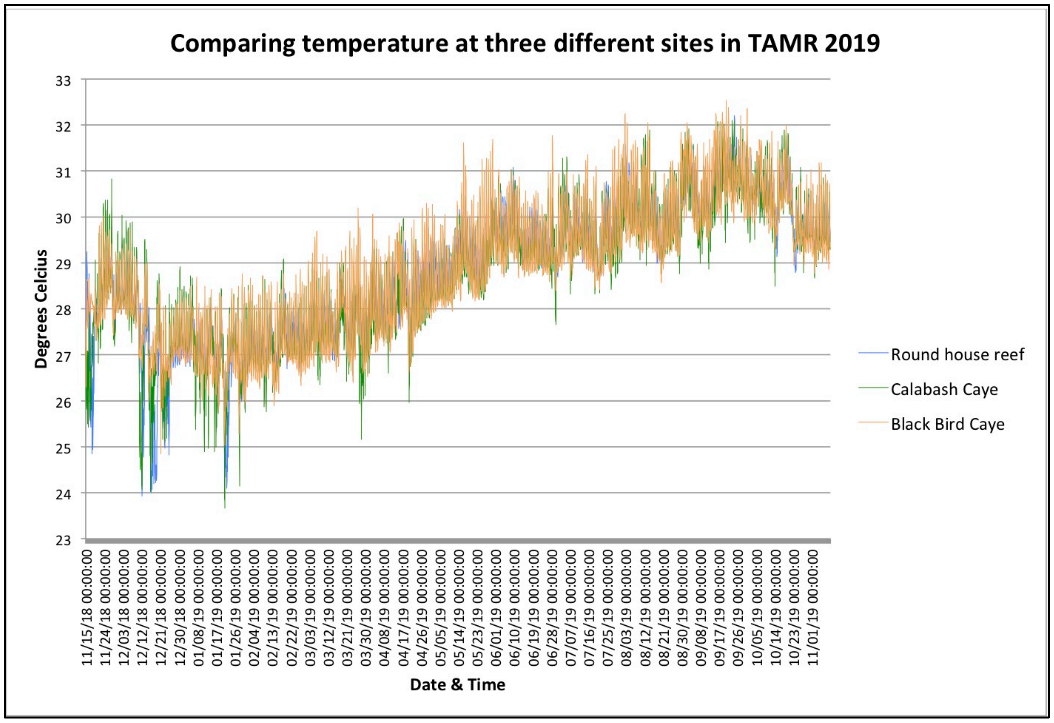


Fig. 8d. Comparing one year (November 2018-November 2019) of *in situ* temperature at three locations in TAMR. Round House reef is blue, Calabsh Caye is green and Black Bird Caye is orange. Data collected hourly in degrees Celsius.

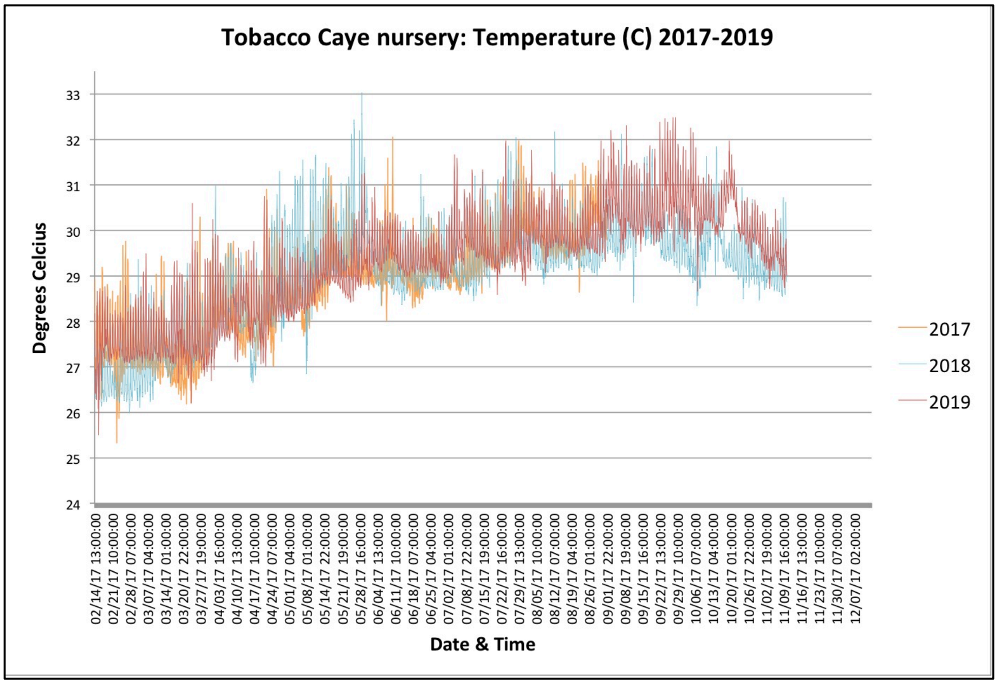


Fig. 8e. Three years of temperature data at Tobacco Caye, South Water Caye Marine Reserve from the nursery table (SWCMR). Years are color coded 2017 is orange, 2018 is blue, 2019 is red. Depth is <0.5m, data collected hourly in degrees Celsius.

