Cayman Islands Coral Reef Health and Resilience Assessments

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Field Report

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SUMMARY

During June 2010, a team of 5-7 marine scientists surveyed 41 shallow reefs off Little Cayman, Cayman Brac and Grand Cayman. These surveys assessed benthic cover, population dynamics (size structure and condition) of reef building corals, and community structure of about 100 species of reef fishes, along with a number of factors that confer resilience. At the time of these surveys, the reefs were recovering from a recent (2009) bleaching event and an ongoing outbreak of white plague was threatening the vitality of these communities. In addition, an infestation by a pest species of macroalgae (*Microdictyon* spp.) carpeted northern Cayman Brac reefs and the algae was overgrowing many of the corals.

Coral cover, as estimated from a minimum of 600 points per reef collected in hardground areas from 5-15 m depth, ranged from about 12% to 35%, with island-wide cover (mean value, pooled for all reefs) of 21% for Little Cayman, 22% for Cayman Brac and 26% for Grand Cayman. The dominant space occupier on these reefs was macroalgae, which occupied about 50% of the bottom. Other important colonizers included non-coral invertebrates (especially branching gorgonians and sponges), pest species (bioeroding and encrusting sponges, gorgonians, hydrozoan corals, colonial anemones and tunicates), and crustose coralline algae. *Montastraea*, *Agaricia* and *Porites*, respectively were the dominant genera of corals, in terms of cover. Evidence of past storms (rubble), residual coral bleaching (pale, but recovering corals), and coral mortality was observed in most transects.

Recruits and juvenile colonies of 23 of the 28 dominant coral taxa were observed on these reefs, although *P. astreoides* and *A. agaricites* dominated in terms of total numbers of recruits, making up 30 and 26% of all recruits (943) seen on these reefs. A number of important broadcast spawning species, including isolated colonies of *M. annularis* (complex), *Diploria* spp., *Colpophyllia, M. cavernosa*, and *S. siderea* were also seen at low abundances. Two isolated *A. cervicornis* recruits were identified, but these corals remain rare throughout all islands. Recruitment appears to be higher at Little Cayman, with up to 4 recruits per square meter of reef substrate. Conversely, crustose coralline algae (CCA), an important cue for recruitment, was more abundant on Grand Cayman reefs.

Larger (4 cm+) reef building corals were dominated by *Agaricia agaricites* (approx. 25% of the population), *M. annularis* complex (25%), *P. astreoides* (13%), and *Siderastrea siderea* (10%), with 26 species making up the remainder. *M. annularis* complex colonies were significantly larger than all other species (mean size >40 cm vs. 16-19 cm for other species). Most colonies of M. annularis were from 20-70 cm diameter, with very few colonies from 4-10 cm, while most other species were 4-30 cm diameter. The *M. annularis* complex also exhibited significantly higher levels of transitional mortality (>32%) and old mortality (>25%), while other species were missing from 20-25% of their tissue overall.

The most significant cause of tissue loss was white plague, an extremely virulent coral disease that denudes tissue in a linear manner at a mean rate of 1 cm per day. This disease affects most (>90%) of the corals found on Cayman Island reefs, but it was most common and was having the greatest impact to *M. annularis* (complex). Other conditions of concern included 1) dark spots disease, primarily because this affected species (*A. agaricites; D. stokessi*) that have not been reported with this condition elsewhere; 2) snail predation, which was minor but a potential factor preventing recovery of acroporid populations; 3) overgrowth by clionid sponges and *Trididemnum* tunicates, which were observed killing corals and colonizing denuded skeletal surfaces and exposed substrates; and 4) *Stegastes planifrons* damselfish, which established algal lawns on massive corals that eventually led to their demise. Most other coral diseases known from the western Atlantic were seen on these reefs, but they were relatively uncommon. One disease, Caribbean yellow band disease has severely impacted M. annularis population on many other islands; this condition was seen in the Cayman Islands, but it was fairly rare. Given the extensive amount of old mortality observed on these corals, and the low but widespread occurrence of CYBD, it is possible that an outbreak of this disease occurred in the past.

Reef fishes were dominated by parrotfishes (38%), surgeonfishes (22%), grunts (9%), and wrasse (8%). Important predators (groupers, snappers, jacks, barracuda) were present but at relatively low abundances. Most fish recorded in transects were in the 6-10 cm size class, followed by 11-20 cm and 0-5 cm with very few fish (<2%) over 40 cm in total length. Most of the parrotfish recorded in surveys were 0-20 cm, while most groupers were in the 11-20 cm size class. Interestingly, some juvenile groupers (0-5 cm) were seen on reefs, while the smallest size classes of snappers were absent.

Reefs showed both positive and negative signs of resilience. Biotic factors that degrade resilience included the high cover of macroalgae, coral diseases and pest species. Human impacts were fairly minimal, with possible exception of fishing pressure (grouper, snapper, conch, lobster); and land-based pollution and sedimentation that may be associated with coastal development, dredging and canal development primarily on Grand Cayman. Shallow sites showed signs of diver/snorkeler impacts, especially shallow *Acropora* reefs off Grand Cayman. Positive factors included the presence of recruits of broadcast spawning species, the presence of large *Montastraea* colonies and other species that appear to be resistant to recent disease outbreaks, and the widespread occurrence of tissue remnants on colonies that have died back. Reef structure, presence of deep water near to reef communities, high relief sites with multiple canopy layers and high wave action/currents in certain locations also help enhance resilience.

In general, reefs of all three islands are in better shape than many other locations in the Caribbean, including the Bahamas, Florida, Puerto Rico, and Jamaica. There have been large, historic declines of acroporids, like that seen in other locations. The most important framework corals, M. annularis complex, have also declined precipitously, but many healthy colonies remain and even in those that have suffered large scale tissue loss, living tissue remnants are surviving and continuing to grow. Reefs also still contained groupers and other important predators, as well as other commercially and ecologically important invertebrates (conch, lobster) and fishes (herbivores and omnivores) at higher abundances and of a larger size than that seen in many other Caribbean localities.

Distinct differences were seen in all aspects of these surveys between islands and within individual reefs. A more detailed analysis will be presented in a subsequent report that incorporates additional data not yet included in the present analysis (e.g. algal composition, Borneman's coral data) to better describe the current status of these reefs. The trends observed in 2010 will also be compared to previous studies to identify the changes that have occurred since these studies, potential future trends, and options to enhance protection and conservation of the reefs.

Background

As part of the Global Reef Expedition: Science Without Borders program of the Khaled bin Sultan Living Oceans Foundation, and the Coral Disease and Health Consortium's (CDHC) *Coral Disease Rapid Response Program*, Andrew Bruckner and a team of supporting scientists (Eric Borneman, Amanda Williams, Glynnis Roberts, Tauna Rankin, Amber Little and Jessica Moye) completed coral assessments on 40 reefs in the Cayman Islands, including 17 off Little Cayman, 12 off Cayman Brac and 11 off Grand Cayman (Appendix I). The primary objective of this study was to characterize the dominant species assemblages found on Cayman Island reefs, their abundance, cover, and/or size structure, and condition. The assessments focused on stony corals, fishes and algae, along with several ecologically important motile invertebrates. Survey approaches included belt and point intercept transect methods with both recorded and photographic observations. The methodology combines attributes of the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol and the IUCN bleaching resilience protocol, with cover of benthic substrates, both living and non-living, assessed using a point intercept method.

The main purpose of this work was to 1) characterize impacts of the 2009 coral bleaching event and associated perturbations 2) identify sites in excellent health, exhibiting a high biodiversity and cover of reef building corals and an intact fish communities; 3) assess changes in reef structure and health since the last region-wide AGRRA assessments (1998-2000); 4) characterize the health and resilience of coral reefs on the three islands and rank reefs in terms of their likelihood to persist and/or recover from future large scale disturbances; and 5) recommend possible options to enhance the conservation and management of the reefs, including recommendations on possible MPAs.

The survey approach used will provide critical information on the impact of the recent (2009) bleaching event and relationships between coral bleaching and disease and other biotic stressors, and also recent patterns of recovery via sexual recruitment and growth of juvenile corals. These assessments form one component of a global assessment of coral reefs being undertaken between 2010-2014, with Caribbean assessments in 2010 and 2011. These surveys will utilize the same rapid assessment protocol to characterize population structure and condition of key reef species (emphasizing corals, fish and algae) across landscape scales, past impacts and patterns of recovery, and current threats and resilience indicators.

Acknowledgements

The intensive surveys completed on the Cayman Islands between June 1-16, 2010 represent the dedicated efforts of a talented group of scientists. I am grateful for the assistance and expertise provided to complete rapid ecological assessments and extensive time devoted to data entry by my team, with special thanks to Eric Borneman, Tauna Rankin, Glynnis Roberts, and Amanda Williams who completed 40 surveys during 13 days of intensive diving. The participation during Little Cayman and Cayman Brac surveys by two Central Caribbean Marine Institute (CCMI) research fellows, Amber Little and Flower Moye is also gratefully appreciated. Brenda Gadd and CCMI was very helpful with lodging, meals, boat transport and dive facilities for Little Cayman surveys, and provided excellent facilities for use during the coral disease rapid response training workshop. Amanda Williams also assisted in compiling the dive sites and creating a georeferenced map, and helped compile recruit, point intercept and fish data. The assistance provided by the Department of the Environment, Government of the Cayman Islands was critical to the success of this project. I am especially thankful for the assistance of Timothy Austin, Deputy Director in securing lodging on Grand Cayman, and providing boat use and tanks for our dives on the Grand Cayman sites. Thanks to John Bothwell for his logistical support and efforts in convening press conferences and an evening lecture. The level of enthusiasm and sense of urgency expressed by the Department of Environment, members of the Coral Reef Club at St Matthews University, and concerned individuals provides me with a great sense of hope for Caymanian coral reefs and an understanding of the importance of future conservation efforts to preserve and restore Cayman Island reefs. Funding for reef surveys in the Cayman Islands was provided by the Khaled bin Sultan Living Oceans Foundation with partial support by the NOAA Coral Reef Conservation Program and in kind support for boats and SCUBA operations in Grand Cayman provided by the Cayman Island's Department of the Environment. All surveys were performed under a research permit # granted by the Government of the Cayman Islands, Department of the Environment.

Introduction

Until the late 1970s, benthic substrates on Caribbean reefs were occupied primarily by reef-building corals, with other large invertebrates like sponges and gorgonians often coexisting at lower abundances. Coral reefs exhibited a generalized zonation pattern with elkhorn coral (*Acropora palmata*) forming large, monospecific stands in the reef crest and shallow fore reef (0-5 m depth); stands of staghorn coral (*A. cervicornis*) at intermediate depths (5-25 m depth) on wave exposed reefs and in shallow, protected environments; massive corals (dominated by *Montastraea annularis* complex) throughout the fore reef (5-30 m depth) and in back reef and lagoonal areas; and plating agaricids near the base of the reef (20-40 m depth). Then things began to change – corals began dying, living coral cover plummeted and fleshy seaweeds (macroalgae) began to carpet the bottom.

The potential for disease to modify benthic coral reef habitats was first observed in the mid 1980s, following the Caribbean-wide massive mortality of the black sea urchin *Diadema antillarum.* Within months of the die-off, macroalgae, normally grazed by these urchins began to proliferate and overgrow corals, and in turn, limited the potential for successful settlement and survival of coral planula and recovery of coral populations (Lessios 1988; Carpenter 1990; Hughes 1994; Aronson et al. 2002). An outbreak of WBD emerged in the USVI in 1977 and spread throughout the Caribbean over a period of about a decade, devastating populations of two critical foundation species, *Acropora palmata* and *A. cervicornis* (Bruckner 2003). This led to a region-wide decline of 90-98% of these two formerly dominant branching corals, concurrent increases in macroalgae, and disappearance of “classic” zonation patterns from many locations (Aronson and Precht 2001, Edmunds and Carpenter 2001). Also new to reefs, widespread coral reef bleaching events were first documented in the Caribbean in 1982, followed by 1987-1988, 1990, 1995 and 1998. During each of these events temperature anomalies have been more pronounced and impacts from bleaching were more severe during the latter events (1995 and 1998), although mortality was spatially patchy.

Since the late 1990s, the most important framework corals remaining on western Atlantic reefs today, *Montastraea annularis* (species complex) have begun to exhibit a conspicuous trend of decline throughout the region due to disease, bleaching, predation and increased competition by other benthic organisms (Bruckner and Bruckner 2003, 2006a,b; Edmunds and Elahi 2007).

These corals are now known to be susceptible to at least five major diseases (Weil 2004, Weil and Cróquer 2009), often exhibiting signs of multiple infections simultaneously (Bruckner and Bruckner 2006a). Two of the most devastating diseases, white plague and yellow band disease, emerged in the mid 1990s and their prevalence increased dramatically throughout the region over the last decade in both nearshore and remote locations, with numerous new and devastating outbreaks occurring in deep water areas and widespread tissue loss (Bruckner and Bruckner 2006a).

During the summer of 2005, anomalously warm water temperatures and doldrum-like conditions coincided with a Caribbean-wide mass bleaching event that further compromised these corals. Temperature extremes were most severe off Puerto Rico, the USVI, the BVI and parts of the eastern Caribbean, with record temperatures reported from some reefs. While recovery from bleaching was noted to start in December, an unusual outbreak of white plague began at the same time and continued over the next six months, devastating reefs. In particular, *M. annularis* (complex) colonies lost 50-60% of their live tissue in many locations off Puerto Rico and USVI and colonies that are several hundred years old have disappeared (Ballantine et al. 2008; Rogers et al. 2008; Bruckner and Hill 2009). The unusually fast spreading rates of white plague, along with an unusually long, but slow sustained tissue loss from YBD are also causing impaired skeletal growth and diminished reproductive output (Bruckner and& Bruckner 2006a; Weil et al. 2006). Continued tissue loss and fission may further reduce the reproductive potential of these colonies as the colony diverts more energy to maintenance, increasing the proportion of small, non-breeding colonies in the population.

While coral diseases, bleaching, hurricane damage and other natural stressors have probably affected reefs since they first developed, the impacts have worsened over the last three decades, partially because they appear to be exacerbated by localized human impacts, especially agricultural and industrial runoff, sewage and overfishing, and also because of increasing acidity and warming linked to global climate change. Many of these stressors have cumulative negative impacts on coral reef ecosystem health and are tightly linked, such as increases in the virulence and severity of diseases during bleaching events and other periods of elevated environmental stress. Others such as overfishing of herbivores and predatory fishes can have cascading impacts on ecosystem health by removing species that are critical in controlling harmful algae and corallivores.

As corals die, exposed benthic substrates are monopolized by fleshy macroalgae, encrusting and bioeroding sponges, and other organisms. These "pest" species further compromise remaining corals through direct competition and overgrowth, and may prevent new recruitment and regrowth of damaged corals. Furthermore continued, progressive elimination of *M. annularis* (complex), the dominant long lived broadcast spawners that have been historically considered the most important structural framework coral in the western Atlantic, will lead to unprecedented changes to benthic communities in the western Atlantic. Because of the life history of these corals, the losses of these corals are likely to be permanent, at least in our lifetimes, with major consequences to other species that depend on *M. annularis* (complex) for habitat.

