Fragments of Hope 2024 Summary report for Research Permit renewal 0020-24

Continued active restoration of critically endangered Caribbean coral species with a focus on acroporids

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. While trial replenishment work began in HCMR in 2011, it was revitalized in 2020 and 2022-2023. This report summarizes work completed in 2024. Due the predicted heat stress which continued from 2023 into 2024, FoH spoke with partners and funders and agreed not to conduct any coral outplanting in 2024. Instead, the focus was on continued capacity building/knowledge exchanges, and two five-day coral identification and bleaching survey methods workshops were conducted (April and July 2024), with 23 Belizean participants.

Bleaching surveys were conducted every month (87 surveys for 2024) and uploaded to the AGRRA website. FoH also assisted the Belize Fisheries Department and Hol Chan with surveys in the northern MPA's, but this data was not uploaded to AGRRA at the Department's request, nor is it included in this report. Bleaching levels in 2024 were unprecedented as were the in situ sea temperatures and ocean heat content. While the southern Belize sites survived the 2023 bleaching events with little total mortality, the opposite happened in 2024. Much of 2024 was spent re-mapping donor corals and finding new corals to continue adding to genetic diversity at nurseries and outplant sites. Many corals were re-genotyped (re-sampled) as were "new corals" for genetic analysis (in 2025).

FoH did identify survivors/more resilient genets and began restocking five nursery tables in three different sites with four different *Acropora cervicornis* genets and one *A. prolifera* genet in two different locations.

Spawning monitoring was conducted at Laughing Bird Caye National Park August 2024 with spawning from acroporid outplants observed on Day Five After the Full Moon.

Seventeen diver-based mosaics were conducted nationwide. FoH can now process the mosaics (where is previously Arthur Gleason at the University of Miami processed), but we still have a back log for the annotation process; to be addressed in 2025 with more capacity building and more appropriate computers and software (two such fast

computers exist at the moment). There are also still challenges with the most shallow sites, that prior to late 2024 were continuous thickets of staghorn; Arthur Gleason (University of Miami) is still working with us to address this and has hired someone to re-process all of the FoH mosaics to date.

Drone ortho-mosaics were conducted at LBCNP, Moho, and all three Silk Cayes, and several inner caye *A. cervicornis* patch reefs, but all of most of these still need annotation. The LBCNP drone orthomosaics from 2019-2024 have been annotated, with the exception of 2023, and in 2024, prior to the beaching event and subsequent mortality, replenished acroporids (three taxa) covered over 10,000m^2 at LBCNP (August 2024).

FoH conducted a number of site visits with funders, partners and the media including but not limited to: the Office of the Prime Minster with the Belize Fisheries Department, and regional journalists from the Caribbean Broadcasting Union. FoH held its 11th Annual General Meeting (all virtual) in November 2024.

FoH sent several representatives to the REEF FUTURES conference in Mexico, December 2024, where several FoH abstracts/talks were accepted and given (5-12 minute oral presentations).

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 92,000 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.

In 2024, the IUCN announced over 40% of the world's corals face extinction[1], and several of the Caribbean's previously common corals are now on the Red List due to both Stony Coral Tissue Loss Disease (SCTLD), bleaching and disease events.

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. However, much replenished coral mortality occurred at LBCNP in 2024 that will be quantified in 2025, with new questions arising about future priority sites that need to be collectively addressed and identified. FoH's work and funding will continue in all sites through 2025. FoH is pursuring additional funding options/sources, as always.

Funding from WWF, F5 Tech Grant, Summit Foundation, Strong Coasts CoPe, BFSF, the McPZ Foundation, plus private donors have supported various activities reported here.

Objective

Continued objectives under the newest grant from BFSF and other entities include:

1. Enhance coral biodiversity on reefs across Belize through replenishment of resilient coral genets from endangered species;
2. Quantify effects of local environment, genotype, and acclimation capacity from outplanted corals

Continued objectives also include:

3. Conduct coral spawning monitoring;
4. Collaborate with the National Coral Reef Monitoring Group to carry out reef monitoring for bleaching across Belize's reef systems;

[1] IUCN 2024 press release

The older objective “to increase coral cover by 10% at each targeted site, needs to be amended due to the severe bleaching events.

Methods

Methods remain the same as in the 2023 summary report.

Results

Capacity building

A five-day workshop was held in Placencia in April 2024, fully subsidized by FoH’s Belize Fund grant. The focus, as agreed with Belize Fund, shifted to coral ID and learning the proper swim bar methodology for bleaching surveys the Belize NCRMN has endorsed to use for almost two decades. This method was not always used or properly used, in 2023. The 11 participants came from northern MPAs (BCMR, TASA, HCMR) and included guides and fishers from Caye Caulker and Placencia (Figure 1). In the April training, the FoH manual was shared, and participants also learned how to make ropes for *A. cervicornis* and *A. prolifera*, and how FoH does growth rates for *A. cervicornis*.

A second training was conducted in July 2024, prompted by request and funds from the CZMAI via external funding specifically to engage partners at SEA; however the NCRMN voted to use bleaching survey funding FoH received late 2023 from WWF to increase participant size to 12 Belizeans: five from SEA, three from Belize Fisheries Department (representing CCMR, SWCMR & Glovers Reef Atoll), as well as student(s) and tour guide(s). The full report on the July training, which did not include the FoH manual nor handling any corals, is shared in Annex I.

Bleaching, Temperature and Mortality Data 2024

Bleaching surveys were conducted every month in 2024 (87 in total by FoH). Sites were primarily in LBCNP, GSSCMR, and near shore Placencia that FoH has been monitoring for many years; 2024 was the most severe to date (Figures 2a-b). FoH has been monitoring several sites in SWCMR since 2017, and that historical October data 2017-2024 is shown in Figure 2c, again illustrating 2024 bleaching levels were the most severe to date. However, the monthly SWCMR surveys (Figure 2d) show a slight drop in bleaching amounts in November, unlike at LBCNP and inner cayes (Figs. 2b and 7c). A quick comparison of in situ temperature data (Celcius) shows a significant difference between the SWC table and shallow outplant sites at LBCNP (Figure 3.)

Mortality data (collected from the bleaching surveys) also reflects observations that 2023 had worse effects on sites north of the Placencia area, while in 2024 the sites near Placencia were more affected than in 2023 and the northern sites. Figures 4a-b illustrate old versus new mortality rates at SWCMR sites and LBCNP sites in 2024.