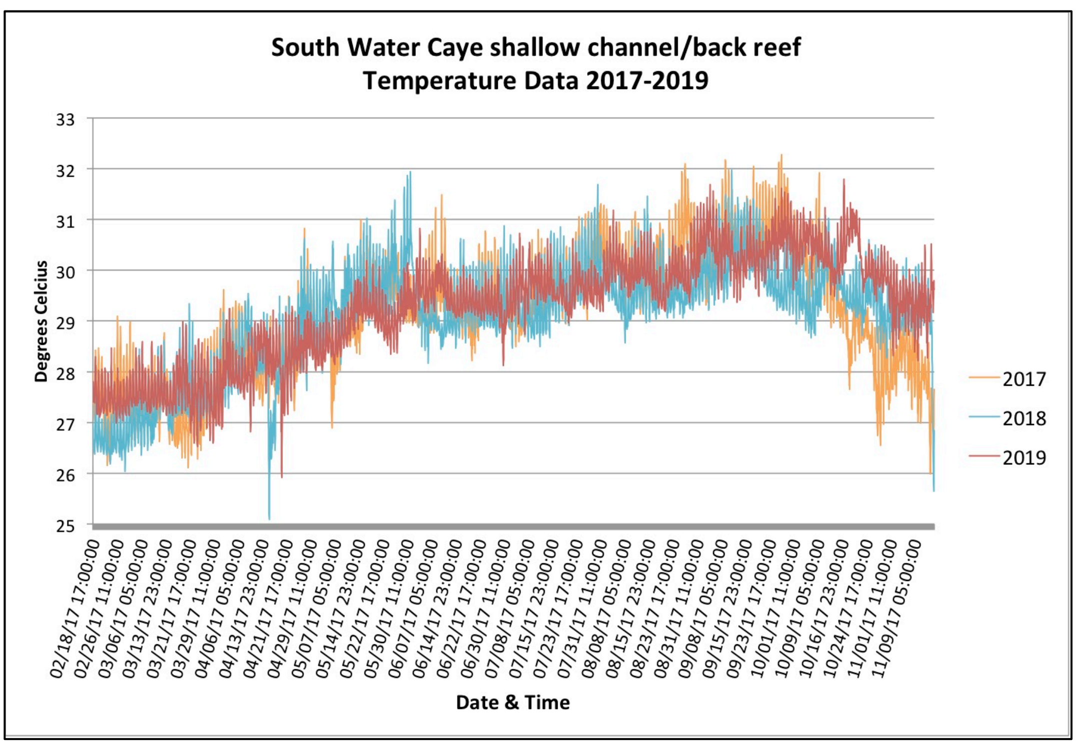


Fig. 8f. Three years of temperature data at South Wtaer Caye, (SWCMR) back reef/channel (from the nursery tables). Years are color coded 2017 is orange, 2018 is blue, 2019 is red. Depth is ~2m, data collected hourly in degrees Celsius.

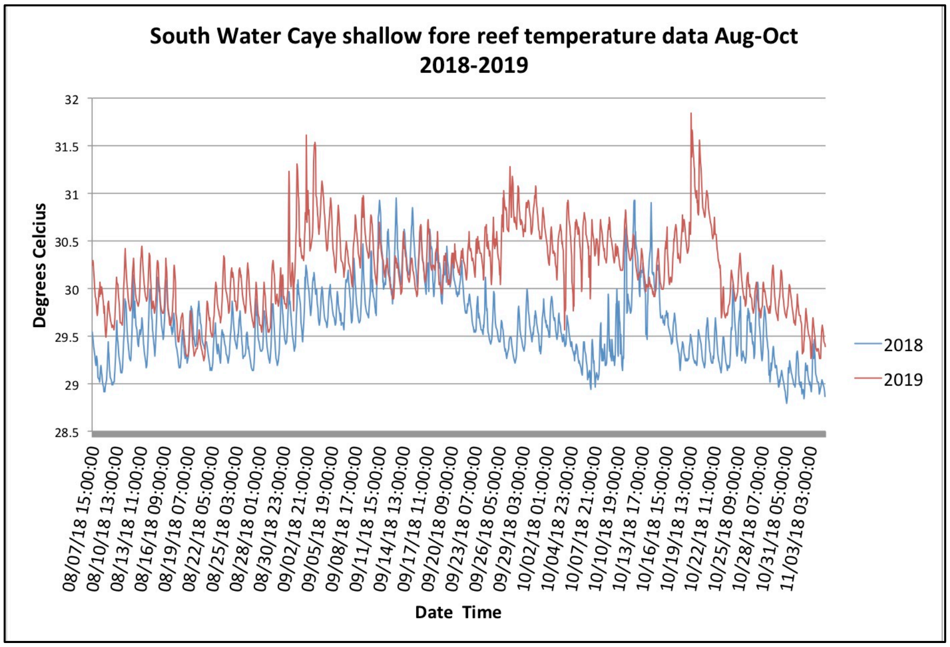


Fig. 8g. Two years (August-October) *in situ* temperature data from the shallow fore reef (SWC outplant plot1), SWCMR. Years are color coded, 2018 is blue and 2019 is red. Depth is ~2m, data is collected hourly in degrees Celsius.