While the current trajectories of reef health do not look promising, there is still time to take action to reverse the trend of reef degradation. In the western Atlantic, reef health varies dramatically between countries. In some senses, diving in the Caribbean is much like going into a time capsule. There are reefs that were badly degraded several decades ago, and coral cover remains low, while other reefs changed less dramatically. Jamaica has often been used as a classic text book case, first in terms of original descriptions of coral zonation, and second in terms of documentation of losses of corals as a result of storms, loss of herbivores and disease, with coral cover declining from 60-80% cover to about 5% cover during the 1980s. Other locations, like the Florida Keys, experienced a slower loss of corals, but the current state is similar – most locations have about 5-10% living coral cover. The Bahamas maintained relatively high cover until 1995, with rapid and extensive losses occurring during the 1995 and 1998 bleaching events; today most Bahamian reefs also have >10% cover. Other reefs that have persisted with fewer large scale mortality events appear to be highly vulnerable to collapse when hit by acute large-scale perturbations. For example, many locations in the USVI and Puerto Rico had high cover of massive and plating corals until recent years, with minimal losses attributed to the 1995 and 1998 bleaching events; areas with 50-60% cover were still commonplace as recently as a decade ago. Unfortunately, the mass bleaching event in 2005 and subsequent disease outbreaks caused dramatic changes, with losses of massive corals exceeding 50% in some locations. Benthic communities on many reefs in Puerto Rico and the USVI also now resemble the Florida Keys and the Bahamas – low amounts of living coral cover, small corals, fewer massive broadcast spawners and more short-lived brooders, and high amounts of macroalgae and other nuisance species.

Several studies from the Cayman Islands since the late 1990s also reported declines in coral cover, but the reefs still had relatively intact populations of massive framework corals as recently as 2008. For instance, Coelho and Manfrino (2007) documented a decline in living cover from about 26% to 16% between 1999 and 2004. This was at least partially attributed to multiple hurricanes, bleaching and disease, and it appeared to have a significant effect on the massive framework corals like *Montastraea* spp. While the Cayman Islands largely escaped the 2005 bleaching event, this region was hit unusually hard by the 2009 bleaching event. One of the main reasons for these surveys was to assess the impact of the 2009 bleaching event, in terms of extent of residual bleaching, partial and whole colony tissue loss, and relationships with disease. The three islands also offer a unique gradient of human impact, with Little Cayman Islands having the lowest level of human pressures due to a total population of less than 200 people.

Methods

Study Sites. The Cayman Islands are in the middle of the Caribbean Sea, and consist of 3 small low-lying, limestone islands: Little Cayman; Grand Cayman; and Cayman Brac. The islands are surrounded by shallow-sloping terraces: the first ends at 8–15 m depth and the lower terrace stops at 15–20 m, before the shelf-edge 'walls' In many locations there are shallow boulder ramparts formed from the once dominant *Acropora palmata* stands. Most reefs have low to medium relief (1–3 m) spur and groove formations. We examined 41 shallow reefs (18 LC, 12 CB and 11 GC) during June 2010 (Fig. 1; Table 1).

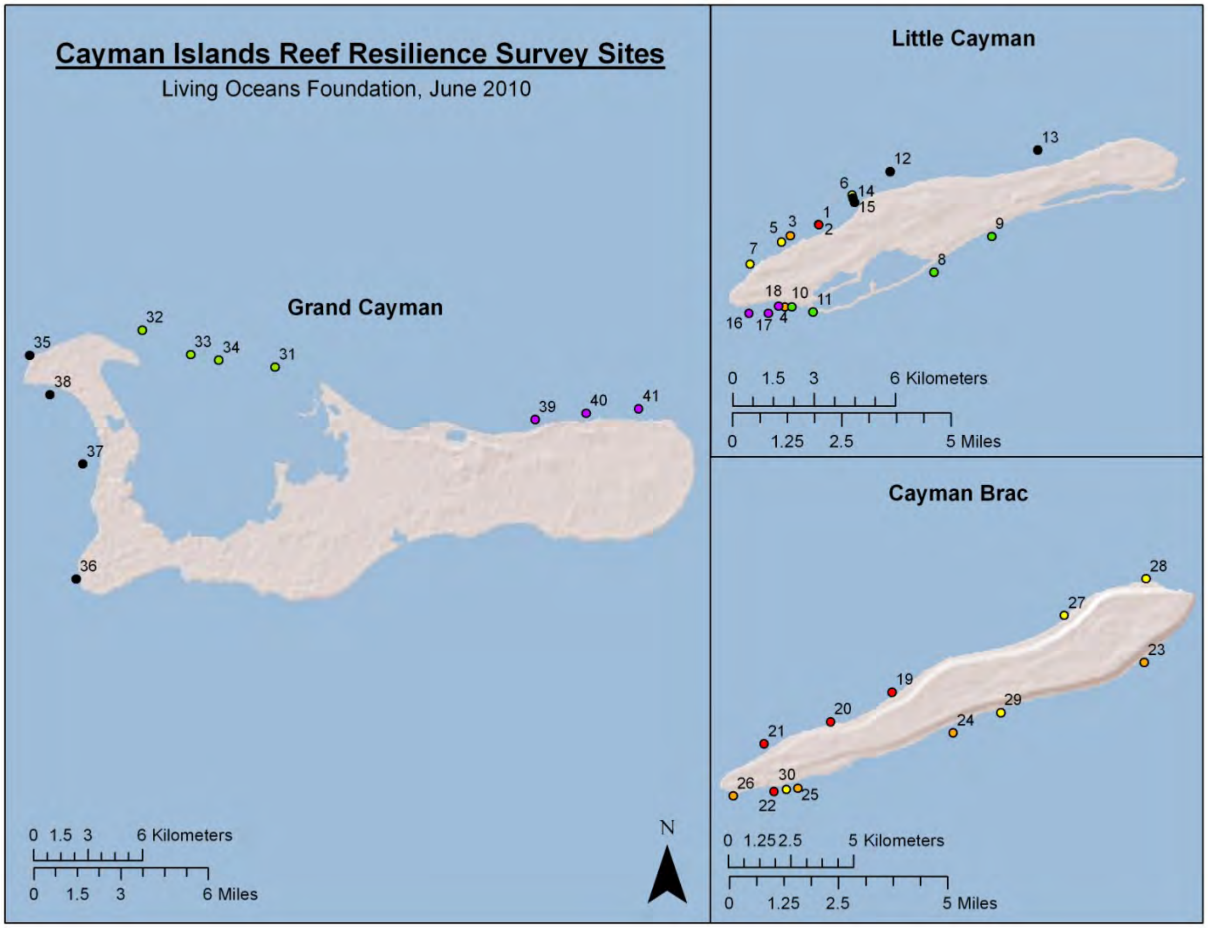


Fig. 1. Location of sites assessed in the Cayman Islands

Survey techniques: Coral, fish and algae community structure were examined on 41 shallow reefs throughout the Cayman Islands (Fig. 1) targeting three depth ranges: 3-6 m, 7-12 m, and 13-18 m depth using three approaches: photographic transects, belt transects, and quadrats. Five measures are recorded for corals: 1) benthic cover; 2) coral diversity and abundance (by species); 3) coral size class distributions (by species); 4) recruitment; and 5) coral condition. For fish, data on abundance and size structure were collected along 2 m X 30 m belt transects for about 65 species of species of fishes, targeting species that have a major functional role on reefs or are major fisheries targets. Other indicators recorded along belt transects included large motile invertebrates (urchins, octopus, lobster, large crabs, queen conch, sea cucumbers); cover and biomass of algae (fleshy macroalgae, turf algae and crustose coralline algae); and prevalence of nuisance species.

Table 1. Sites examined in the Cayman Islands. Date of survey and coordinates are provided.

#	Site	Date	Time	Longitude °W	Latitude °N	Island
1	Donna's Delight	6/3/2010	9:00:00 AM	-80.080666	19.684466	Little Cayman
2	Mixing Bowl	6/3/2010	11:01:52 AM	-80.0808	19.68455	Little Cayman
3	Coconut Walk	6/4/2010	9:08:41 AM	-80.09015	19.68084	Little Cayman
4	Windsock Reef	6/4/2010	12:30:00 PM	-80.0919	19.6573	Little Cayman
5	Joy's Joy	6/5/2010	9:45:51 AM	-80.09312	19.67884	Little Cayman
6	Paul's Anchor	6/5/2010	12:40:00 PM	-80.069683	19.69435	Little Cayman
7	Jigsaw	6/5/2010	2:47:09 PM	-80.10345	19.67137	Little Cayman
8	Lucas Ledge	6/6/2010	8:58:47 AM	-80.04257	19.66875	Little Cayman
9	Coral City	6/6/2010	10:46:29 AM	-80.02336	19.68061	Little Cayman
10	Grundy's Garden	6/6/2010	1:29:05 PM	-80.08973	19.6573	Little Cayman
11	Soto Trader	6/6/2010	3:53:57 PM	-80.08262	19.65556	Little Cayman
12	Rock Bottom	6/7/2010	10:37:53 AM	-80.05712	19.70216	Little Cayman
13	Penguin's Leap	6/7/2010	11:26:19 AM	-80.00812	19.70928	Little Cayman
14	Nancy's Cup of Tea	6/7/2010	1:56:13 PM	-80.06939	19.69335	Little Cayman
15	Meadows	6/7/2010	4:00:00 PM	-80.06883	19.691833	Little Cayman
16	Lighthouse Reef	6/8/2010	8:17:40 AM	-80.10384	19.65506	Little Cayman
17	Dynamite Drop-off	6/8/2010	9:43:13 AM	-80.09748	19.65515	Little Cayman
18	Richard's Reef	6/8/2010	12:16:32 PM	-80.09411	19.65751	Little Cayman
19	Plymouth Rock	6/9/2010	9:27:08 AM	-79.83217	19.71712	Cayman Brac
20	Snapper Reef	6/9/2010	11:16:13 AM	-79.85423	19.70651	Cayman Brac
21	Cemetery Wall	6/9/2010	1:17:35 PM	-79.87812	19.69862	Cayman Brac
22	Angelfish Reef	6/9/2010	3:14:18 PM	-79.87454	19.68148	Cayman Brac
23	Treasure Trove	6/10/2010	9:03:04 AM	-79.74163	19.72778	Cayman Brac
24	Gilembow	6/10/2010	10:53:12 AM	-79.81021	19.70251	Cayman Brac
25	Pillar Coral Reef	6/10/2010	1:07:03 PM	-79.86606	19.68259	Cayman Brac
26	Tarpon Reef	6/10/2010	2:38:27 PM	-79.88923	19.67984	Cayman Brac
27	Cuffs Reef	6/11/2010	9:06:28 AM	-79.77026	19.7446	Cayman Brac
28	Bert Brothers Boulders	6/11/2010	10:53:01 AM	-79.74094	19.7578	Cayman Brac
29	Norbert's Reef	6/11/2010	1:10:52 PM	-79.79315	19.70976	Cayman Brac
30	Elkhorn Forest	6/11/2010	3:03:08 PM	-79.87003	19.68212	Cayman Brac
31	Pinnacle Reef	6/13/2010	9:46:22 AM	-81.29413	19.37935	Grand Cayman
32	Bear's Paw	6/13/2010	11:37:24 AM	-81.36041	19.3978	Grand Cayman
33	Tarpon Alley	6/13/2010	1:17:32 PM	-81.33631	19.38557	Grand Cayman
34	Blue Peter	6/13/2010	3:07:53 PM	-81.32227	19.38285	Grand Cayman
35	Pipeline	6/14/2010	9:29:17 AM	-81.41648	19.38523	Grand Cayman
36	Disneyland 2	6/14/2010	12:07:24 PM	-81.39343	19.27379	Grand Cayman
37	Wildlife Reef	6/14/2010	2:15:00 PM	-81.39003	19.33105	Grand Cayman
38	Peppermint Reef	6/14/2010	3:38:44 PM	-81.40632	19.36562	Grand Cayman
39	Babylon	6/15/2010	9:54:10 AM	-81.16447	19.35322	Grand Cayman
40	Little Bluff	6/15/2010	11:30:10 AM	-81.13893	19.35639	Grand Cayman
41	Split Rock	6/15/2010	1:44:24 PM	-81.1127	19.35865	Grand Cayman

1. Coral community structure and population dynamics.

A belt transect 10 m long and 1 m wide is used to record the number, size and condition of colonies of all coral species for colonies larger than 4cm. A one meter bar, marked in 1 cm increments is used to measure the diameter, width perpendicular to the diameter, height, and amount of mortality. Mortality is divided into three categories: recent, transitional and old. Recent is used for tissue loss occurring within the last 3-5 days; transitional, for mortality for 4-30 days, and old for mortality older than 30 days. Sampling for corals smaller than 4 cm is done using a minimum of five 0.25 m^2 quadrats per transect, with each quadrat located at fixed, predetermined intervals (e.g. at 2,4, 6, 8., 10 m). Within the belt, each coral is recorded to genus and species and a single measure of its maximum diameter is recorded.

Fig. 2. Diver deploying a 10 m transect

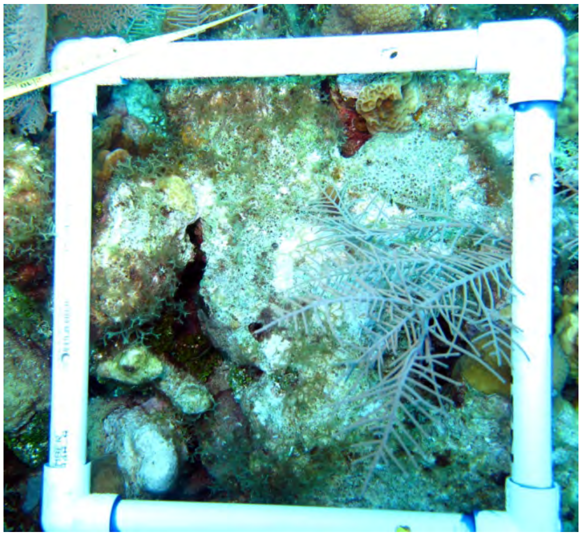


Fig. 3. Five 25 X 25 cm quadrats are placed along each transect line at 2, 4, 6, 8, and 10 m to assess recruitment and algal community structure. Quadrats alternate between the right and left side of the line; large corals are avoided when placing quadrat.