Some bleaching surveys were conducted in TAMR in early October 2024, and Figure 5a illustrates October bleaching levels from 2021-2024, reflecting the same results/pattern that 2024 bleaching levels were the most extreme to date. Figure 5b is a graph of in situ temperature data from the shallow back reef nursery table at Calabash Caye, TAMR 2021-2024 reflecting 2024's higher temperatures (in black) July-September.

The northern MPAs bleaching data is owned by the Belize Fisheries Department and has been submitted separately, as FoH only assisted with personnel and small funds.

Figures 5c-e are the national maps reflecting bleaching levels in October 2023 (including non-FoH sites), October 2024 (FoH sites) and November 2024 (FoH sites). The sites are color coded (red being > 40% partial bleaching or whole bleaching/ 200 corals surveyed by site). Only in one year past (2029) did November results remain or exceed October bleaching levels; October typically being the "peak " bleaching month in Belize.

All FoH 2007-2024 temperature data sets are housed online 2007-2024 FoH temp data, and are also included on the external hard drive for the Belize Fisheries Department.

While some mortality data was discussed above, FoH will need to repeat some specific outplant mortality data collected post-2023. This data was the subject of the accepted main FoH abstract at Reef Futures 2024 (Appendix II) entitled "High survival rate (79-96%) of 1,238 outplanted *Acropora palmata* at four different sites in southern Belize (ages 1-17 years on the reef), post-2023 bleaching event(s)." The entire talk is posted here. For example, the number of outplanted *A. palmata* colonies could still be counted at South, Middle Silk Caye and Moho Caye (Figure 6a), whereas at LBCNP it is impossible to count all; there only the oldest 2006 outplants were assessed post 2023 and of those, zero had 100% mortality. This assessment will be repeated in 2025 for post-2024 mortality rates on outplanted *A. palmata* colonies.

In the inner cayes (False, Larks and Bugle) near Placencia and in Figure 6b including Moho Caye, old mortality rates were higher than new mortality rates in 2024. In situ temperature table from the shallow ~1m) table nursery at False Caye peaked at nearly 34C in July 2024 (Figure 6C), yet genotypes sourced from Loggerhead (*A. prolifera* Figure 6d) and near shore "RG" and False Caye *A. cervicornis* had recovered at False Caye nurseries by October 2024, unlike LBCNP or Moho where bleaching continued through December (Fig. 7c). Donor *A. palmata* colonies on the lee ward side of near shore Lark's Caye also were healthy and not bleaching in October 2024 (Figure 6e). Figure 6g is a draft example of basic map illustrating where in Belize the "RG" near shore *A. cervicornis* genet has been relocated to, including Caye Caulker (Figure 6f) which as over October 25, 2024 was still alive.

Nurseries restocked with post 2023 "winners"/survivors.

Based on results post-2023, FoH continued to restock nurseries with surviving/winning genets post-2023. A new nursery table was added at False Caye at a slightly deeper depth (~15ft) near the wild *A. cervicornis* small patch there. The Loggerhead Caye sourced *A. prolifera* was re-propagated from successful nursery grown corals at near shore False Caye for the same location, and also relocated to the offshore Silk Caye nursery table (Figs. 6g and 7a). Seven new ropes were made with 73 *A. prolifera* fragments for the two nursery locations. An additional 15 *A. cervicornis* ropes with four different genets were restocked at three different nursery locations with 174 starter fragments (Figure 7b).

Spawning 2024

Outplanted acroporid coral spawning monitoring was conducted at Laughing Bird Caye National Park Aug 19-26, 2024, based on the 2022 elkhorn spawning dates (Days 1-2 AFM) at LBCNP. *A. palmata* spawning was observed on Day 5, AFM, holding to more historical patterns than in 2022. Originally the plan was to monitor outplants at Moho Caye, since LBCNP spawning has been previously documented, however weather conditions did not allow safe conditions at this location, and also affected a few night's observations at LBCNP. With a generous donation of a catamaran from the Moorings Belize, much day work was conducted including diver-based mosaics, fish and bleaching surveys over the same time period.

Diver based mosaics and fish surveys

All except two (Caye Caulker and Mexico Rocks) mosaic plots of the existing 19 were repeated in 2024. However only 10 mosaics have been processed (large files stored online 2024 diver-based mosaics) and none annotated as yet. Since the 2023 training on this method occurred, newly trained people have been collecting the imagery (whereas 2014-2022 mages were collected by a single, same person) and the learning curve is steep for the right camera settings, the right swimming speed, and the keeping the cameras level. Since FoH has two appropriate computers do now complete our own processing (as opposed to sending outside of Belize), we can review the results in more real time and had to repeat many of our mosaics, due to above learning curves. At both Moho Caye and LBCNP however, the issues of shallow, continuous stands of *A. cervicornis* (prior to 2024 bleaching and mortality events) remained challenging. Arthur Gleason (University of Miami) continues to address this issue where in many cases, photos must be realigned manually, versus with the software. Colleagues at Boston University have also been re-examining older FoH processed mosaics, experimenting with CoralNet a semi-AI (computer-learning software). See the Discussion section for how FoH plans to address these gaps, and others.

Regarding fish survey data (methods shared in previous reports) collected on each of the diver-based mosaic plots and three inner caye plots (Lazy, Dale, Saddle) wild *A. cervicornis* patches as "control sites" for replenished plots, the last analysis was 2015-2020 (shared in previous reports), that grouped fishes by trophic levels. Ethan Deyle (Boston University) is leading an effort to streamline the fish data analysis, reading in our raw data sheets adapted from AGGRA to R data objects, then proceeding with analysis using R scripts that can be "push button" re-run whenever new data sheets are available from field surveys. This data pipeline is complete and quality checked for processing the actual number of fishes, and the code to calculate biomass from size classes and to aggregate biomass by functional groups (e.g. grazing herbivores, excavating herbivores, piscivores) will be completed in 2025. Figure 8 shows a preliminary look at ten-year data sets for LBCNP (fully protected), Moho (unprotected) and the inner cayes plots (unprotected) we shared during the FoH AGM (November 2024), see Figure 8. The figure shows actual number of fishes, grouped by snappers and grunts, under and over 15cm (Figure 8).