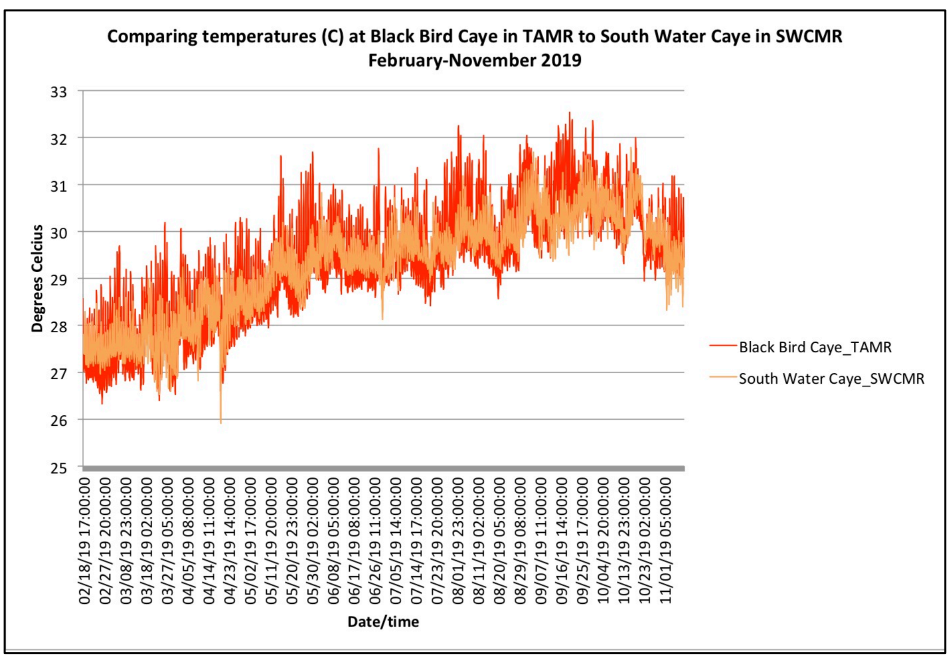
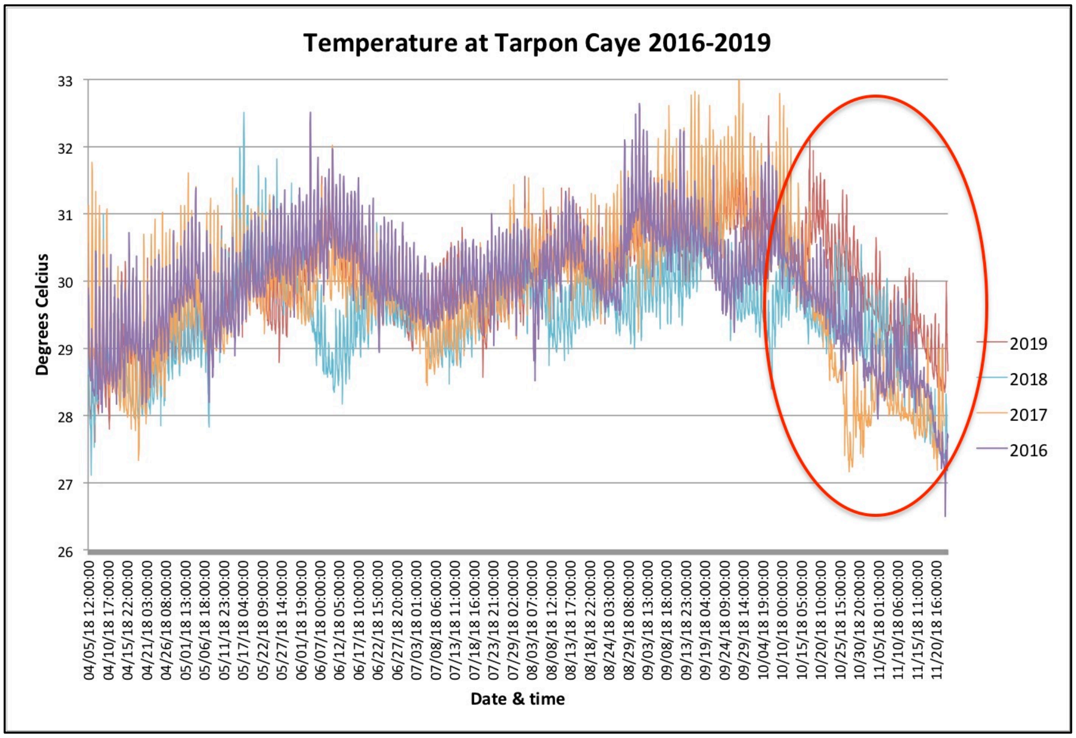
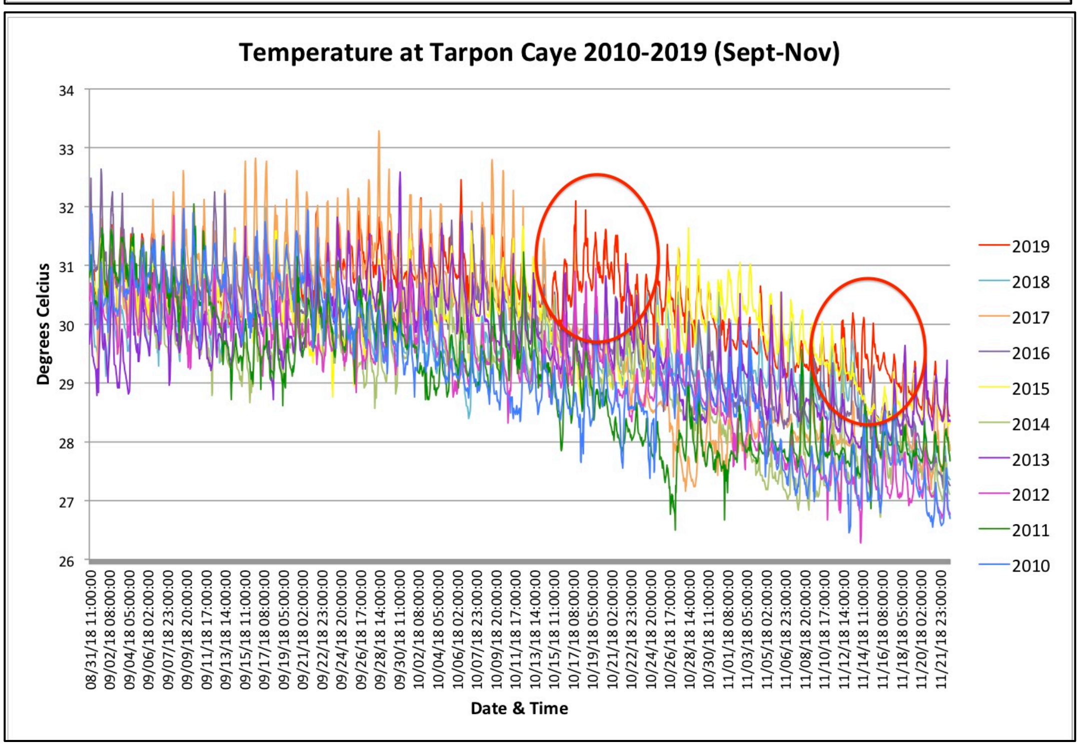


Fig. 8h. Comparing temperatures in 2019 from northern Belize, Black Bird Caye in TAMR (red) , to central Belize, SWCMR (orange). Both data sets from the back reef nursery tables ~ 2m, data colected hourly in degrees Celsius.