2. Condition of corals

Visual estimates of tissue loss, using a 1 m bar marked in 1 cm increments, was recorded for each colony over 4 cm in diameter. Tissue loss was categorized as recent (occurring within the last 1-5 days), transitional (filamentous algae and diatom colonization, 6-30 days) and old (>30 days). For each coral with recent mortality, the cause of mortality is identified if possible, including identification of the type of disease, extent of bleaching, predation, competition, overgrowth or other cause of mortality. If the coral exhibits recent tissue loss, the amount of remaining tissue, percent that recently died and percent that died long ago were estimated for the entire colony surface. Each coral was carefully examined to identify cryptic predators such as snails and recent lesions are examined to determine if the lesion is associated with skeletal damage, color change, and unusual growth patterns. In particular, colonies with band-like patterns of tissue loss from diseases were differentiated from predation and other possible causes. Data sheet for recording coral observations is shown in Appendix I.

3. Benthic cover

Cover of benthic organisms (plants and animals) was estimated using a point intercept method. At each site a minimum of 6 ten meter long transects are deployed. The organism and substrate type is recorded every ten cm for a total of 100 points per transect. Substrates included hardground, rubble, sand/silt, and dead coral. All corals were identified to species. Gorgonians are recorded as sea fan or branching/encrusting gorgonian. Sponges were further differentiated into crustose, rope, massive, tube and barrel sponges. Algae were divided into five functional groups (fleshy macroalgae, erect coralline algae, crustose coralline algae, turf algae, cyanobacteria) with certain nuisance species recorded to genus (*Microdictyon, Halimeda, Lobophora*, *Dictyota*, *Stypopodium*). Other nuisance species recorded to genus or higher taxonomic level include: *Trididemnum, Erythropodium, Briareum, Palythoa, Cliona langage, Cliona delitrix, Anthosigmella, Millepora*. Data sheet for point intercept surveys is shown in Appendix II.

4. Fish assessments

On each reef two divers completed a minimum of six 30 X 2 m belt transects to assess the community structure of the dominant reef fish species. All species were identified and their size is estimated to the nearest 5 cm using a T-bar marked in 5 cm increments for scale. The assessment focused on species that are ecologically relevant to the health of reefs and also important for commercial or recreational fisheries. The emphasis is on herbivores (parrotfish, surgeonfish, chubs, damselfish), invertebrate feeders and larger piscivores. Parrotfish are also separated into initial phase and terminal phase. Data sheet with all species listed is shown in Appendix III.

5. Resilience indicators

Ecological resilience relates to the entire scope of positive and negative factors affecting a community, such as resource extraction, pollution and invasive species. There are four levels of analysis of resilience that were undertaken:

1) The primary biotic components that make up the reef community - corals, algae, large motile invertebrates and fish communities;
2) The ecological interactions that drive dynamics within and among these groups;
3) Habitat and environmental influences that directly affect the reef associated organisms and the interactions between them; and
4) External drivers of change, including anthropogenic and climate factors.

Resilience data were recorded on a semi-quantitative scale (Likart) of 1-5 (1=minimum, 2=low levels, 5=maximum) for approximately 50 indicators. Where an indicator can be quantified directly (e.g. visibility in meters, slope in degrees) the actual quantity is recorded. Indicators include: 1) the relative abundance of every genera of corals and measures of the largest corals; 2) estimates of cover of broad categories (coral, algae and substrate); 3) physical parameters including depth, temperature, turbidity, sediment characteristics, topographic complexity, slope, and shading; 4) coral condition, prevalence of disease, and presence of coral associates and coral predators; 5) anthropogenic stressors; and 6) oceanographic and environmental parameters such as degree of exposure, facing direction of the reef, proximity to deepwater and possible upwelling, current patterns, and distance to neighboring reefs. See Appendix IV.

6. Photo-documentation

Extensive photographic documentation of reef habitats examined and individual colonies in various states of health were taken during surveys. At each site an overview of the reef is taken from above at four compass points and then representative shots of the bottom are taken. Representative photographs of individual colonies located along belt transects with lesions, including signs of disease, predation, physical damage, and overgrowth, were also taken. One set of photoquads, each 0.25 m long was taken at each location. These represent predetermined locations along each belt transect (2, 4, 6, 8 and 10) examined by Bruckner, with a minimum of 10 quadrats (2 transects) per site.

Results

1. Benthic cover

Coral reefs on the three islands were relatively uniform in cover of living organisms, although there were noticeable site specific differences (Fig. 4, Table 2).

Macroalgae was the dominant space occupier on all reefs. Macroalgal cover ranged from 46% (All Grand Cayman sites) to 56% (All Little Cayman sites), with a low of 35% at Little Bluff (GC) and 46% at Meadows (LC) and to a high of 66% at Windsock and Paul's Anchor (LC). Grand Cayman reefs had significantly lower cover of macroalgae (mean for all sites= 46%), while no sites on Cayman Brac had less than 50% cover by macroalgae (Fig 4). In all locations very little of the substrate (<5%) was covered by turf algae, although epilithic turfs often occurred on macroalgae. *Dictyota* and *Lobophora* were the two dominant genera of macroalgae seen at all sites. In addition, reefs off the northeast end of Cayman Brac exhibited high cover of *Microdictyon*.

Substantial differences were noted among reefs for the cover of crustose coralline algae (CCA). The highest amount of CCA overall was noted on Grand Cayman reefs (15%) and lowest on Little Cayman (3.3%). At least eight sites on Little Cayman (Donna's Delight, Coconut Walk, Richard's, Coral City, Rock Bottom, Meadows, Lighthouse reef and Dynamite drop-off) had moderate cover of CCA (4-6%), while all sites on Grand Cayman, except two (Pipeline, 6.8%; Split Rock, 9.8%) had over 10% coverage by CCA. Cayman Brac exhibited three trends; moderate cover on Angelfish (5.9%), Plymouth Rock (5.3%), Snapper Reef (4.5%) and Gilenbow (3.7%), high cover (7-9%) on Bert's Brothers, Norbert's, Treasure Trove, Cuffs, Tarpon and Pillar Coral, and very high cover (>10%) on Cemetery Wall and Elkhorn Forest).

Living coral cover was highest overall on Grand Cayman (26%) and lowest on Little Cayman (22%), although these differences were not significant. The highest living coral cover overall was at Meadows (Little Cayman, 33% cover) and Gundy's Garden (Little Cayman, 35%). Norbert's reef had highest cover on Cayman Brac (38%), while Little Bluff had the highest cover on Grand Cayman (33%). Poor sites for living coral cover included Lighthouse Reef (LC, 12%), Coconut Walk (LC, 13%), Cemetery (CB, 17%) and Blue Peter (GC, 15%) (Fig. 5. Table 2).

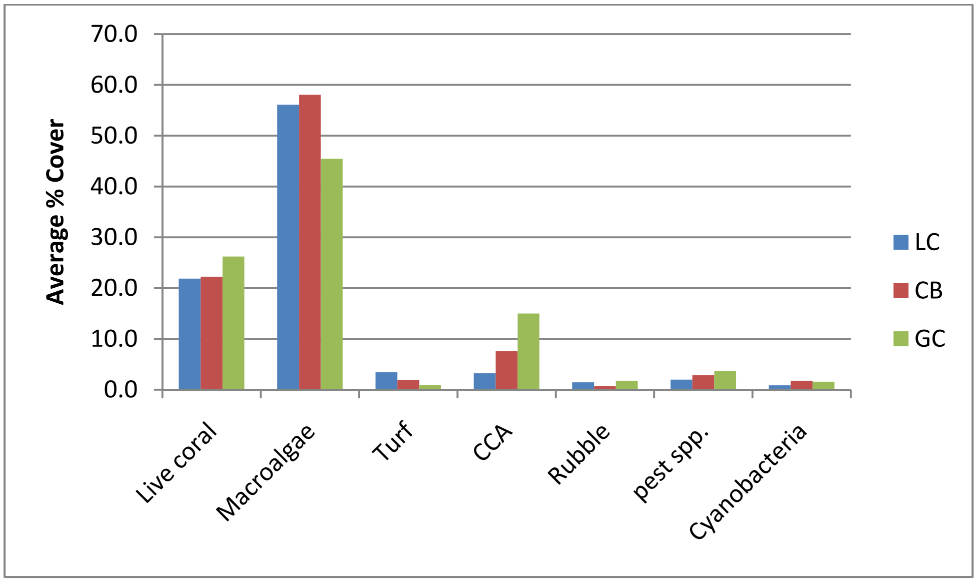


Fig. 4 Cover of key benthic attributes, including stony corals (live coral), algal functional groups (macroalgae, turf and crustose coralline algae, CCA), and factors that degrade resilience (rubble, nuisance species and cyanobacteria).

Most locations where surveys were completed were characterized as hardground areas with shallow spurs, 1-2 m in height at their peak, surrounded by sandflats and sand channels. All transects were positioned such that they extend along the reef, and not into sandy areas, channels or other soft bottom habitats, so cover by sand was minimal. Biological components and benthic features that degrade resilience, including rubble, cyanobacteria and invertebrate nuisance species were recorded on most transects, although they generally occupied a small percentage of the substrate. A large amount of rubble was observed on one site on Little Cayman (Nancy's Cup of Tea), one on Cayman Brac (Cemetery Reef), and three sites on Grand Cayman, Babylon, Bears Paw, and Peppermint Reef (Table 2). The highest cover of cyanobacteria was observed on LC at Lucas Ledge (4.6%), Little Bluff, Grand Cayman (5.2%) and Gilenbow (4.6%), Cayman Brac. Nuisance species (not including macroalgae) covered from 2-4% of the bottom with substantially higher cover on Grand Cayman reefs; these invertebrates also were observed overgrowing living corals (see section on coral community structure). The dominant nuisance species included the brown and orange boring sponges in the genus *Cliona*, encrusting sponges such as *Anthosigmella* and *Chondrilla*, the tunicate *Trididemnum*, and the encrusting gorgonian *Erythropodium*. On Little Cayman three sites had higher than normal cover of nuisance species (Lucas Ledge, 4.6%; Pipeline, 7.7%, Windsock, 6.4%, and Little Bluff, 7.3%). Two reefs on

Cayman Brac (Snapper Reef, 4% and Tarpon Reef, 6.7%) and three on Grand Cayman (Pinnacles, 5.3%; Pipeline, 7.7% and Little Bluff, 7.2%) also had high cover of nuisance species (Fig. 6; Table 2).

One component of the point intercept method involves recording the substrate type under the line. Categories included pavement (or hardground), rubble, sand, dead coral, live coral and recently dead coral. It is also important to note that most of the substrate that was not colonized by corals or other invertebrates consisted of long dead corals that were no longer recognizable to species (but still exhibited a coral shape); very few reefs had large open areas of low-relief hardground that had not been previously colonized by coral. While the entire reef framework is constructed primarily of coral, the intent of the survey was to record dead coral only when the point was located above an old dead coral skeleton that was still recognizable to genus, whereas other hard substrates were listed as pavement. This would include corals that died within the last 2-5 years maximum, as the corallite structures become eroded and undistinguishable over longer time periods. Only three sites on Little Cayman (Coconut Walk, Windsock and Donna’s Delight) were examined in this manner (by Bruckner); these sites show the expected cover of dead corals – 6-20%. The primary researcher that completed all other PI surveys, however, characterized anything that was not flat, open limestone as dead coral. Thus, this measure does not provide an indication of the amount of coral that had died within the last 3-5 years, but rather the percent of the bottom without living coral that contains some structure (e.g. long dead skeletons either in growth position or cemented into the reef, but with no visible corallites or other skeletal structures.

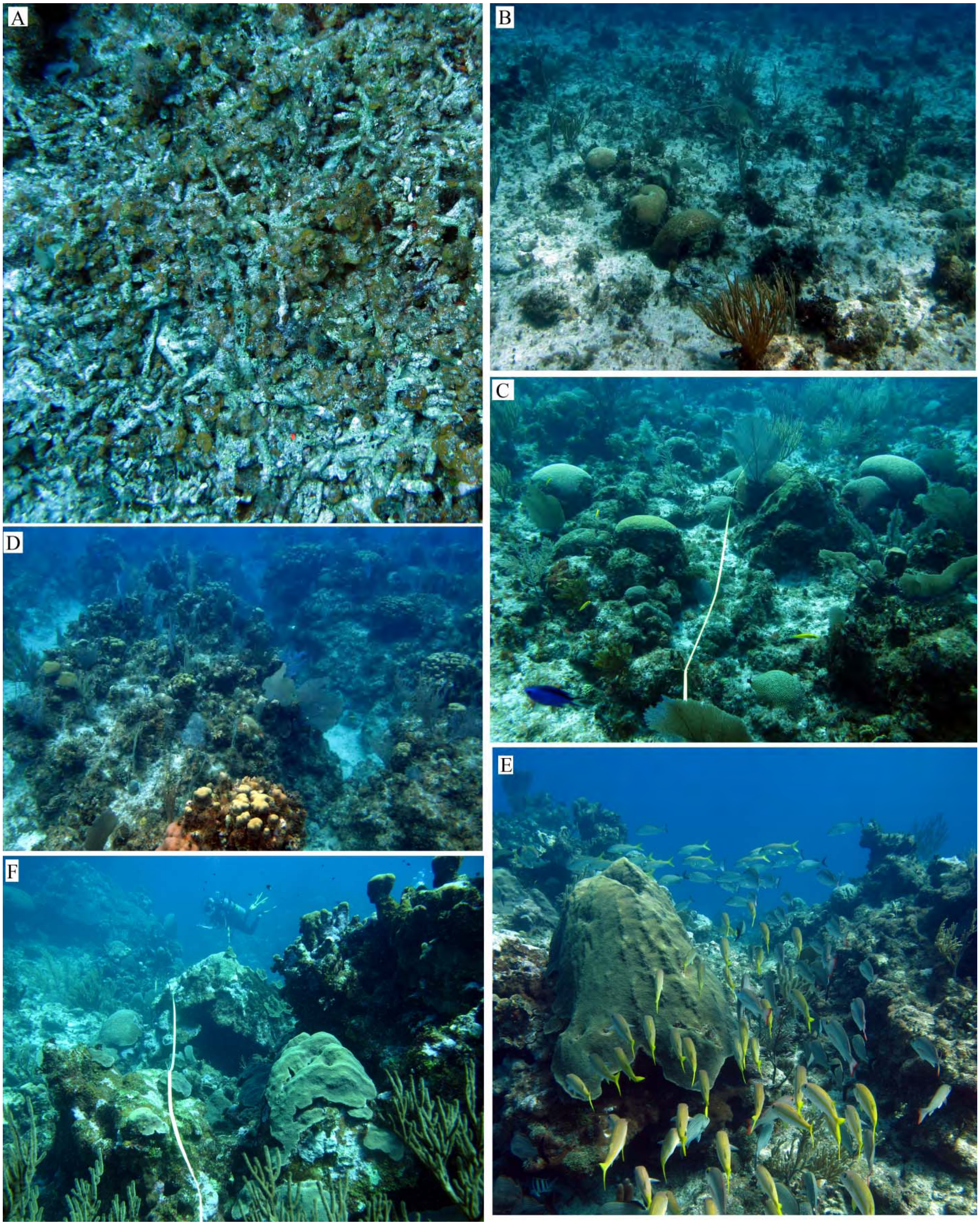


Fig. 5. Representative shallow water habitats in the Cayman Islands. A. Low relief rubble field. Coral was removed and/or flattened by storms or other physical impact. Most dead fragments are *A. cervicornis* which are colonized by turf and macroalgae. B. Low relief hardground with isolated massive and branching corals. C. Moderate relief reef habitat with 0.5-1m boulder corals. D. Moderate relief spur and groove reef system with small to intermediate sized massive corals. E.- F. High relief *Montastraea faveolata* dominated reef .