Drone Ortho mosaics 2024

LBCNP was the impetus for beginning this work/methodology, since 2019, to quantify larger replenished coral coverage areas than the diver-based mosaics plots (Petersen, et al. 2023). These "flights' are usually repeated annually, but was completed four times in 2024 for LBCNP in attempts to document bleaching and changes; all LBCNP processed drone images are housed online LBCNP drone mosaics 2019-2024. Annotated LBCNP2drone ortho-mosaics from 2021 (Fig 9a) and 2022 (Fig. 9b) reflect m^2 by all three replenished acroporid taxa and then totaled. These changes are not from continued outplanting but by natural asexual spread during storm events. 2019-2020 had an increase of 7% acroporid coral cover, 2020-2021 doubled to 14%, and 2021-2023 increased by 56% coverage. FoH is still catching up on most processed drone mosaics annotation, so missing LBCNP 2023 but have the LBCNP 2024 mosaic annotated, prior to the bleaching event, which shows replenished acroporid cover was almost 10,500m^2 (Figure 9c).

FoH has used the drone mosaics to quantify other replenished areas/sites, as well as natural, wild stands of corals. Other processed drone ortho mosaics from 2024 are housed online 2024 drone mosaics.

As with the diver based mosaics, although FoH has a backlog of annotation (and some processing) to complete, the images acquired and the processed mosaics are forever there to be analyzed; another issue for FoH is this huge amount of large data storage (estimated at well over 25 TB to date) currently housed in multiple locations, both online and in external hard drives. See Discussion section below for plans to address this and more, in 2025 and beyond.

Fig. 1. Participants and instructors in the workshop: "Coral ID and Monitoring for Bleaching & Disease in Belize, in Relation to Reef Restoration Future Strategies" April 8th-12th, 2024 in Placencia.

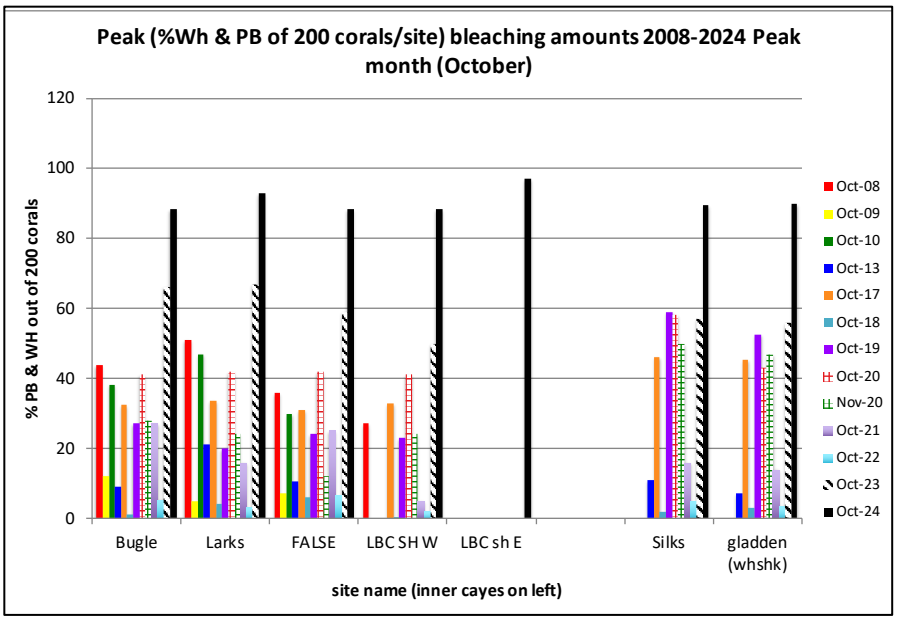
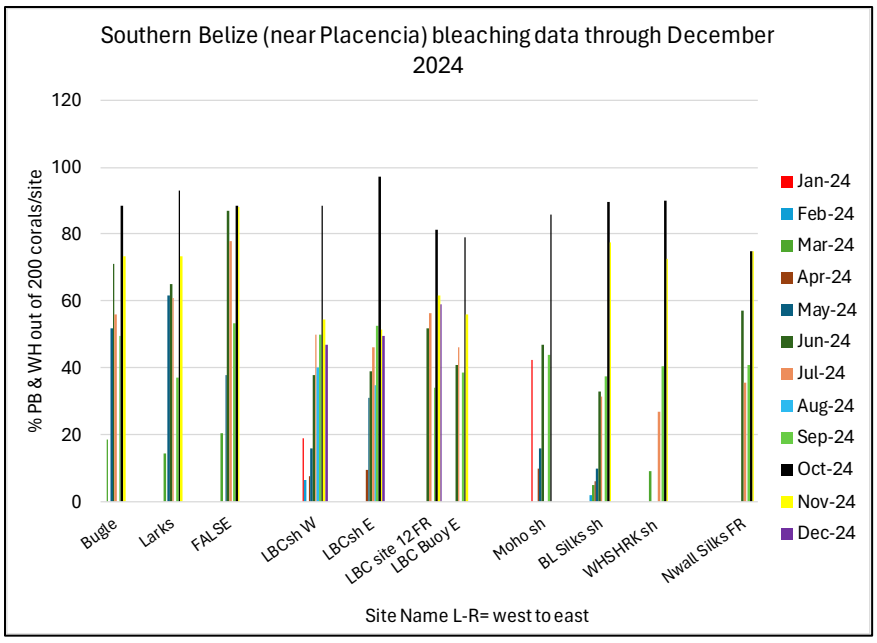


Fig. 2a. Bleaching surveys conducted in and near LBCNP and GSSCMR October 2008-2024. Each site has 200 corals surveyed, the Y-axis is the percentage of either partially bleached or wholly bleached corals, and the X-axis is sites nearshore to offshore, left to right.



Figs. 2b. Bleaching surveys conducted in and near LBCNP and GSSCMR by FoH January-December 2024, in southern Belize.