Figs. 8i-j. Tarpon Caye is one of Fragments of Hope's original nursery sites from 2009, and inside SWCMR; temperature data 2016-2019 (top) and 2010-2019 (bottom) is shown to illustrate the 2019 hgher temperature trends nationwide in 2019 , shown in red in both graphs. Bottom graph also shared as an example of difficulties in illustrating long term data (see Fig. 13 from NOAA sataellite temperature data, long term data set).

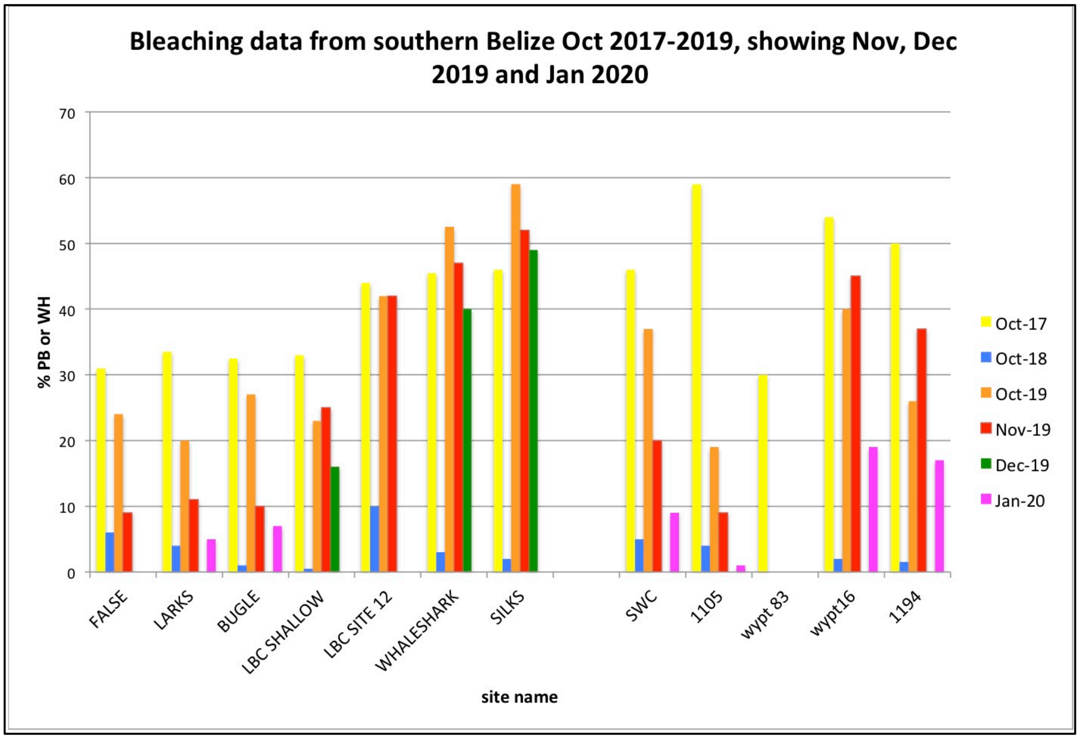


Fig. 9a. Results of bleaching surveys conducted in southern Belize by FoH in October 2017-2019, with follow up data November-December 2019 and January 2020 for some sites. Each site has at least 200 corals surveyed and the Y-axis is the percentage of those that had either partial or whole bleaching.