Table 2a Little Cayman Summary: % cover																			
Substrate	Windsock	Mixing Bowl	Donna's Delight	Coconut Walk	Joy's Joy	Paul's Anchors	Jigsaw	Lucas Ledge	Coral City	Grundy's Garden	Soto Trader	Rock Bottom	Penguin's Leap	Nancy's Cup of Tea	Meadows	Lighthouse Reef	Dynamite Drop-Off	Richard's Reef	Mean
Sand	0.0	2.3	1.0	0.0	0.0	0.6	1.1	1.3	1.3	2.2	1.1	2.1	0.4	1.8	1.5	0.2	0.0	1.4	1.0
Hardground	63.3	26.1	59.0	61.5	1.3	0.2	1.7	2.2	0.1	0.2	0.3	4.9	0.0	0.5	3.8	0.0	0.3	1.4	12.6
Rubble	6.4	0.1	0.5	2.0	0.8	0.8	1.9	0.5	0.8	0.7	0.0	3.1	2.9	3.4	1.9	0.6	0.0	0.1	1.5
Dead coral	6.4	50.6	14.5	21.0	65.5	77.3	67.9	69.5	71.8	59.4	73.0	66.4	70.7	72.7	56.8	82.0	68.8	72.4	59.3
Live coral	23.9	19.9	18.5	13.0	24.4	16.9	23.9	23.9	23.3	34.7	23.1	17.7	22.2	18.0	32.8	12.1	23.8	22.9	21.9
Bleached	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.2	0.0	0.0	0.2	0.1
invert	0.0	1.0	6.5	2.5	8.1	4.3	3.5	2.7	2.8	2.9	2.6	5.8	3.4	3.3	3.0	5.2	7.0	1.6	3.7
Algae																			
Macroalgae	66.1	55.0	49.5	59.5	61.5	66.3	56.3	56.0	56.3	46.2	57.4	55.0	51.8	64.9	46.6	60.3	55.5	45.7	56.1
Turf	1.8	9.4	15.5	2.5	0.4	0.2	0.1	0.9	1.8	2.9	5.0	1.8	2.0	1.9	3.6	2.0	0.5	9.9	3.5
CCA	0.0	4.0	7.5	6.5	1.3	2.0	1.1	1.1	3.3	0.8	0.4	4.6	4.4	2.1	2.6	5.5	5.3	6.5	3.3
Cyano	0.0	0.1	0.0	0.0	0.4	0.1	0.1	4.6	1.7	0.6	0.2	1.1	3.1	0.6	1.1	1.0	0.7	0.5	0.9
coral	23.9	19.9	18.5	11.0	24.3	16.9	23.9	23.9	23.3	34.7	23.1	17.7	22.6	18.2	33.0	12.1	23.8	23.0	21.9
invert	0.0	5.7	6.5	9.0	8.6	10.2	10.5	5.3	5.5	2.8	3.3	11.7	9.5	5.8	6.6	13.5	13.4	3.5	7.3
pest spp.	6.4	1.1	1.5	0.0	1.3	0.7	0.5	4.6	3.3	2.8	1.3	1.1	0.3	2.2	3.9	0.6	0.8	3.1	2.0
Coral																			
Montastraea	9.2	6.0	5.5	3.0	2.9	3.1	4.9	6.3	11.4	18.2	5.3	3.3	5.6	3.3	11.4	0.5	5.2	9.0	6.3
Agaricia	5.5	3.1	4.5	2.0	10.3	5.1	8.3	3.1	3.4	4.1	5.2	4.8	5.9	6.3	9.7	0.8	5.4	2.1	5.0
Porites	6.4	2.9	2.0	3.0	5.5	1.1	2.4	3.3	1.8	3.8	1.0	3.3	5.3	2.4	4.6	5.5	1.6	3.7	3.3
Diploria	0.9	1.6	1.0	0.0	0.3	0.8	1.2	2.8	1.7	2.7	4.1	0.2	0.3	0.3	0.6	1.1	4.1	2.9	1.5
Colpophyllia	0.0	0.0	0.0	0.0	0.1	0.0	0.3	1.2	0.6	0.8	0.0	0.1	0.1	0.0	0.7	0.0	1.2	0.1	0.3
Siderastrea	0.9	2.4	1.5	1.5	1.1	2.7	3.0	4.8	1.3	3.0	4.4	2.6	2.7	2.6	1.5	1.7	2.3	3.2	2.4
Acropora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
other spp	0.9	3.9	4.0	3.5	4.3	4.0	3.9	2.4	2.4	2.2	3.2	3.5	2.4	3.2	4.5	2.6	4.1	1.9	3.1
noncoral	76.1	80.1	81.5	87.0	75.6	83.1	76.1	76.1	76.8	65.3	77.0	82.3	77.9	82.0	67.2	87.9	76.2	77.1	78.1
Summary																			
Live coral	23.9	19.9	18.5	11.0	24.3	16.9	23.9	23.9	23.3	34.7	23.1	17.7	22.6	18.2	33.0	12.1	23.8	23.0	21.9
Macroalgae	66.1	55.0	49.5	59.5	61.5	66.3	56.3	56.0	56.3	46.2	57.4	55.0	51.8	64.9	46.6	60.3	55.5	45.7	56.1
Turf	1.8	9.4	15.5	2.5	0.4	0.2	0.1	0.9	1.8	2.9	5.0	1.8	2.0	1.9	3.6	2.0	0.5	9.9	3.5
CCA	0.0	4.0	7.5	6.5	1.3	2.0	1.1	1.1	3.3	0.8	0.4	4.6	4.4	2.1	2.6	5.5	5.3	6.5	3.3
Rubble	6.4	0.1	0.5	2.0	0.8	0.8	1.9	0.5	0.8	0.7	0.0	3.1	2.9	3.4	1.9	0.6	0.0	0.1	1.5
pest spp.	6.4	1.1	1.5	0.0	1.3	0.7	0.5	4.6	3.3	2.8	1.3	1.1	0.3	2.2	3.9	0.6	0.8	3.1	2.0
Cyano	0.0	0.1	0.0	0.0	0.4	0.1	0.1	4.6	1.7	0.6	0.2	1.1	3.1	0.6	1.1	1.0	0.7	0.5	0.9

Table 2b. Cayman Brac Summary: % cover													
Substrate	Plymouth Rock	Snapper Reef	Cemetery Wall	Angelfish Reef	Treasure Trove	Gilembow	Pillar Coral Reef	Tarpon Reef	Cuffs Reef	Bert Brothers Boulders	Norbert's Reef	Elkhorn Forest	Mean
Sand	0.0	0.3	0.4	1.1	0.4	2.1	0.2	0.2	0.2	0.3	0.1	0.1	0.4
Hardground	2.1	0.8	28.8	23.6	1.1	2.8	4.9	1.9	3.4	5.2	1.0	0.4	6.3
Rubble	0.3	0.8	2.0	0.7	0.4	0.2	0.1	0.4	2.6	0.8	0.2	0.5	0.7
Dead coral	71.3	74.8	48.8	49.8	74.8	67.8	72.0	71.3	68.2	66.7	64.7	78.1	67.3
Live coral	21.2	21.4	16.5	22.7	21.0	23.8	20.3	22.8	23.6	23.7	32.0	17.5	22.2
Bleached	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
invert	5.1	1.9	3.5	2.2	2.4	3.3	2.5	3.3	2.0	3.3	2.1	3.4	2.9
Algae													
Macroalgae	58.7	63.6	60.4	58.2	55.9	56.6	61.7	53.5	57.0	64.7	50.4	56.0	58.1
Turf	0.7	1.3	1.4	2.6	3.1	0.8	1.2	1.5	1.6	3.1	1.6	4.4	1.9
CCA	5.3	4.5	10.8	5.9	7.7	3.7	7.3	9.3	6.8	7.8	6.3	16.0	7.6
erect coralline	0.2	1.3	0.7	0.2	0.3	0.3	0.0	0.2	0.6	0.6	0.3	0.2	0.4
Cyanobacteria	1.7	0.3	0.8	0.9	3.4	5.1	1.0	2.0	1.3	0.9	3.5	0.3	1.8
none	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
coral	21.2	21.4	16.5	22.7	21.0	23.8	20.3	22.8	23.8	23.7	32.0	17.5	22.2
invert	6.1	2.0	4.8	3.3	2.9	6.0	4.4	2.1	1.5	2.7	1.7	3.5	3.4
nuisance spp	2.8	4.0	1.7	2.5	3.1	0.3	1.9	6.7	3.3	3.0	3.1	2.4	2.9
Coral													
Montastraea	4.8	7.3	3.3	6.3	4.4	4.9	5.5	9.8	6.9	9.9	11.0	2.4	6.4
Agaricia	5.3	2.9	5.8	4.3	3.6	4.3	4.0	4.3	4.7	6.4	4.8	5.1	4.6
Porites	6.3	5.3	3.9	5.2	3.5	3.8	2.3	3.9	5.8	2.1	3.4	2.5	4.0
Diploria	0.8	0.5	0.3	2.2	3.5	3.3	2.3	1.2	0.3	0.7	2.3	2.3	1.6
Colpophyllia	0.0	0.2	0.0	0.0	0.5	0.3	1.4	0.3	0.0	1.2	0.0	0.1	0.3
Siderastrea	0.8	2.4	1.1	2.3	2.4	5.6	2.6	1.0	2.3	0.8	3.8	1.3	2.2
Acropora	0.0	0.0	0.0	0.6	0.5	0.0	0.0	0.3	0.1	0.0	0.8	2.4	0.4
other spp	3.4	2.9	2.1	2.0	2.6	1.6	2.2	2.0	3.5	2.7	6.0	1.4	2.7
noncoral	78.8	78.6	83.5	77.3	79.0	76.2	79.7	77.2	76.4	76.3	68.0	82.5	77.8
Summary													
Live coral	21.2	21.4	16.5	22.7	21.0	23.8	20.3	22.8	23.8	23.7	32.0	17.5	22.2
Macroalgae	58.7	63.6	60.4	58.2	55.9	56.6	61.7	53.5	57.0	64.7	50.4	56.0	58.1
Turf	0.7	1.3	1.4	2.6	3.1	0.8	1.2	1.5	1.6	3.1	1.6	4.4	1.9
CCA	5.3	4.5	10.8	5.9	7.7	3.7	7.3	9.3	6.8	7.8	6.3	16.0	7.6
Rubble	0.3	0.8	2.0	0.7	0.4	0.2	0.1	0.4	2.6	0.8	0.2	0.5	0.7
pest spp.	2.8	4.0	1.7	2.5	3.1	0.3	1.9	6.7	3.3	3.0	3.1	2.4	2.9
Cyanobacteria	1.7	0.3	0.8	0.9	3.4	5.1	1.0	2.0	1.3	0.9	3.5	0.3	1.8

Table 2c. Grand Cayman Summary: % cover												
Substrate	Pinnacle Reef	Bear's Paw	Tarpon Alley	Blue Peter	Pipeline	Disneyland 2	Wildlife Reef	Peppermint Reef	Babylon	Little Bluff	Split Rock	Mean
Sand	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Hardground	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.8	0.0	0.5	6.6	1.0
Rubble	0.2	3.0	1.0	0.2	0.0	1.5	1.8	6.2	4.8	0.5	0.2	1.8
Dead coral	79.7	75.0	69.7	85.3	68.8	72.2	65.6	65.2	67.0	66.3	65.2	70.9
Live coral	19.7	21.5	29.3	14.5	31.2	26.3	29.6	27.8	27.5	32.5	27.0	26.1
Bleached	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.7	0.2	0.8	0.2
invert	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algae												
Macroalgae	47.2	48.5	45.7	53.5	43.0	41.3	36.2	40.4	54.8	34.7	55.0	45.5
Turf	0.5	0.2	3.0	0.0	0.0	1.0	4.2	0.4	0.0	1.2	0.0	0.9
CCA	16.5	17.7	12.0	14.8	6.8	23.7	18.2	19.0	12.2	14.3	9.8	15.0
erect coralline	0.0	0.7	0.7	9.5	0.0	0.2	0.2	0.2	0.0	0.2	0.0	1.1
Cyanobacteria	0.2	1.0	1.7	0.2	1.8	1.5	2.4	2.0	0.8	5.2	0.4	1.6
none	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
coral	19.7	21.5	29.3	14.5	31.2	26.3	29.6	27.8	28.2	32.7	27.8	26.2
invert	9.2	3.8	0.7	4.0	8.7	3.3	2.2	2.0	2.2	3.3	6.4	4.2
nuisance spp	5.3	4.0	2.3	2.8	7.7	2.3	4.0	2.8	1.8	7.3	0.4	3.7
Coral												
Montastraea	4.5	2.8	11.7	0.7	8.7	3.8	8.8	6.6	4.2	8.5	5.6	6.0
Agaricia	4.7	4.5	2.0	3.3	7.8	7.5	9.2	10.0	8.8	5.2	8.6	6.5
Porites	0.8	3.5	2.0	2.5	3.0	4.0	5.2	2.8	5.0	12.8	2.8	4.0
Diploria	1.0	1.3	0.0	1.5	1.8	1.5	0.2	0.0	0.3	0.0	0.2	0.7
Colpophyllia	0.0	0.0	4.3	0.0	0.7	1.3	0.0	0.0	0.0	1.8	0.4	0.8
Siderastrea	7.2	8.0	0.7	4.2	2.0	4.2	2.6	1.8	4.5	2.5	2.0	3.6
Acropora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.3	0.2	0.4	0.3
other spp	1.5	1.3	8.7	2.3	7.2	4.0	3.6	5.4	3.3	1.5	7.0	4.2
noncoral	80.3	78.5	70.7	85.5	68.8	73.7	70.4	72.2	72.5	67.5	73.0	73.9
Summary												
Live coral	19.7	21.5	29.3	14.5	31.2	26.3	29.6	27.8	28.2	32.7	27.8	26.2
Macroalgae	47.2	48.5	45.7	53.5	43.0	41.3	36.2	40.4	54.8	34.7	55.0	45.5
Turf	0.5	0.2	3.0	0.0	0.0	1.0	4.2	0.4	0.0	1.2	0.0	0.9
CCA	16.5	17.7	12.0	14.8	6.8	23.7	18.2	19.0	12.2	14.3	9.8	15.0
Rubble	0.2	3.0	1.0	0.2	0.0	1.5	1.8	6.2	4.8	0.5	0.2	1.8
pest spp.	5.3	4.0	2.3	2.8	7.7	2.3	4.0	2.8	1.8	7.3	0.4	3.7
Cyanobacteria	0.2	1.0	1.7	0.2	1.8	1.5	2.4	2.0	0.8	5.2	0.4	1.6