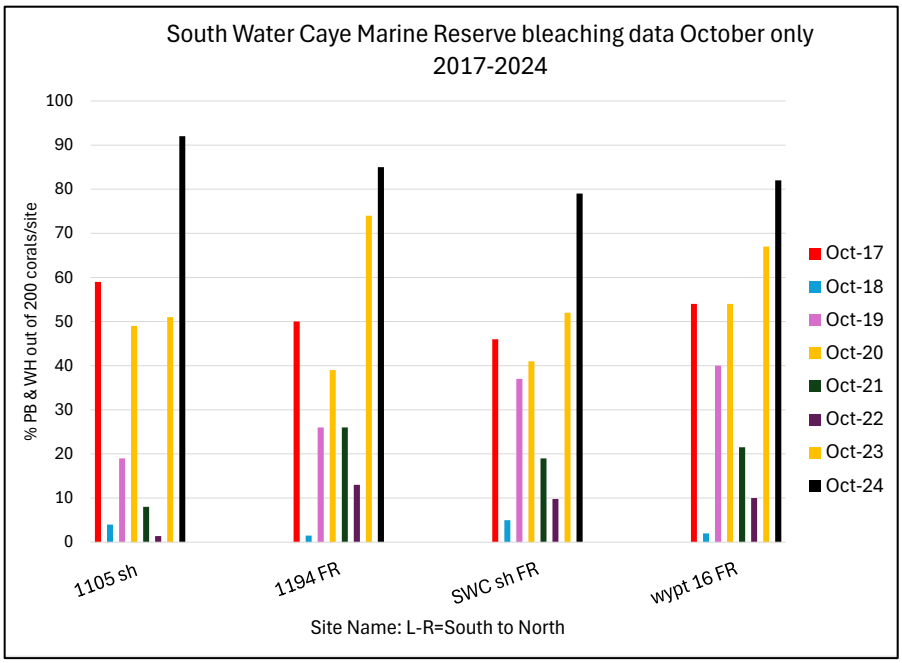


Fig. 2c. Comparing peak (usually October) bleaching levels at four sites (two fore reef 40-60ft, one shallow fore reef and back reef site-1105) 2017-2024 in SWCMR.

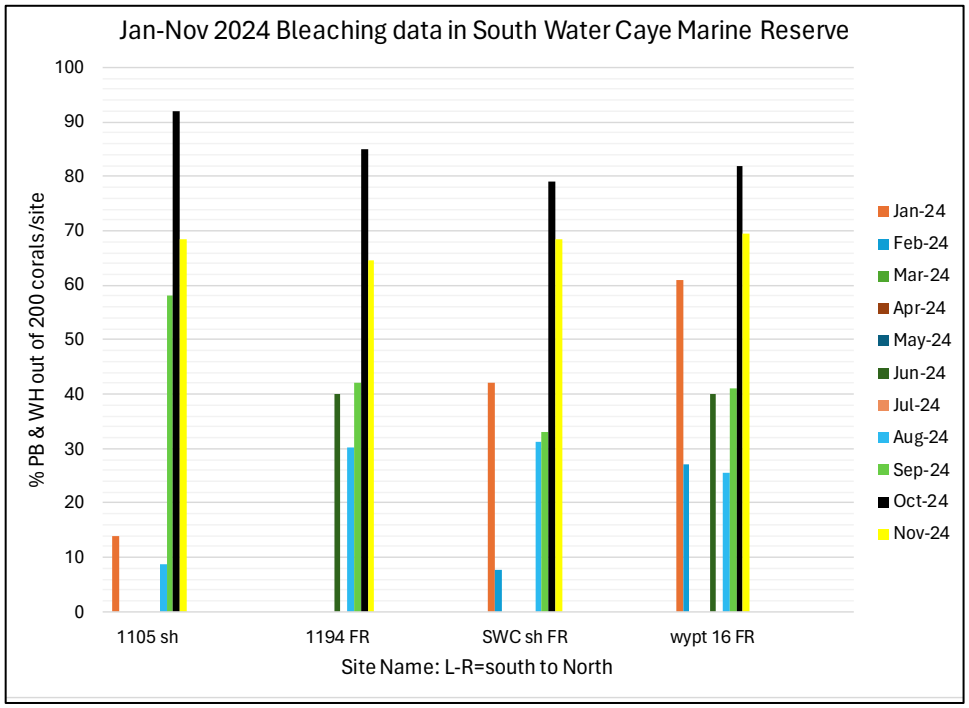


Fig. 2d. The 2024 monthly surveys conducted by FoH at four sites in SWCMR, 2024.

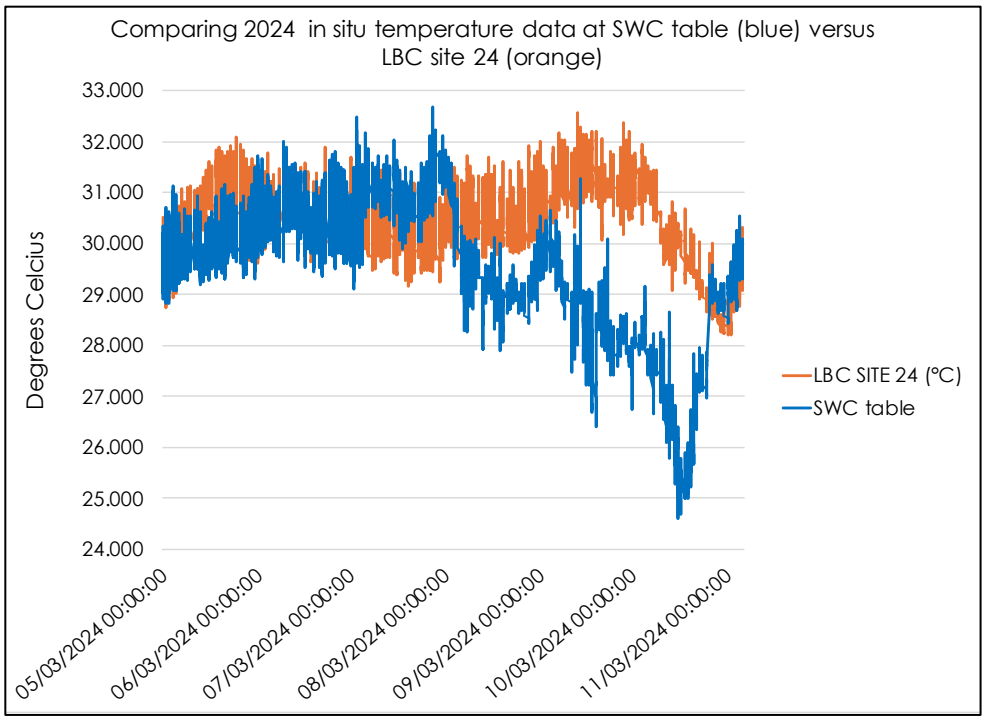


Fig 3. Comparing 2024 (May-November) in situ temperature data from SWC table nursery (Blue) and a shallow outplant site at LBC (orange) illustrates a significant difference with higher temperatures at LBC August-early November 2024.