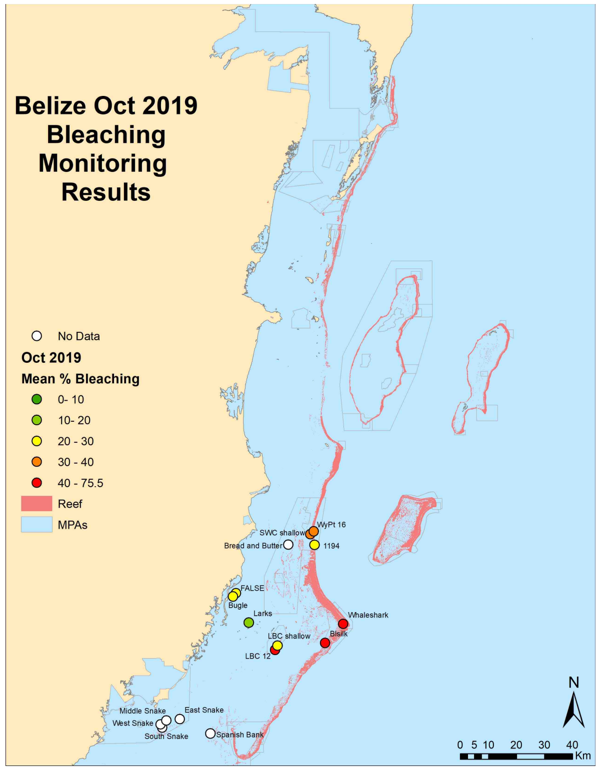
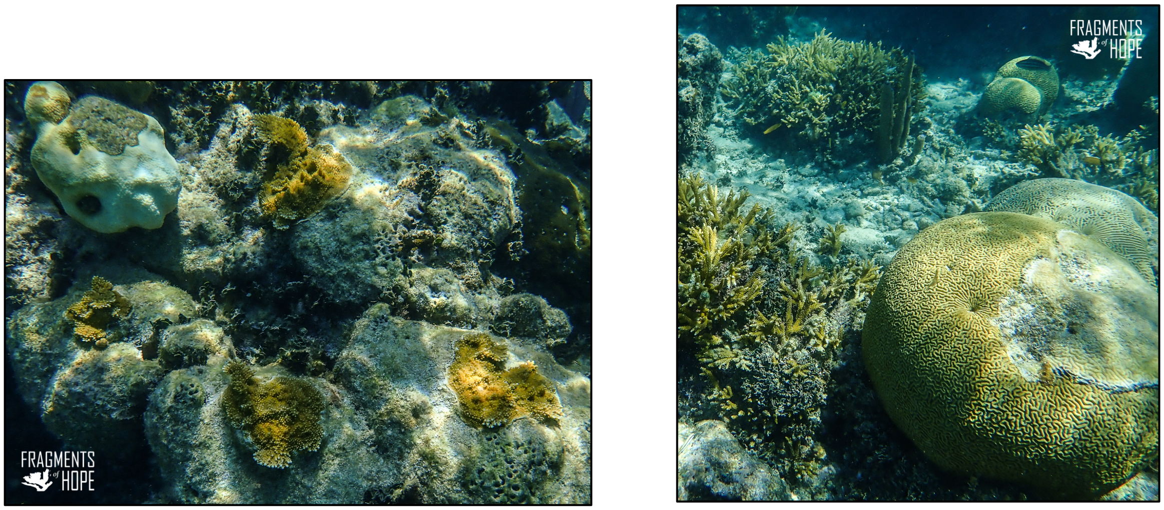


Fig. 9b. Bleaching survey data from southern Belize only. Each site had a minimum of 200 corals surveyed and is color-coded by the percent of bleaching (whole and partial), green being the least (010%) and red the most (>40%).

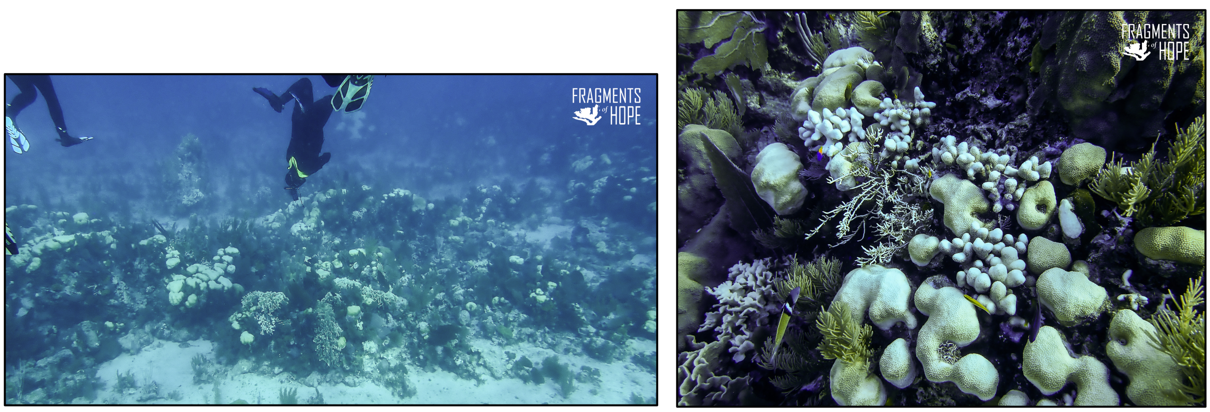
Figs. 10a-b. Nursery-grown *A. cervicornis* outplanted on ropes with cement nails, on back reef at Black Bird Caye, Turneffe Atoll Marine Reserve (TAMR) with minimal to no bleaching November 2019 (L) and July 2020 (R).

Figs. 10c-d. Nursery-grown *A. cervicornis* outplanted on ropes with cement nails, on back reef at Black Bird Caye, Turneffe Atoll Marine Reserve (TAMR) with partial bleaching November 2019 (L) and recovered in July 2020 (R).

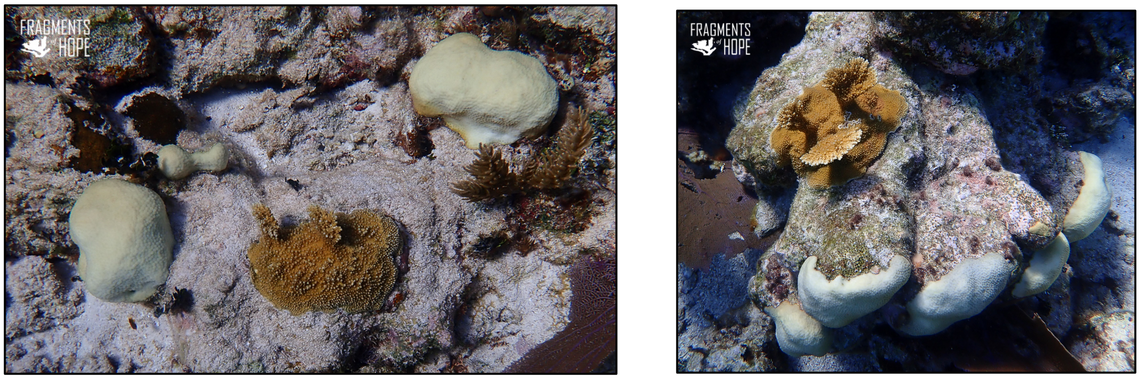
Figs. 10e-f. Natural, wild stand of *A. cervicornis* on the back reef at Black Bird Caye Turneffe showing partial bleaching (and damsel fish damage) in November 2019 (L) and recovered in July 2020 (R).