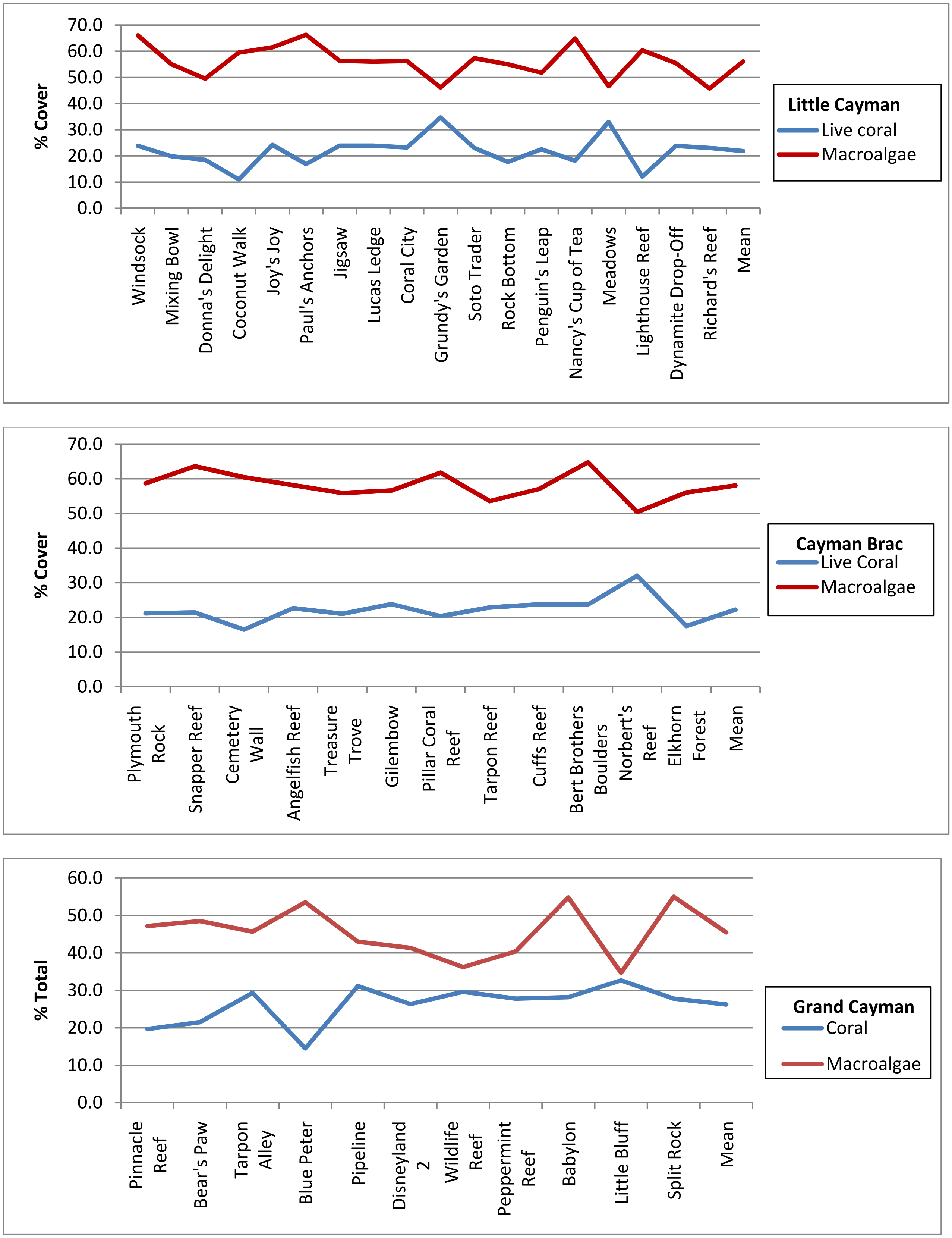


Fig. 6. Relationship between macroalgae and live coral. A. Little Cayman. B. Cayman Brac and C. Grand Cayman.

A total of 28 species of scleractinian corals and two hydrozoan corals were identified in the point intercept surveys. In all locations, the genus *Montastraea* and the genus *Agaricia* were the dominant corals in terms of living cover. Benthic cover by these two taxa was typically around 5-7% cover each, and together they represented 50-80% of the total living coral cover. Reefs on Grand Cayman had slightly lower cover of living *Montastraea* and *Diploria* and significantly higher cover of *Agaricia* and *Siderastrea* when compared to Cayman Brac and Little Cayman. Branching *Porites* (*P. porites* and *P. furcata*) and submassive *P. astreoides* were the next most abundant corals, in terms of living cover, occupying 3-4% of the bottom (Fig. 7).

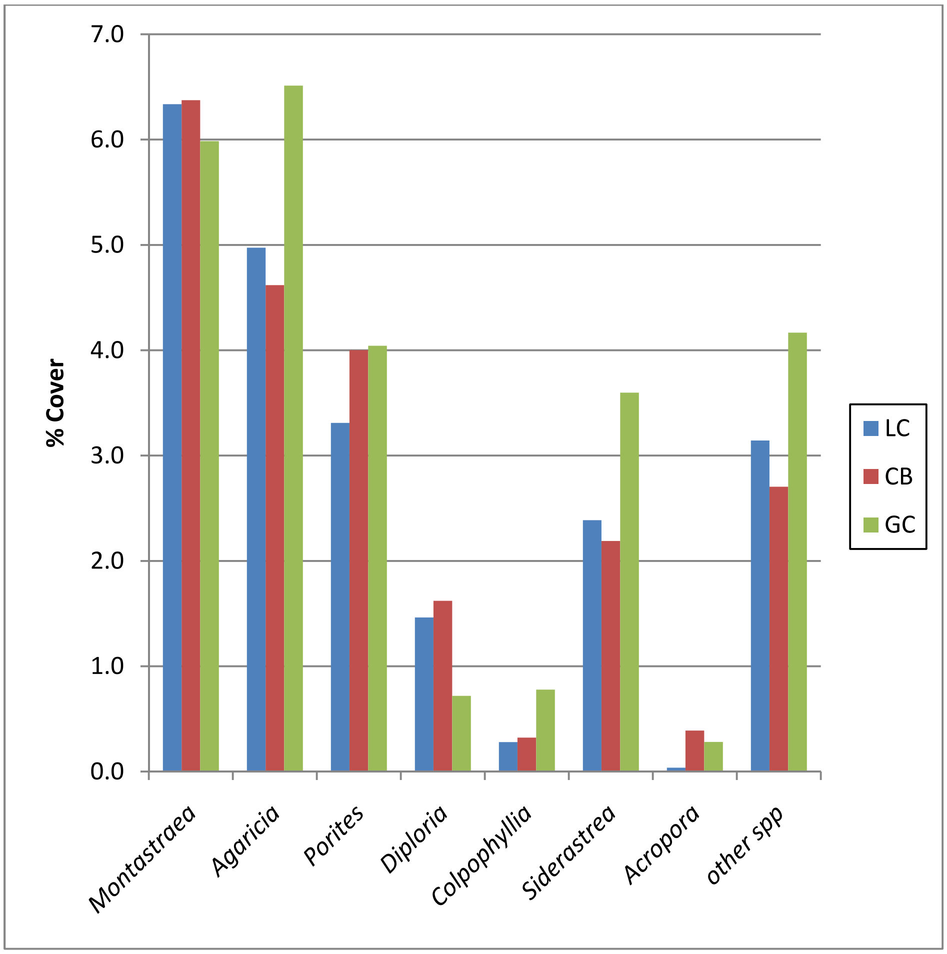


Fig. 7. Percent cover of the dominant reef building corals and other invertebrates for all Little Cayman (LC), Cayman Brac (CB) and Grand Cayman sites. In all locations *Montastraea annularis* complex, *Agaricia agaricites*, *Porites astreoides*, *P. porites* and *S. siderea* were the dominant corals in terms of live cover.

2. Recruitment

The abundance of coral recruits and juvenile corals (0-3 cm) were estimated in 0.25 m^2 quadrats (total of 1560 quadrats examined on all reefs) placed adjacent to transects lines (both belt transects and point intercept transects; 5 quadrats per transect, at 2, 4, 6, 8 and 10 m). A total of 25 species of corals were observed (23 scleractinian corals and two hydrozoans). The dominant recruits in all sites were *Agaricia agaricites* and *Porites astreoides*, although a number of sites had successful recruitment of important broadcast spawners (Fig 8, 9). The total number of recruits of these two species per unit area was significantly higher on Little Cayman reefs (3.5-4 colonies per square meter) when compared to other sites. Little Cayman sites also had higher numbers of recruits of several other species, although this was significant only for *P. porites*, and *S. sidereal*. While numerous remnants of *M. annularis* and *M. faveolata* were identified, only four sexual recruits of *M. annularis* were confirmed (it was not possible to separate these to the species level, however). In addition, only two *A. cervicornis* recruits were recorded, one on Cayman Brac and one on Grand Cayman. In areas with former *A. palmata* stands, isolated recruits and small, asexually generated fragments were found, with a single sexual recruit on one reef in Cayman Brac (Elkhorn Forest). Recruits were least common overall on Grand Cayman reefs. *Siderastrea radians*, an encrusting coral that is relatively small in size as an adult (generally < 10 cm) and is not an important reef builder, was one of the dominant corals observed in Grand Cayman quadrats. It was also common in quadrats located nearshore, on shallow reefs, especially where there was considerable sand movement during periods of high wave action.

In general, recruits exhibited excellent health. No bleached recruits were identified. Certain species appeared to be tolerant of high cover/biomass of macroalgae, especially many of the brooding corals like *P. astreoides* and *A. agaricites*. Recruits were usually found on the substrate, especially near crevices and the margins and base of larger corals. In some cases recruits had colonized dead skeleton, but this was generally only on long dead skeletal surfaces. It was much more common to find tiny tissue remnants on corals that were otherwise largely dead (Fig. 14).

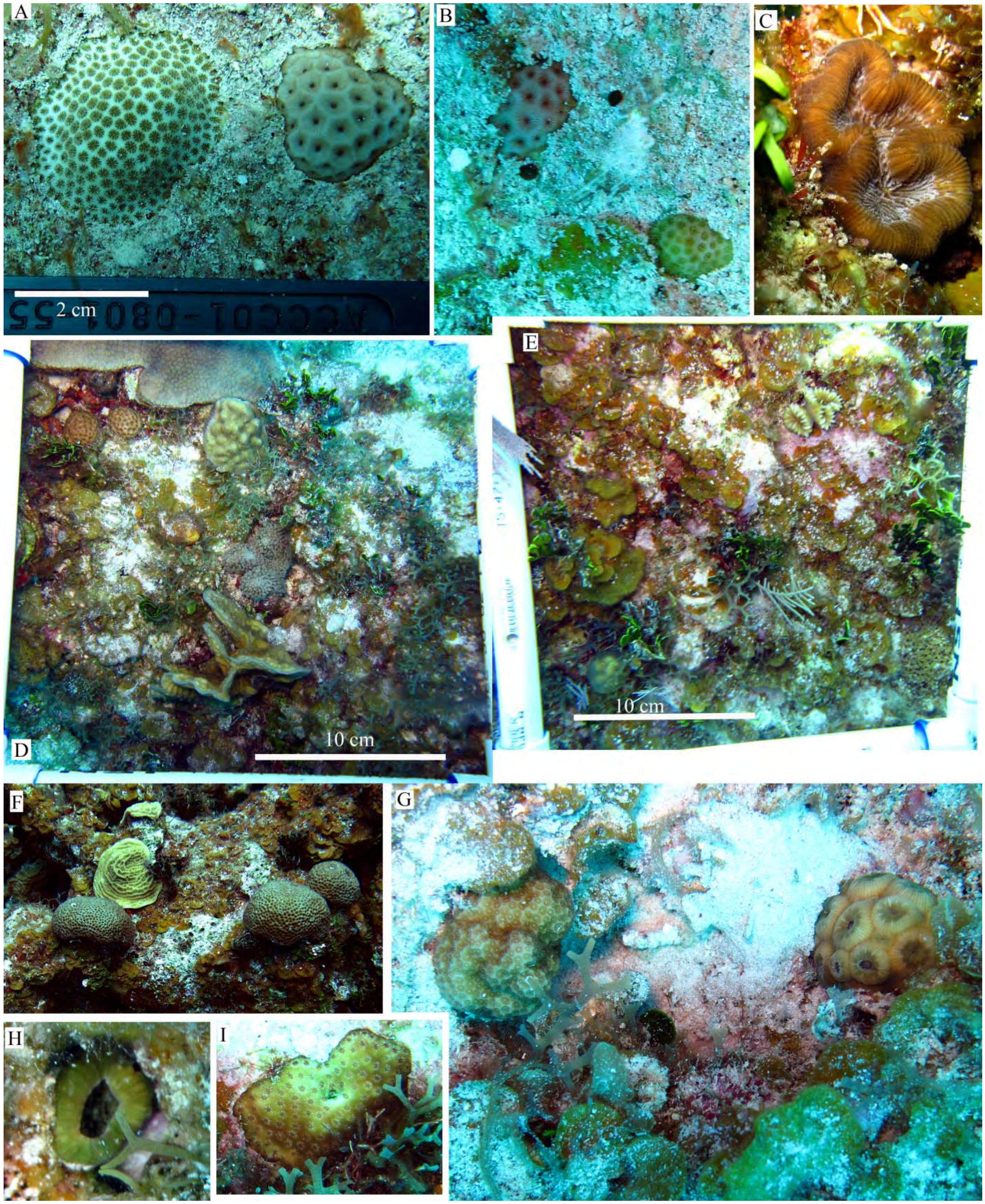


Fig 8. Coral recruitment and juvenile corals. A. small colonies of *S. siderea* and *S. intersepta*. B. Juvenile *S. siderea* and *P. astreoides*. C. Juvenile *C. natans* among macroalgae. D. Representative quadrat showing juvenile colonies of *A. agaricites*, *P. porites*, *P. astreoides* and *S. siderea*. E. Quadrat with a juvenile *E. fastigiata* coral. The substrate is colonized by CCA, turf and macroalgae including *Halimeda* and *Lobophyllia*. F. Juvenile *S. siderea* and *A. agaricites* colonies. G. Small colonies of *P. astreoides* and *M. cavernosa*. H. *M. cavernosa* recruit. I. *M. annularis* (complex) recruit.