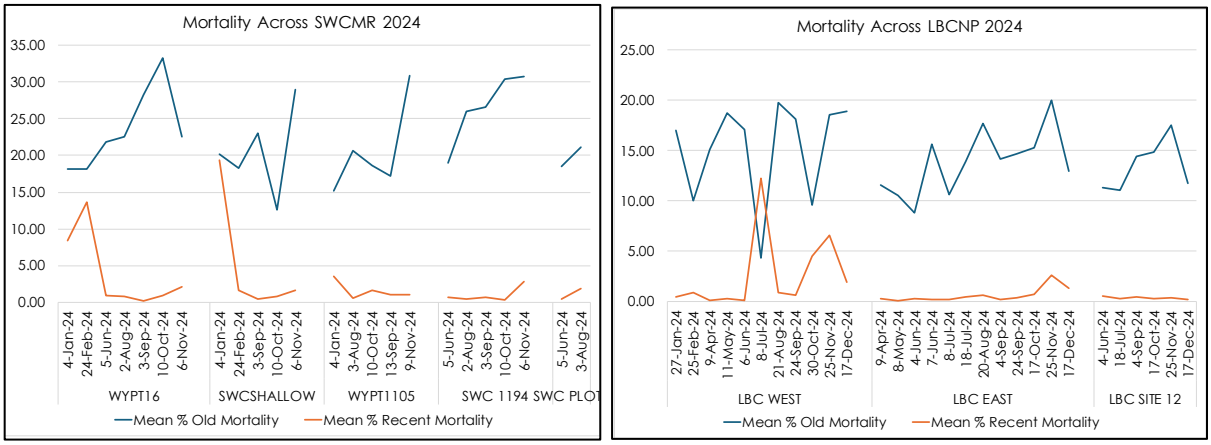


Fig. 4a-b. Mortality data (old and new) of all species pulled from the bleaching surveys conducted in 2024 at SWCMR (L) and LBCNP (R). The scale of old mortality is higher at SWCMR than LBCNP. New mortality was higher at SWCMR in early 2024, reflecting the severity of 2023, but was over 10% on the lee ward side of LBCNP mid 2024, aligning with higher temperatures reflected at LBCNP in Figure 3.

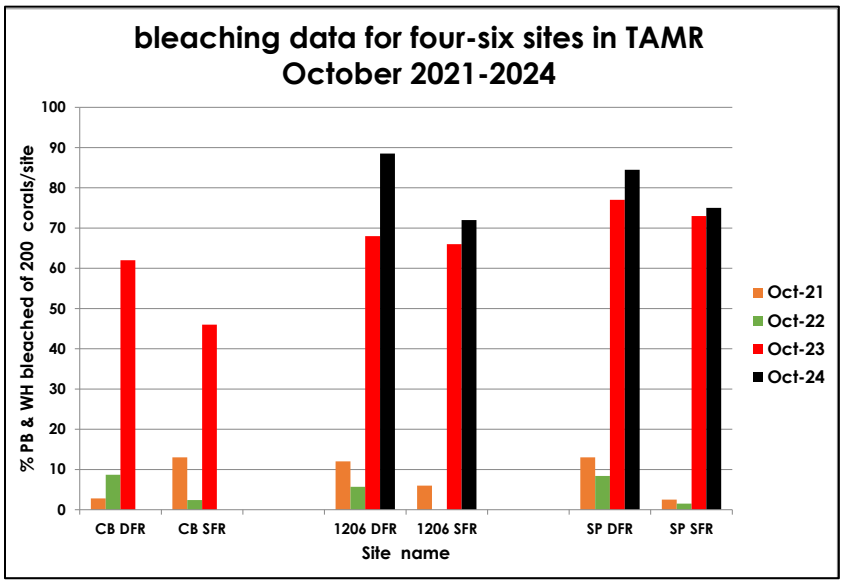
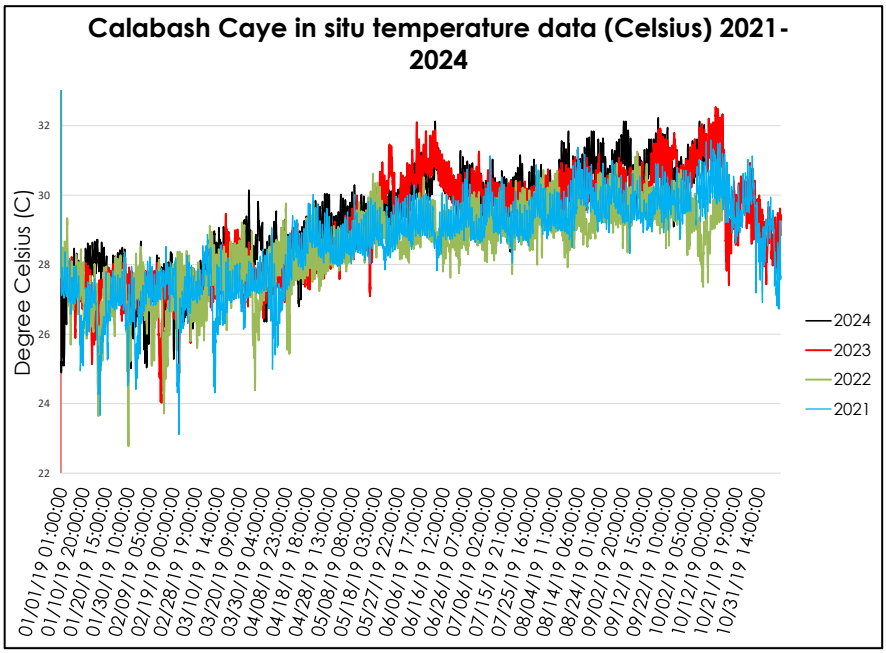
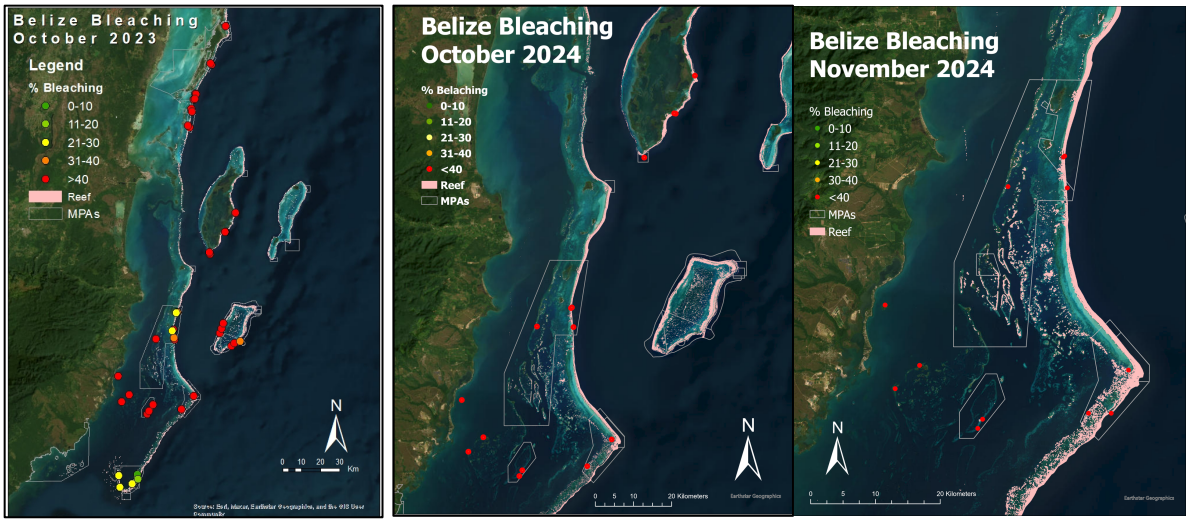