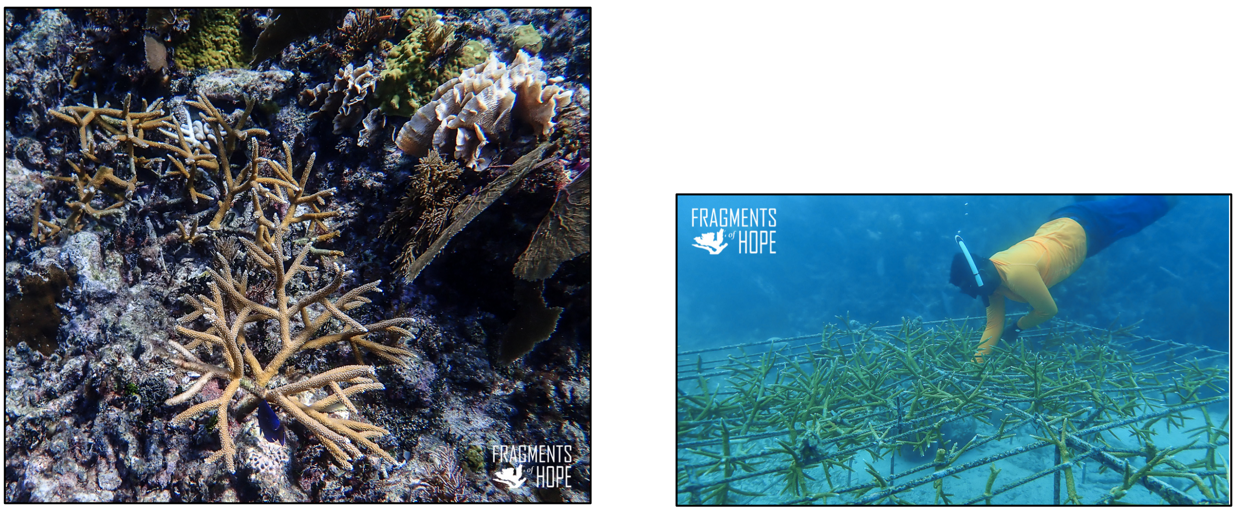
Figs. 10g-h. Directly outplanted *A. palmata* micro-fragments (no nursery time) set in May 2018, photo from November 2019, not bleaching, on shallow fore reef at Black Bird Caye,compared to fully bleached *Orbicella annularis* (L) and Black Band disease on *Pseudodiploria strigosa* near unaffected natural/wild *A. prolifera* at the same site, November 2019 (R).



Figs. 11a-b. Photos from shallow fore reef (~5m) at Calabash caye November 2019 showing severe bleaching of star and finger corals.

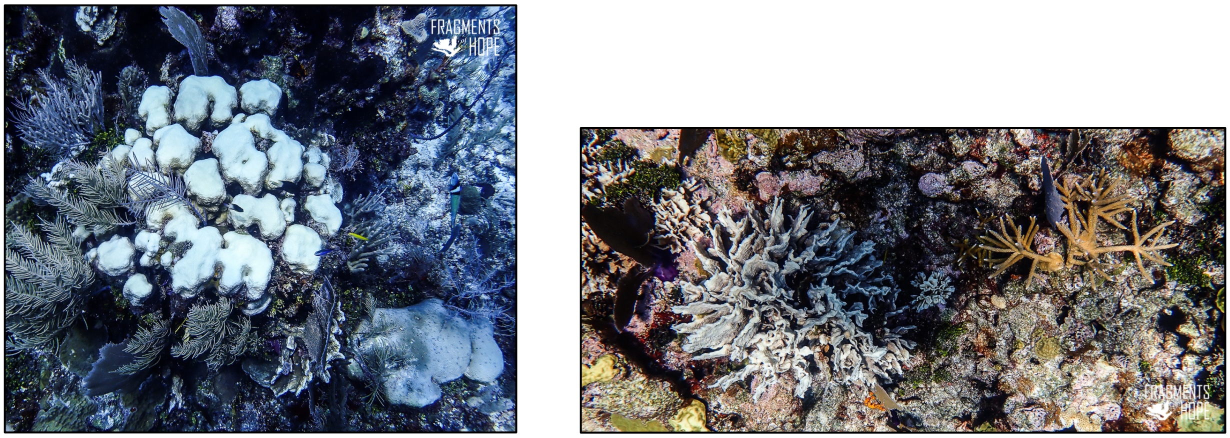


Figs. 11c-d. Directly outplanted *A. palmata* micro-fragments on the Calabash shallow fore reef set in May 2018, photos from November 2019, not bleaching, next to fully/wholly bleached wild/natural *Orbicella annularis*.