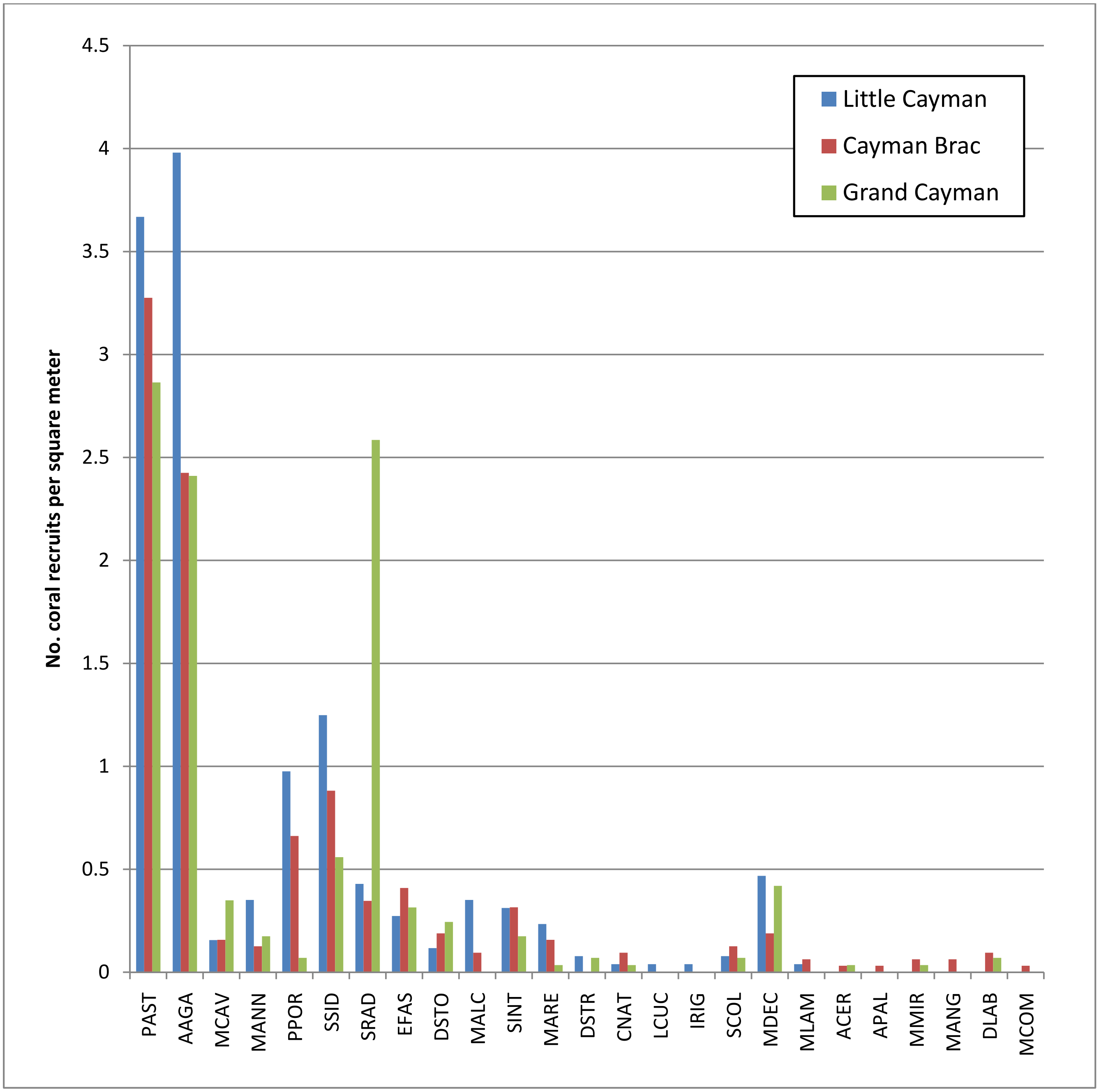


Fig. 9. Total number of coral recruits recorded per square meter of reef on the Cayman Islands, pooled by island. Species abbreviations are the first letter of the genus and first three letters of the species.

The density of recruits was highly variable between sites, although the mean number was fairly similar when all reefs were pooled by island. More than half of the quadrats in all three islands contained 0 recruits, while 25% contained a single recruit, 8-15% contained 2 recruits and only about 5-7% had 3 or more recruits with a maximum of 8 recruits seen in a single quadrat on Little Cayman and Cayman Brac and a max. of 5 recruits/quadrat on Grand Cayman (Fig. 10).

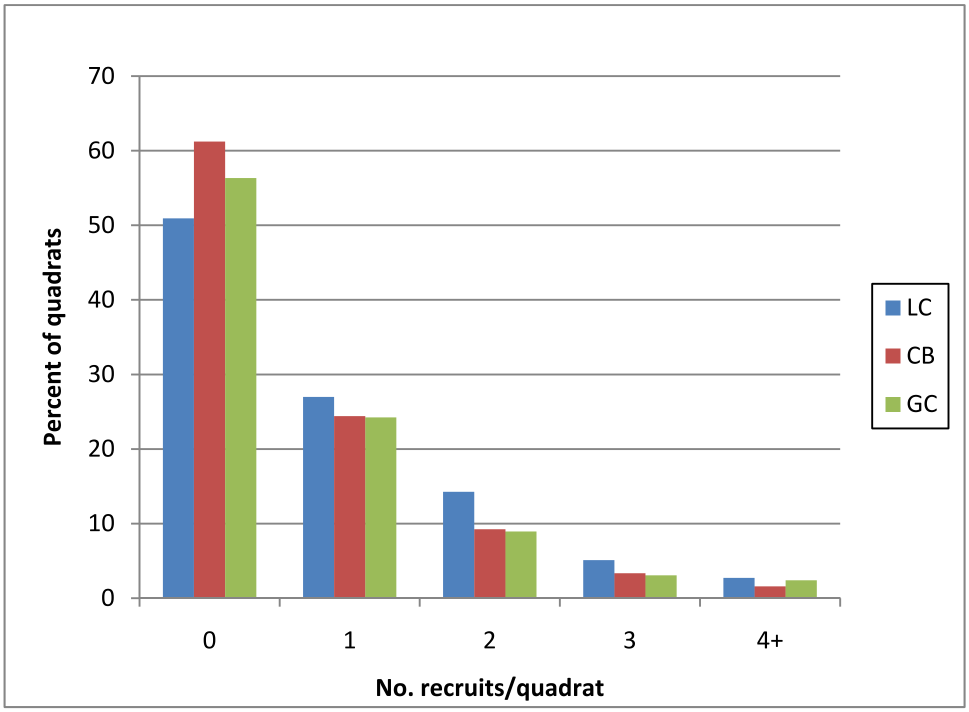


Fig. 10. Number of recruits and juvenile corals (0-3 cm diameter) recorded in 0.25 m2 quadrats on Little Cayman (LC), Cayman Brac (CB) and Grand Cayman (GC).

3. **Coral community structure**

All of the results presented in this section are from belt transects by one researcher (Bruckner) ; data from the second researcher (Borneman) was unavailable. Bruckner examined a total of 6046 scleractinian corals that were 4 cm or larger in diameter on 41 reefs located off the three islands. These surveys included a total of 106 transects. Summary characteristics of the corals (pooled by island) are shown in table 3. The density of corals was remarkably uniform when all sites are pooled by island. Grand Cayman reefs had the highest density at 6.2 corals per square meter, while coral density on Cayman Brac reefs was lowest with 5.4 colonies per square meter. *Agaricia agaricites* was the most common coral recorded on transects, making up 21% (CB) to 26% (LC, GC) of the total coral population. The three species of *M. annularis* (complex) also made up over 25% of all corals on each island; *M. annularis* was the dominant member of the group on Grand Cayman (15% of all corals) and Cayman Brac (13%), while *M. faveolata* and *M. annularis* were at roughly equal proportions (12%) on Little Cayman. Other dominant corals included *P. astreoides* (12-14%) and *S. siderea* (8-14%). Cayman Brac also had significantly fewer colonies of *A. agaricites* and more colonies of *S. siderea* than both Little Cayman and Grand Cayman.

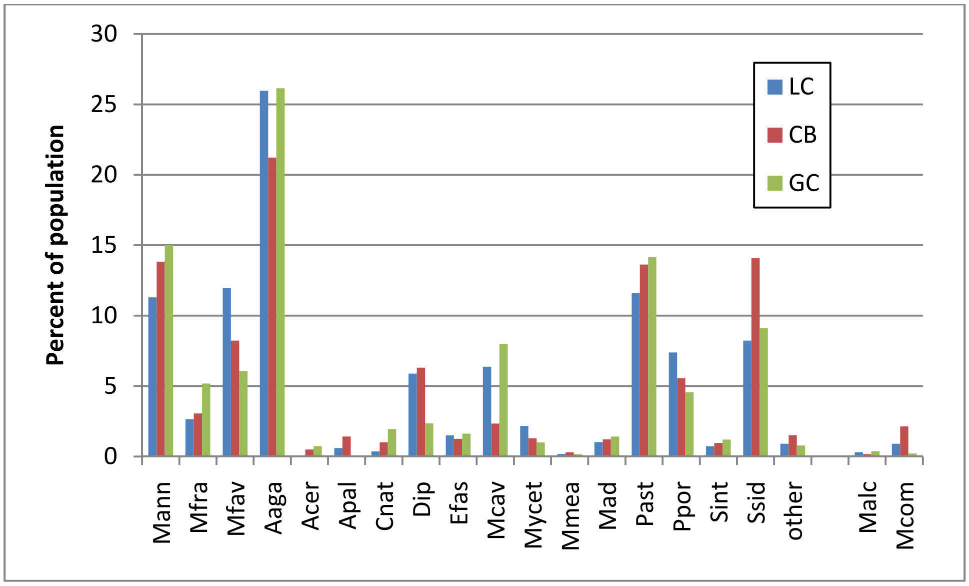


Fig. 11. Breakdown of coral taxa recorded in belt transects for Little Cayman (blue), Cayman Brac (red) and Grand Cayman (green). Three species are pooled for *Mycetophyllia* (Mycet), including *M. lamarkiana*, *M. danaana* and *M. ferox*; *Diploria strigosa* and *D. labyrinthiformis* are pooled (Dip); Mad includes *Madracis mirabilis, M. decactis* and *M. pharensis*; other includes *Dendrogyra cylindricus, Isophyllia sinuosa, I rigida, Dichocoenia stokessi, Mussa angulosa, Helioseris cuculata*, and *Manacina aereolata*.

Corals (pooled for all reefs and species per island) were very similar in mean size between islands (25-27 cm diameter), but there were minor (non significant) differences between species groups with the largest *M. annularis* colonies (mean = 46.4 cm) on Cayman Brac and the smallest on Grand Cayman (mean=42 cm); all other species were slightly larger in mean size on Grand Cayman (22 cm) and smallest on Little Cayman (mean=19 cm). Colonies of *M. annularis* (complex) were missing a significantly large amount of tissue (>60%) than other species. In all corals there was a relatively low amount of recent mortality but a much higher amount of transitional mortality (tissue loss within the last two months) which suggests a major disturbance had occurred and was still ongoing at the time of the surveys. Transitional mortality was also substantially higher in *M. annularis* (complex) than in other species; the amount of recent mortality in this taxa was greatest on Grand Cayman reefs (1.5%). Both *A. cervicornis* and *A. palmata* colonies were rare. *A. cervicornis* was not identified on Little Cayman and in other locations it occurred as isolated colonies; no thickets were found. *A. palmata* was not observed on any of the mid depth reefs (8-15 m depth) but small thickets were seen in shallow water (1-3 m depth) off Cemetery Reef. One reef on Cayman Brac (Elkhorn Forest) formerly had large stands of this coral, but only isolated standing colonies and a number of fused fragments were surviving on this reef.

Table 3. Mean size of corals, colony density and amount of tissue loss pooled for all transects surveyed by island. Tissue loss was characterized as recent dead (loss that occurred within the last 3-7 days), transitional (8-30 days) and older mortality (old dead, > 30 days) from reefs off the Cayman Islands. Data are shown for all species (, *M. annularis* complex (Ma), and all species except for *M. annularis* (other).

	Little Cayman			Cayman Brac			Grand Cayman		
	All	Ma	Other	All	Ma	Other	All	Ma	Other
Total # colonies	1703	427	1276	2414	605	1809	1929	506	1423
Density (#/m^2)	5.7	1.4	4.3	5.4	1.3	4.0	6.2	1.6	4.6
Diameter (cm)	25.3	44.4	18.9	26.6	46.4	20.0	27.5	42.3	22.2
Width (cm)	21.1	37.4	15.6	23.7	41.8	17.6	24.1	38.7	18.9
height (cm)	21.1	37.4	15.6	23.7	41.8	17.6	24.1	38.7	18.9
% old dead	14.1	28.1	9.4	12.6	26.3	8.0	16.5	32.4	10.9
% transitional dead	16.4	32.2	11.1	16.9	33.5	11.3	19.3	35.2	13.7
% recent dead	0.3	0.5	0.3	0.3	0.4	0.3	0.5	1.5	0.2

The size structure of colonies was remarkably similar between locations, with only minor differences in certain size classes. In general, *M. annularis* colonies were larger than all other species (Fig. 12 a,b). There were relatively few colonies of *M. annularis* that were 10 cm or smaller in diameter, whereas 23-37% of the colonies of other species were in this size class. There were also minor differences between islands, with many juvenile corals (other species) on Grand Cayman (23% of the population) when compared to Little Cayman and Cayman Brac. In all locations, over 80% of other species were less than 40 cm diameter while <40% of the M. annularis colonies were in these size classes. The largest corals overall were *M. annularis* and *M. faveolata* with some corals that were over 600 cm diameter. All other species were considerably smaller, with few colonies over 1 m in diameter. Cayman Brac and Little Cayman had a larger proportion of colonies of other species that were 4-10 cm, while Grand Cayman reefs had a higher proportion of corals in the 20 cm size class (Fig. 12b).