Fig. 5a. Bleaching data during October 2021-2024 reflecting the most severe bleaching in 2024. Site names and coordinates are from the University of Belize. The sites on the left (CB=Caye Bokel) could not be surveyed when FoH was in TAMR due to Hurricane Milton passing, affecting Belize with strong west winds that stirred the waters near Caye Bokel to zero visibility in early October 2024.



Figs. 5b. In situ temperature (Celsius) from the shallow back reef nursery table at Calabash Caye, TAMR, 2021-2024.



Figs. 5c-e. Nationwide maps showing severity of bleaching by color code (L-R) in October 2023 (all NCRMN sites included), October 2024 (FoH sites only) and November 2024 (FoH sites only).

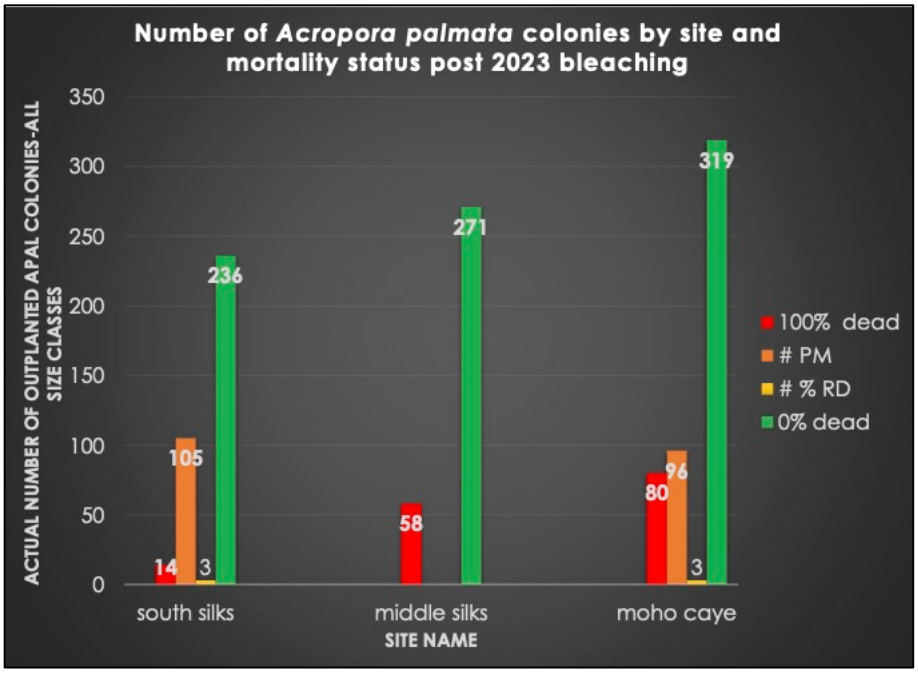


Fig. 6a. Actual number of outplanted *A. palmata* colonies (X -axis) at three sites in southern Belize divided by how many were 100% dead (red), partially dead (PM in orange), recently dead (RD in yellow, and completely unaffected (green). Data from the tw silk cayes were collected n February 2024 and data from Moho Caye November 2023.

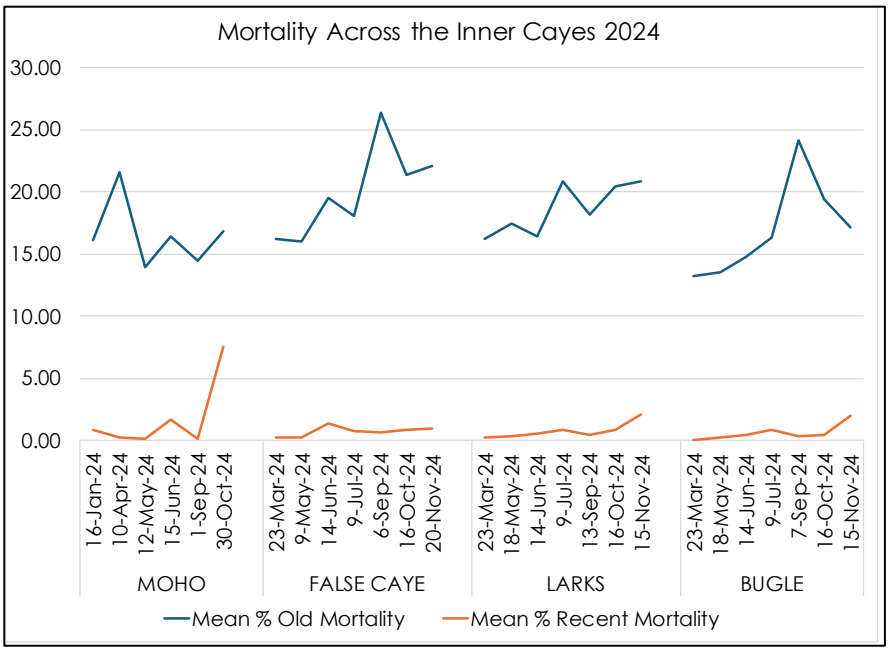


Fig. 6b. Mortality (old and new) collected from the bleaching surveys from four unprotected 'inner cayes' near Placencia. Moho recent mortality data is similar to LBCNP's recent mortality data (Fig 4b), as it is just north of LBCNP, with less surveys completed at Moho.