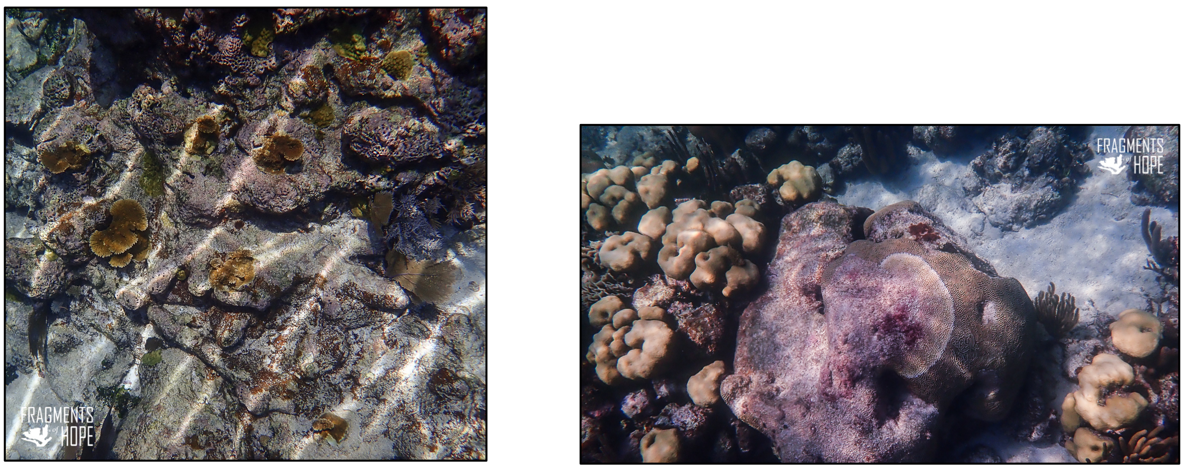


Figs. 11e-f. Nursery-grown outplanted (in April 2019) *A. cervicornis* on the shallow fore reef at Calabash Caye, not bleaching in November 2019, compared to *Agaricia tenuifolia* (L). The *A. cervicornis* in the Round House nursery site never bleached, photo from November 2019.

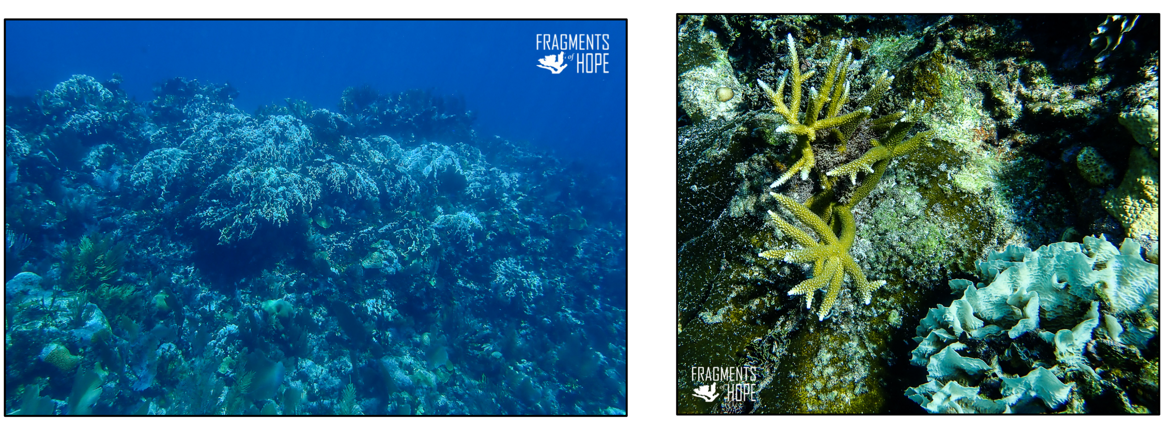
Fig. 12a-b. Nursery-grown outplanted (January 2018) *A. cervicornis* at South Water Caye plot 2, shallow back reef/channel not bleaching in October 2019 (L) and shallow Tobacco Caye Table 1 November 2019 not bleaching (R).



Figs. 12c-d. Bleaching *O. annularis* (L) and *A. tenuifolia* next to unaffected nursery grown, outplanted *A. cervicornis* (R) on the shallow fore reef at South Water Caye October 2019.



Figs. 12e-f. Directly outplanted (April 2017) *A. palmata* micro frags on the shallow fore reef at SWC, photo from October 2019 (L) and bleaching *O. annularis* and *P. strigosa* with Black Band disease shallow back reef SWC in October 2019.



Figs. 12g-h. Almost all of the *A. tenuifolia* bleached on the shallow fore reef at South Water Caye in November 2019, (L) but nursery-grown outplanted *A. cervicornis* did not bleach (R).