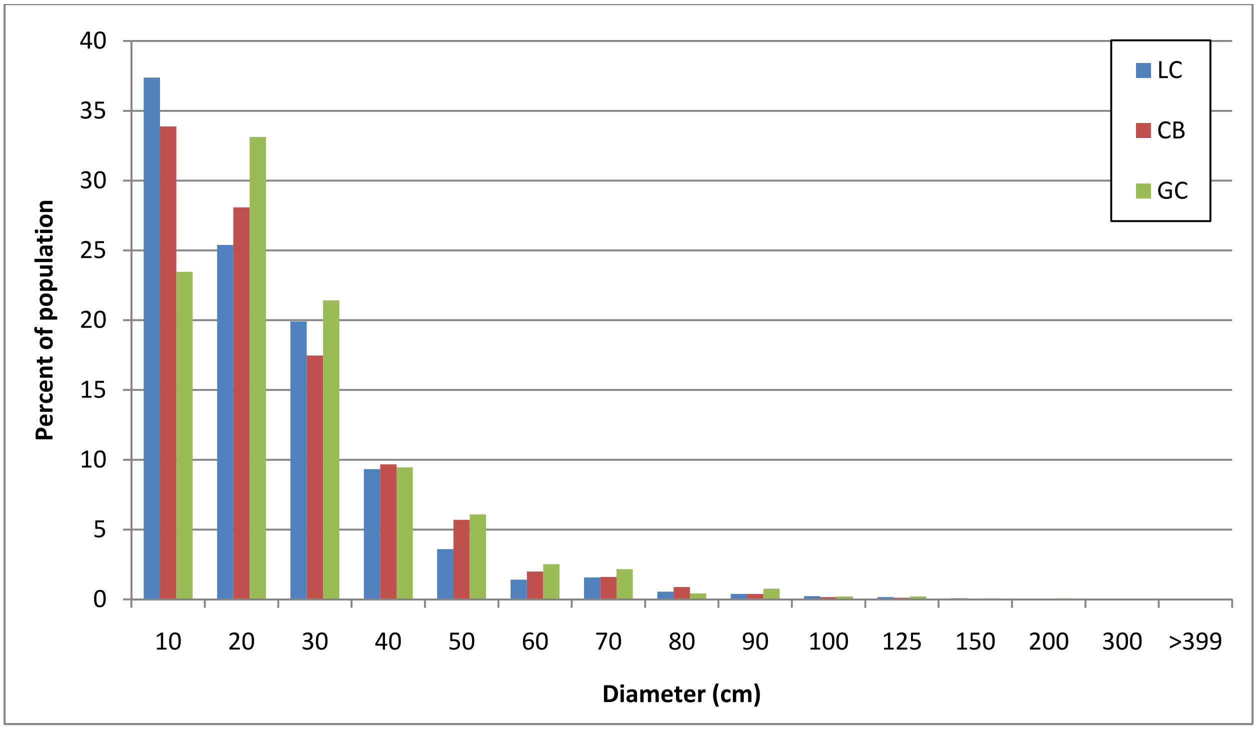


Fig. 12a Size structure of all species except *M. annularis* (complex) on Little Cayman (LC), Cayman Brac (CB) and Grand Cayman (GC).

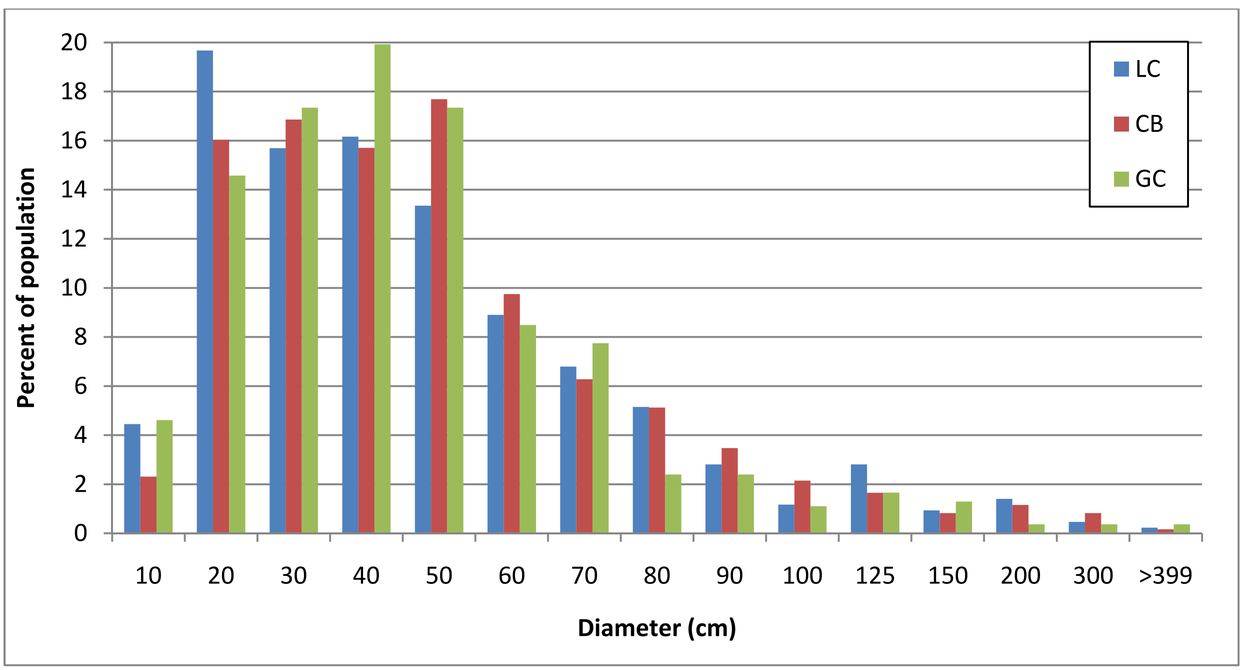


Fig. 12b Size structure of *M. annularis* (complex) on Little Cayman (LC), Cayman Brac (CB) and Grand Cayman (GC).

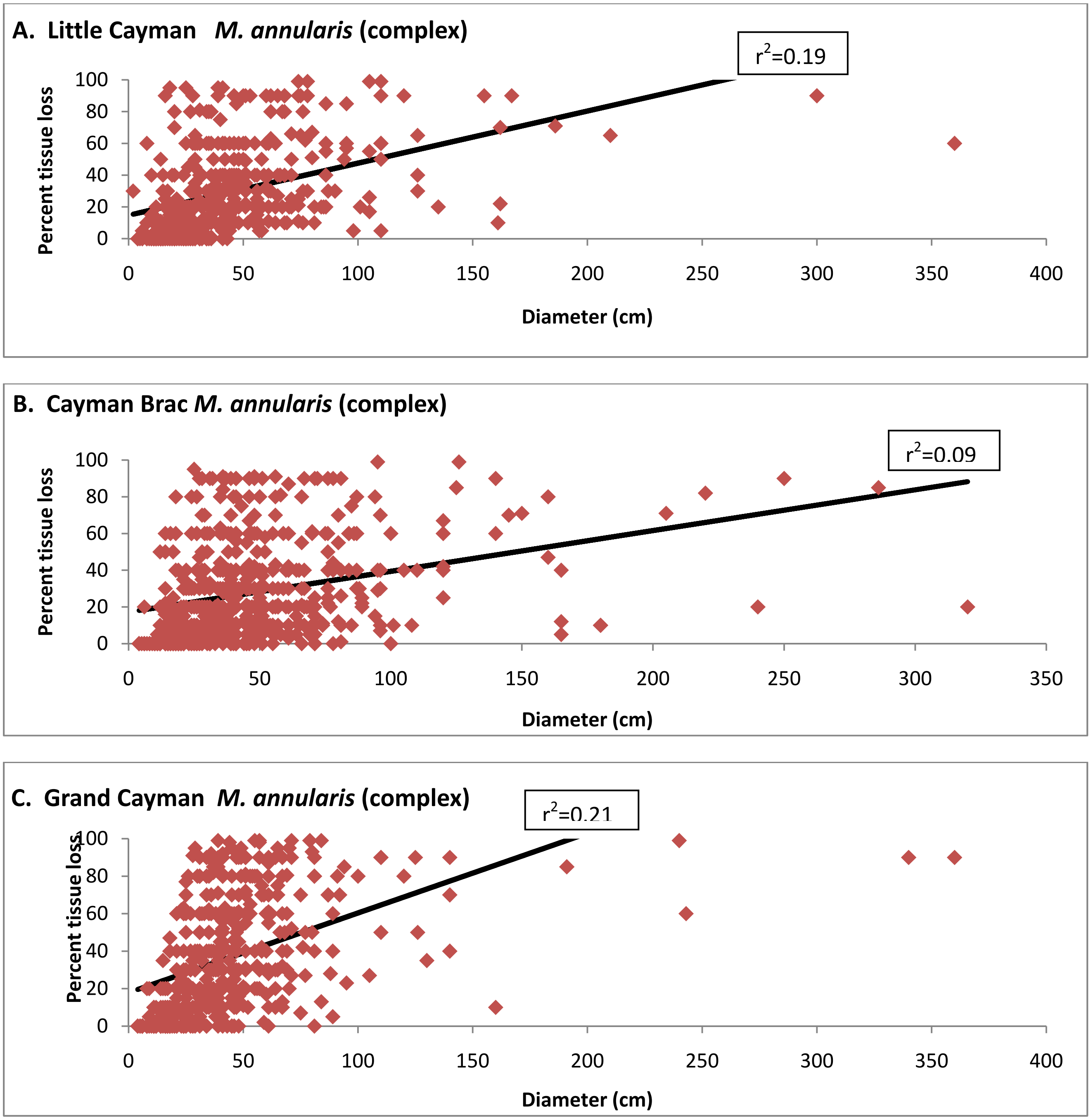


Fig. 13a. Relationship between size (diameter in cm) and amount of missing tissue (recent, transitional and old mortality are pooled) for reefs off Little Cayman (a), Cayman Brac (b) and Grand Cayman (c) for *Montastraea annularis* (complex).

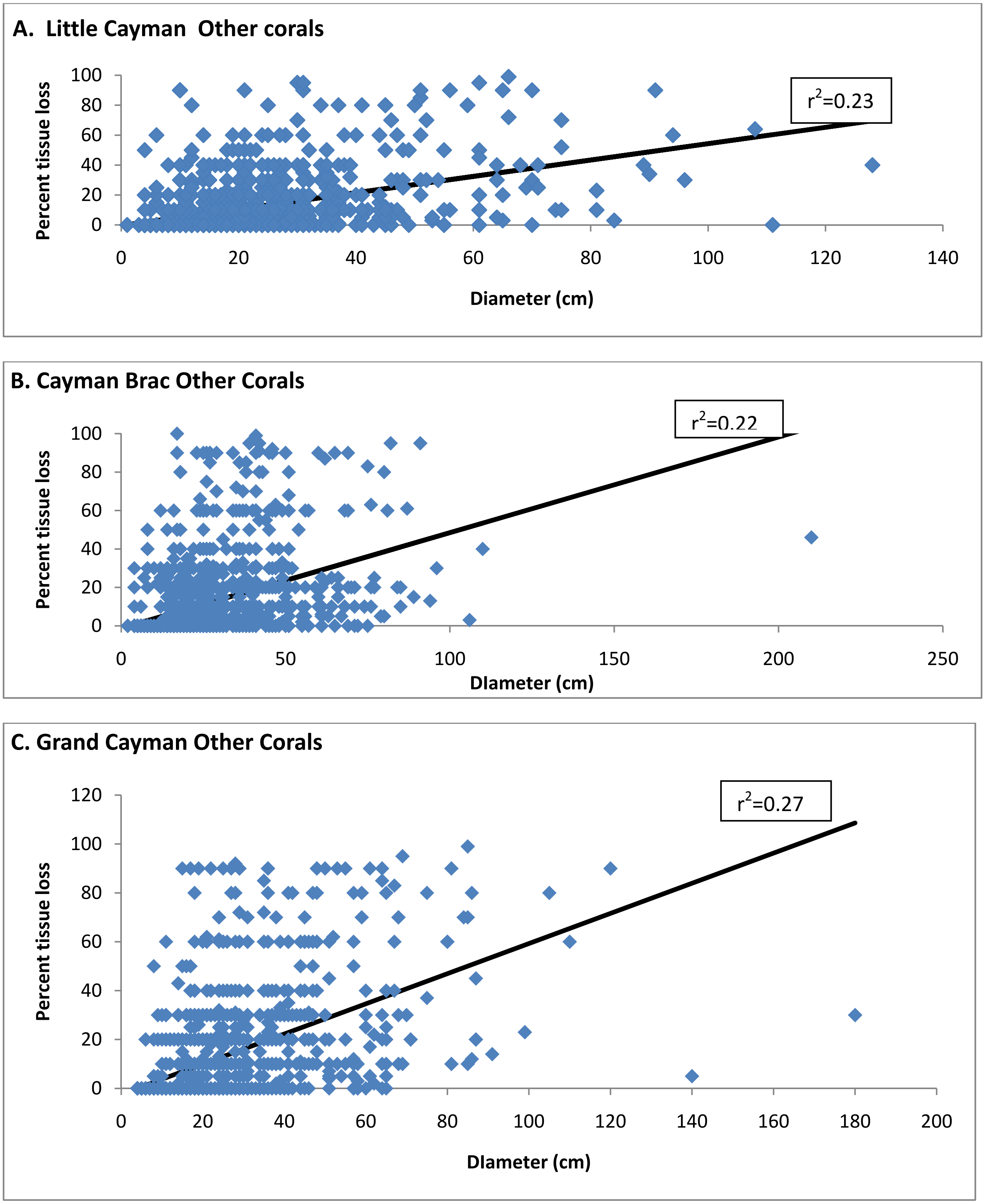


Fig. 13b. Relationship between colony size and amount of missing tissue (recent, transitional and old mortality are pooled) for reefs off Little Cayman (a), Cayman Brac (b) and Grand Cayman (c) for all species except the *M. annularis* complex

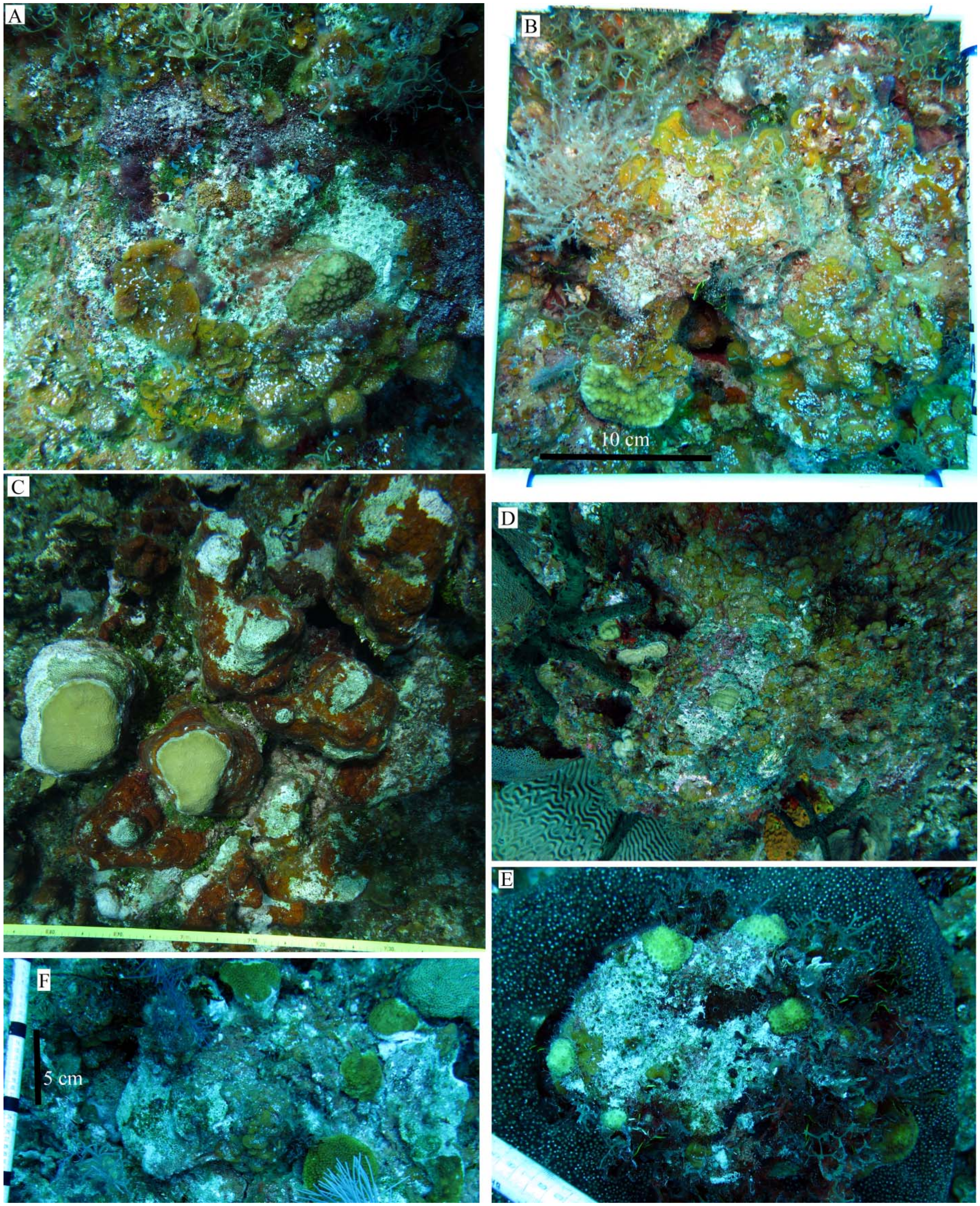


Fig. 14. Examples of resilience in corals. A. remnant of *M. franksi*. B. *M. faveolata* remnant. C. *M. annularis.* most lobes died and are overgrown by *Peysonneli* algae. D. *D. labyrinthiformis* with 99% mortality. A small remnat is visible in the center of the colony. E. *M. faveolata* colony being overgrown by *Cliona langae*. Five small remnants remain, and are exhibiting continued growth. F. *M. franksi* remnants.