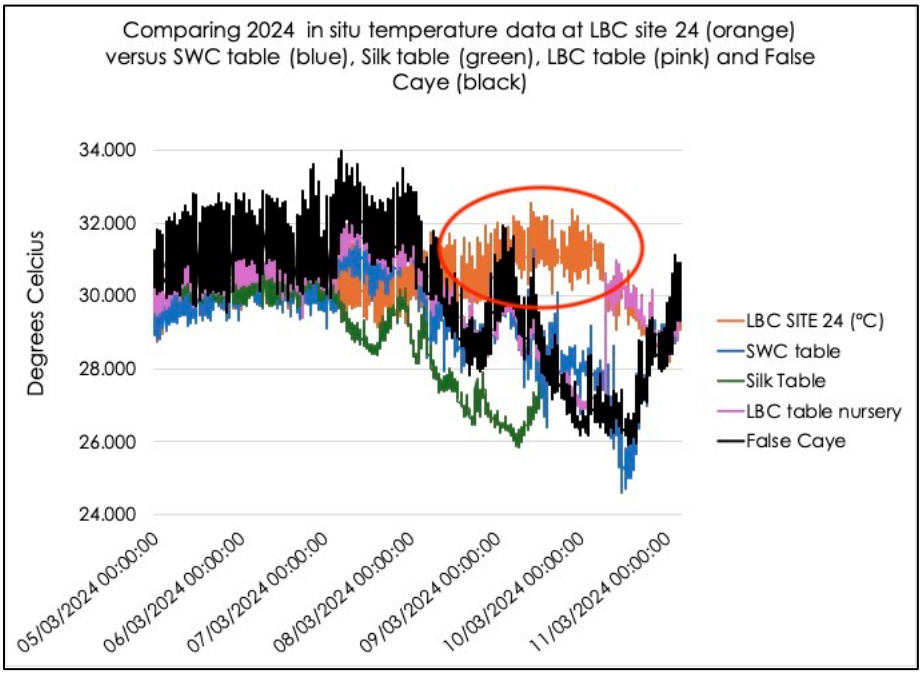


Fig. 6c. Adding additional 2024 temperature data from multiple sites including near shore False Caye (in black) which reached a maximum of almost 34 C in July 2024.

Figs. 6d-f. Example "winning" *A. prolifera*, sourced from Loggerhead Caye, in the False Caye nursery 16 October 2024 (L), "winning" *A. palmata* donor/mother colony on the lee ward side of near shore Larks Caye 16 October 2024 (middle) and "winning" *A. cervicornis* genet in the Caye Caulker nursery as of October 25, 2024 (R).

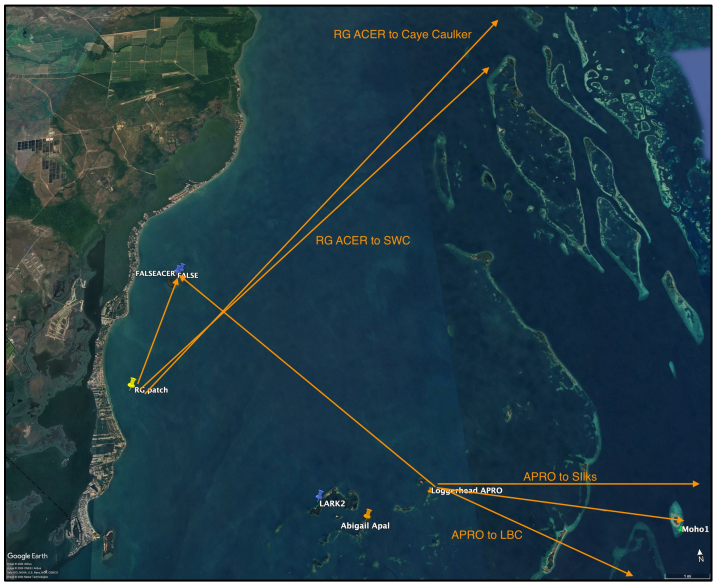


Fig. 6g. Draft example of where the Loggerhead sourced *A. prolifera* has been translocated, as well as the near shore sourced "RG" *A. cervicornis* genet has been transplanted.

Figs. 7a-c. Silk Caye table nursery 29Oct24, showing unaffected *A. prolifera* and bleaching *A. cervicornis*, both sourced from Loggerhead Caye (L). New deeper table at False Caye showing recovered *A. cervcornis* genets (two, both sourced near shore) 20 Nov24 (middle) versus still bleaching and partially recently dead *A. palmata* transplant from 2006 at LBCNP, 20 Nov24 (R).

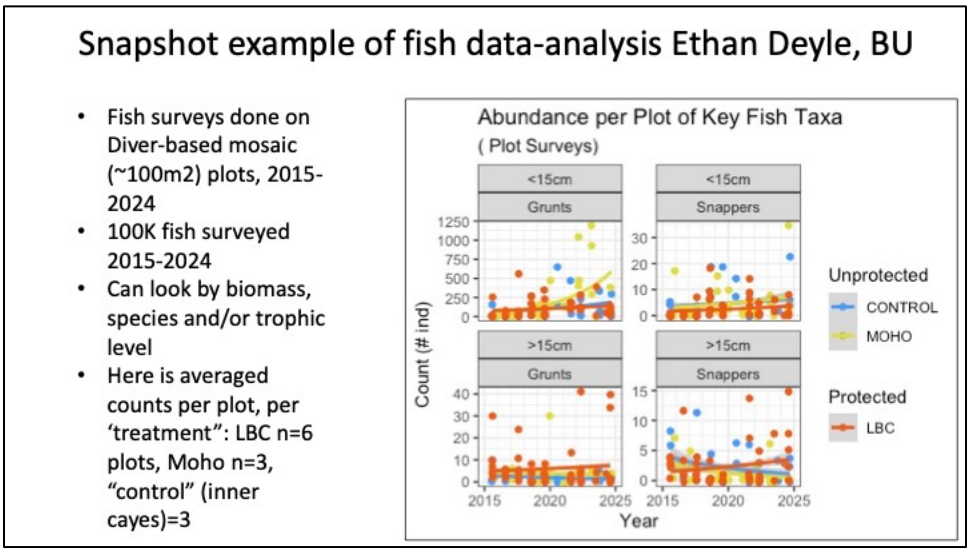
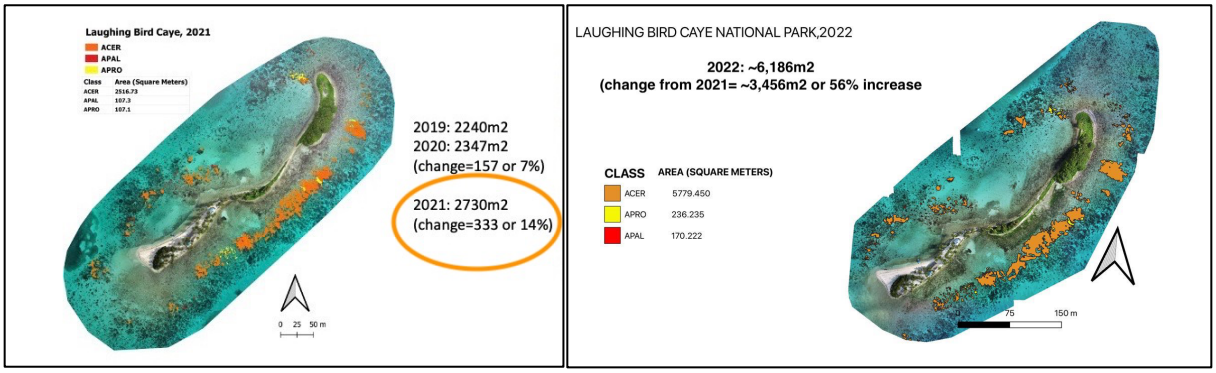