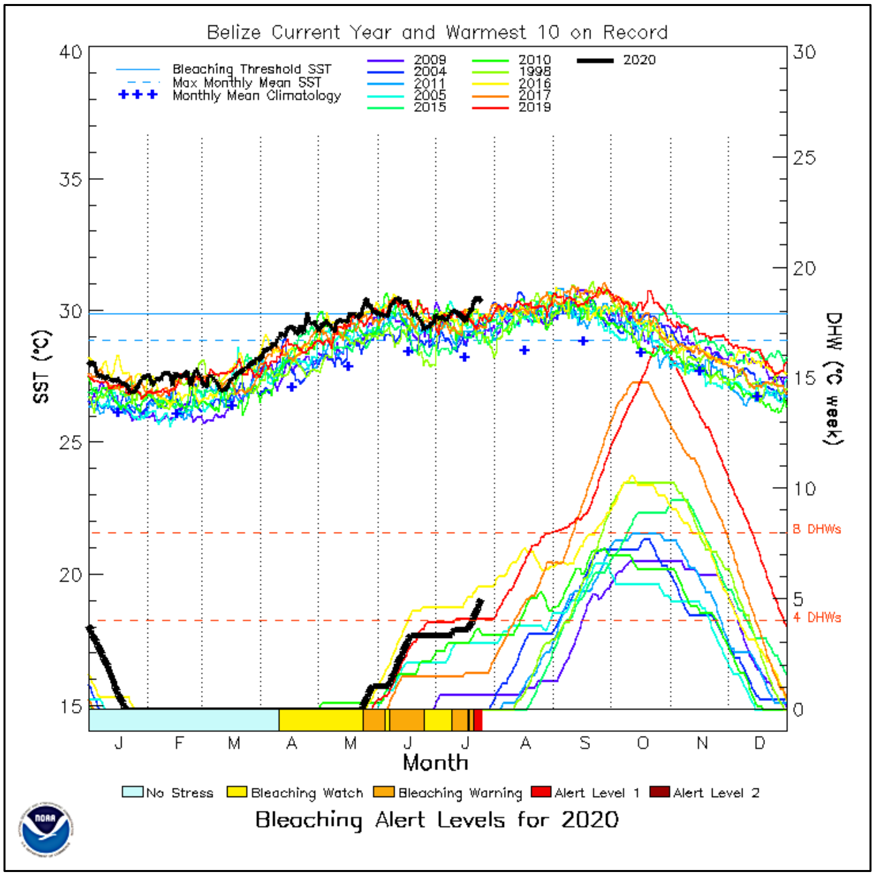


Fig. 13. Sea surface satellite temperature data from NOAA's Coral Reef Watch. This figure shows the warmest ten years, by color, on record for Belize, not necessarily consecutive. The thick black line is 2020 data. On the bottom right are the Degree Heating Weeks[6] (DHWs), ilustrating that 2017 and now 2019 were the most severe bleaching events for Belize. While 1998 is not included here, it is shown in Figs.1e and 13b. where 2017 and 2019 surpassed that year in DHWs.

[6] https://www.pacioos.hawaii.edu/voyager/info/coral_bleaching_degree_heating_weeks.html

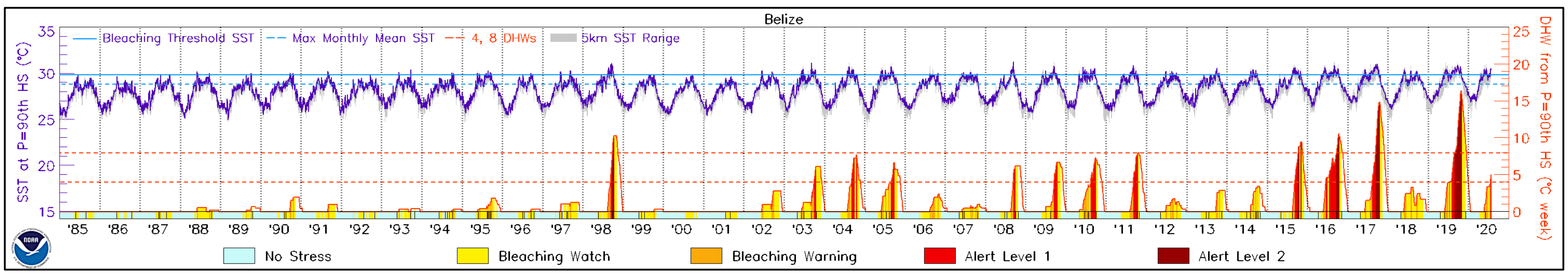


Fig. 13b. Long time series from NOAA's sea surface satellite temperature data, from the Glover's Reef virtual station. The colored peaks on the bottom reflect the bleaching alert levels based on DHWs.

2.0 Discussion, Lessons Learned & Recommendations Looking Forward

Predictions of annual bleaching events have been made for almost two decades, now proving true in Belize and globally (Hoegh-Guldberg 1999). Emissions need to be reduced drastically, and until then reef restoration efforts in Belize continue to source and utilize the corals/genets with the most temperature tolerance (Bowden-Kerby and Carne 2012, Carne et al. 2016). This is done by mapping/sourcing corals during our warmest months. While it is encouraging that acroporids now show more resilience than other coral species, and also remain unaffected by SCTLD, much research remains to verify if essential reef ecosystem fuctions such as coastline protection, biodiversity maintenance, etc., can be provided by acroporid dominated shallow reefs. Fragments of Hope is dedicated to finding these answers through long term studies, adopting and adapting new technologies as they are available (e.g. more advanced host and symbiont genetic analyses, faster coral replenishment methods, higher resolution and quantitiave monitoring methods, etc.).

Maximum temperatures were previously compared by year and site, but long term data suggests these are meaningless. DHWs are much more appropriate in both predicting and describing bleaching events. However the *in situ* temperature data reflect yearly temperature fluctuations by as much as 6°C, which may provide more tolerance/resilience (Oliver and Palumbi 2011, Palumbi et al 2014). Additionally these data dispel some published literature about maximum thresholds for corals (e.g >50% mortality at 30.5°C, Foo and Asner 2020[7]).

Recent publications on long term studies have also demonstrated a correlation between heavy nutrients and severe bleaching (Lapointe et al. 2019)[8] and waste water treatment is at least a viable although expensive option for Belize, compared to any emission reductions in Belize which are neglible amounts, globally.

While FoH continues to assist partners with addressing SCTLD, it is also recommended that Black Band Disease (BBD) be treated where applicable, as that treatment is known to

[7] https://iopscience.iop.org/article/10.1088/1748-9326/ab7dfa/meta
[8] https://link.springer.com/article/10.1007/s00227-019-3538-9

effective (Aeby et al. 2015) and BBD is prevalent on all sites and on the same slower growing corals species that are susceptible to SCTLD.

A place to house all coral bleaching data and *in situ* temperature data for Belize is needed; UB has started a data base for coral bleaching data but not all partenrs are using it, and there is currently no specific database manager,or identified funds for this position.

Finally, if MPA managers and co-managers thoughout Belize cannot conduct regular, coodinated bleaching surveys September-December (depending on each month's severity of bleaching), either because of logistical or finanical restraints, it is recommended that a national approach/team be created with specific funds. These bleaching surveys can be combined with BBD treatment and/or SCTLD treatment (if present). More training workshops need to be held and include experienced, interested divemasters, fishers and students since there is currently a paucity of field based marine biologists in Belize.

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