Fig. 8. Visualization of trends in size classes of grunts and snappers. Trends in counts of < 15 cm fish can be interpreted as the changes in the abundance of juveniles, while > 15 cm can be interpreted as changes in abundance of adults. The trend lines show a simple generalized linear model of *Count* as a function of *Year* fit through each of the grouped sites (n = 6 for LBC, n = 3 for Moho, n = 3 for the inner caye "control" locations with no coral replenishment).



Figs. 9a-b. Annotated drone ortho-mosaics from 2021 (L) and 2022 (R) reflecting m^2 by all three replenished acroporid taxa and then totaled. These changes are not from continued outplanting but by natural asexual spread during storm events. 2019-2020 had an increase of 7% acroporid coral cover, 2020-2021 doubled to 14%, and 2021-2023 increased by 56% coverage.

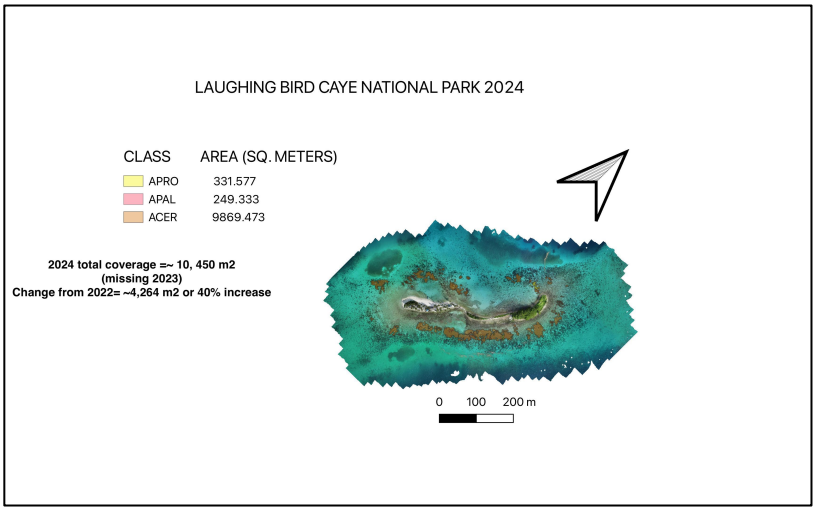


Fig. 9c. The 2024 LBCNP drone ortho mosaic annotated above was conducted prior to the 2024 bleaching event August 2024)

Discussion, Recommendations & Future Plans

The last two years (2023-2024) were the hottest ever on record, and debates remain as to whether this was a two-year anomaly (El Niño then late La Niña) as has been tied to previous global bleaching events, or whether global warming is just increasing each year[2] (Tollefson, 2025). Regardless, NOAA declared this the 4th Global Bleaching Event in 2024[3] and many scholars predict the worse-case scenarios[4] (Ripple, et al. 2024). Since coral mortality began for much of the region in mid-2023, there have been many increased critiques on the futility of reef restoration efforts, along with many varied solution suggestions such as "shading" or "feeding" corals, or treating with "pro-biotics".

In late September 2024, L. Carne was asked to write an opinion piece in Nature (Annex VI) on why coral reef restoration is still a valid effort. For FoH, our strategies remain the same: mapping survivors, genotyping and propagating those survivors, with added emphasis (as in 2024) on building skills sets both in water, and for 2025, with more technology-based skills as a focus. While our coral restoration techniques remain relatively low-tech and low-cost, the way FoH quantifies results (diver based and drone ortho mosaics) has become expensive, and includes issues with lots of large file/data storage. To address this, and our back log of processed but not yet annotated mosaics, FoH will use funding and action plans under the approved CORDAP award[5] entitled, "Building the tools for scientific population management of critically endangered coral species in Belize as a model for other restoration programs". The Fisheries Department has received the full proposal and kindly endorsed this program, scheduled to begin early 2025.

Another popular theme is "land-based nurseries" as "gene banks" for endangered coral species. While this not an FoH plan nor area of expertise, FoH is happy to work with the NCRMN partners, should Belize decide to try this route, or add to our existing tool box.

With such uncertain and rapidly changing environmental and political conditions regarding fossil fuels, we must be ready to employ adaptative management changes and hopefully begin to address the local impacts to coral reefs, collectively.

[2] Nature Vol 637 p.523
[3] NOAA press release
[4] BioScience, Volume 74, Issue 12, December 2024, Pages 812–824,
[5] FOH_CORDAP_award

Annexes I-: Reports from:

- Annex I: Report to CZMAI for July 2024 training.
- Annex II: Accepted abstract for Reef Futures 2024 talk
- Annex III: Spawning data sheet 2024 (Excel file)
- Annex IV: Student Linden Cheek summary report
- Annex V: Student Claudia Baron Aguilar summary report
- Annex VI: Carne_Worldview_Nature

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