The amount of tissue loss (pooled, old, transitional and recent mortality) on individual colonies ranged from 0-99%, with a minor but significant correlation between the amount of tissue loss and colony size for *M. annularis* (Fig. 13a) and a slightly greater correlation observed in other species (Fig. 13b). It is important to note that numerous colonies exhibited tissue loss that exceeded 75% of their surface regardless of the size, although most (>90%) corals with transitional and recent mortality were 20 cm or larger in diameter. Another tendency is for large colonies to be subdivided into smaller isolates, which continue to shrink in size possibly until they die. There were also a high proportion of colonies that lost most of their tissue, but small tissue remnants had survived and were continuing to grow (Fig. 14).

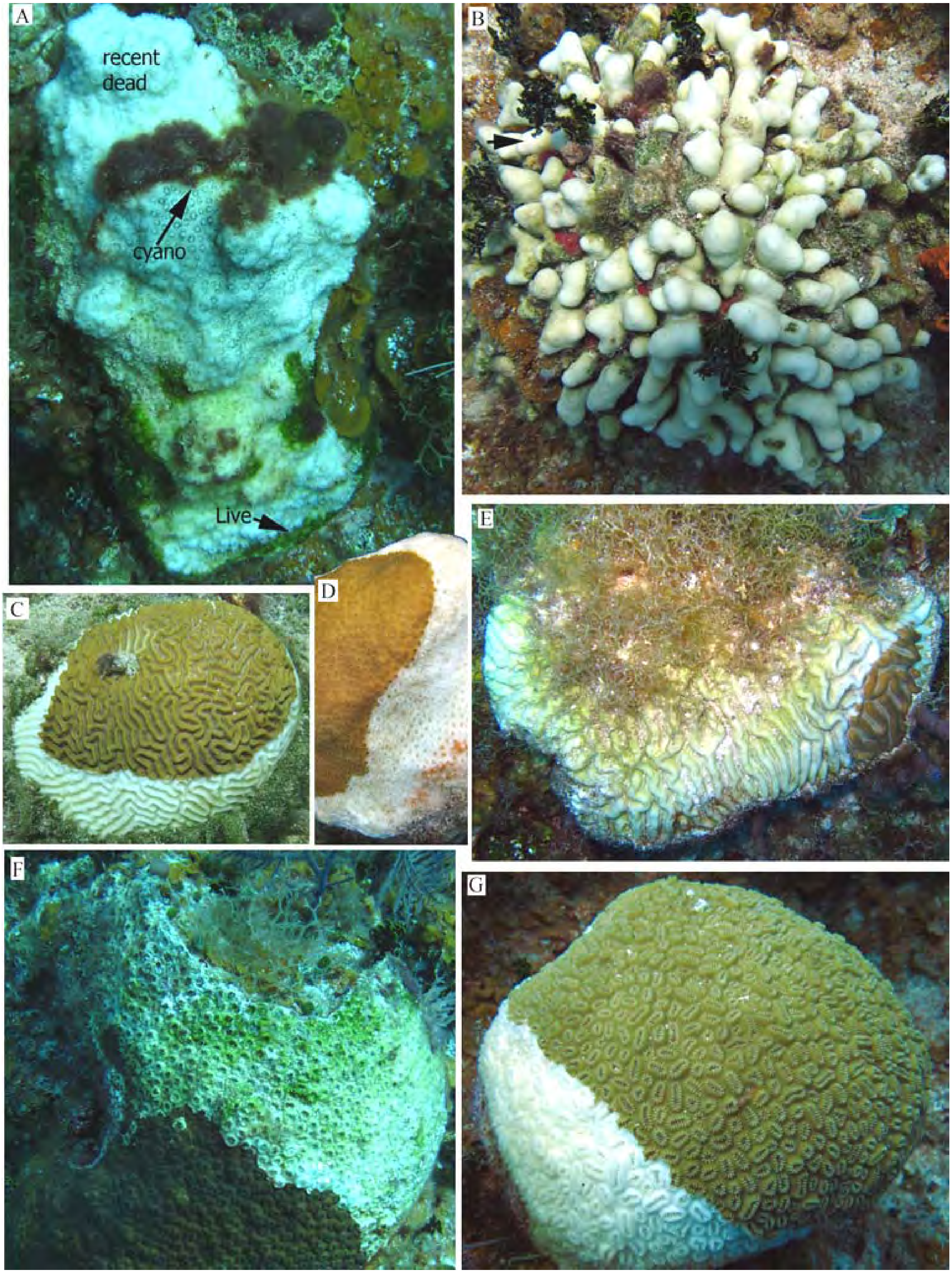
Table 4. Biotic stressors affecting reef building corals in the Cayman Islands. The total percent of colonies with disease[(white plague (plague), Caribbean yellow band disease (CYBD), black band disease (BBD), red band disease (RBD), growth anomalies (GAs), Caribbean ciliate infection (CCI), and dark spots disease (DSD)], signs of predation [*Coralliophila abbreviata* snails, fish bites (spot biting), and focused biting by *Sparisoma viride*], overgrowth by a tunicate (*Trididemnum*) or sponge (*Cliona* spp.) and damselfish (*Stegastes planifrons*) algal lawns for all species pooled (All), *M. annularis complex* (Ma) and all species except *M. annularis* (other) for Little Cayman, Cayman Brac and Grand Cayman reefs.

	Little Cayman			Cayman Brac			Grand Cayman		
Condition	All	Ma	Other	All	Ma	Other	All	Ma	Other
Plague	2.4	5.9	1.3	2.7	6.0	1.6	6.1	18.0	1.9
CYBD	0.1	0.2	0.0	0.1	0.5	0.0	0.2	0.8	0.0
BBD	0.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
RBD	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1
GAs	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
CCI	0.1	0.2	0.1	0.1	0.3	0.1	0.0	0.0	0.0
DSD	0.9	0.0	1.3	1.9	0.2	2.5	1.6	0.0	2.2
Snails	0.4	0.2	0.4	0.4	0.3	0.4	0.2	0.4	0.1
Spot biting	2.1	5.2	1.0	1.2	3.0	0.6	0.8	1.4	0.6
Focused biting	0.4	1.6	0.0	0.0	0.0	0.0	0.3	0.6	0.1
Trididemnum	0.5	0.9	0.4	1.0	2.6	0.4	1.3	2.2	1.1
Cliona	1.7	4.0	0.9	1.0	2.0	0.7	1.4	1.4	1.4
S. planifrons	1.8	2.1	0.5	1.8	2.5	1.6	3.0	4.7	2.2

There were numerous biotic stressors observed on these reefs. The most serious stressor was the coral disease "white plague", which was causing extensive and rapid mortality in affected corals. *M. annularis* and *M. faveolata* colonies, which were the largest corals on these reefs and also often the most abundant, were experiencing the most sever impacts from this disease, with many large colonies having lost 30-70% of their tissue within the last 1-2 months. The second most common condition was dark spots disease, which affected *S. siderea* and *S. intersepta*, as well as several species that are not known to be susceptible to this disease. New records for DSD were obtained for *Agaricia agaricities, Meandrina meandrites,* and *Dichocoenia stokessi*. Interestingly, *Agaricia* was only found with DSD on Little Cayman and Cayman Brac, while this condition was not seen on this species on Grand Cayman reefs. Other coral diseases were present, but generally at low levels. BBD was restricted mostly to brain corals and other favid species, generally in very shallow habitats. Examples of the major diseases are shown in Figures 15-22.

Fig 15. Examples of recent mortality on reef building corals. A. Recent tissue loss in *Montastraea franksi*. All white skeletal areas are recently (0-5 days) denuded of tissue. Algal and cyanobacterial colonization is visible in two locations. Live tissue (<1% of the colony) is visible at the base (arrow). B. *Porites porites* with near total tissue loss. Colony died for unknown reasons within last 2-5 days. Tissue loss was unusually rapid, as indicated by minimal algal colonization. C. *Diploria strigosa* with a white plague lesion. Tissue loss ensued at the edge of the colony and is advancing upward. D. Close-up of a characteristic white plague lesion on *M. annularis*. E. Recent and old tissue loss in *Colpophyllia natans*. Colony is affected by white plague. A small portion of live tissue (brown) remains at the right end of the colony. Areas of old mortality (> 3 months) are colonized by *Dictyota* spp.(brown macroalgae). F. Progressive tissue loss in *M. cavernosa*. G. Characteristic white plague lesion in *Dichocoenia stokessi*. Tissue loss is advancing from the base of the colony (lower left) upward.

Fig. 15



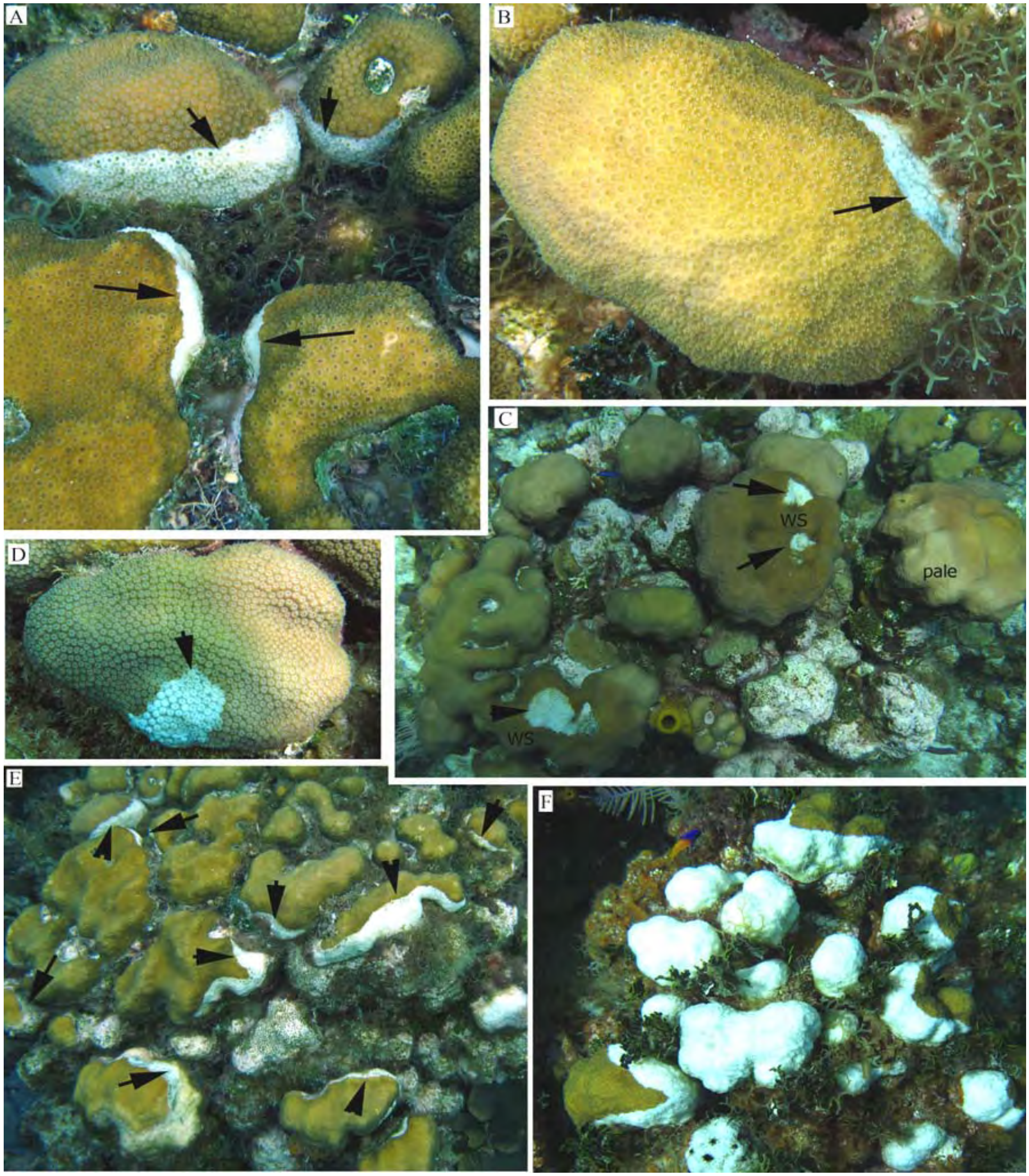


Fig. 16. White plague lesions on *Montastraea annularis*. A. Four adjacent lobes exhibit recent tissue loss at the margin of the colony, adjacent to algae. Tissue loss is advancing upward. B. Close up photo of an individual lobe of *M. annularis* with a new white plague lesion. The lesion initiated at the base of the lobe, adjacent to *Dictyota* (algae) and is advancing upward. C. Colony of *M. annularis* recovering from bleaching (pale). Lobes that have regained most of their pigmentation exhibit signs of multifocal recent tissue loss (ws) located within the perimeter of living tissue. D. Close-up of an individual lobe of *M. annularis* with a small patch (3 X 4 cm) of recent tissue loss. E. Multiple new white plague infections. Lesions are visible on ten lobes of *M. annularis*. F. Severe case of white plague. Nearly 80% if the colony died within the last 3-5 days.

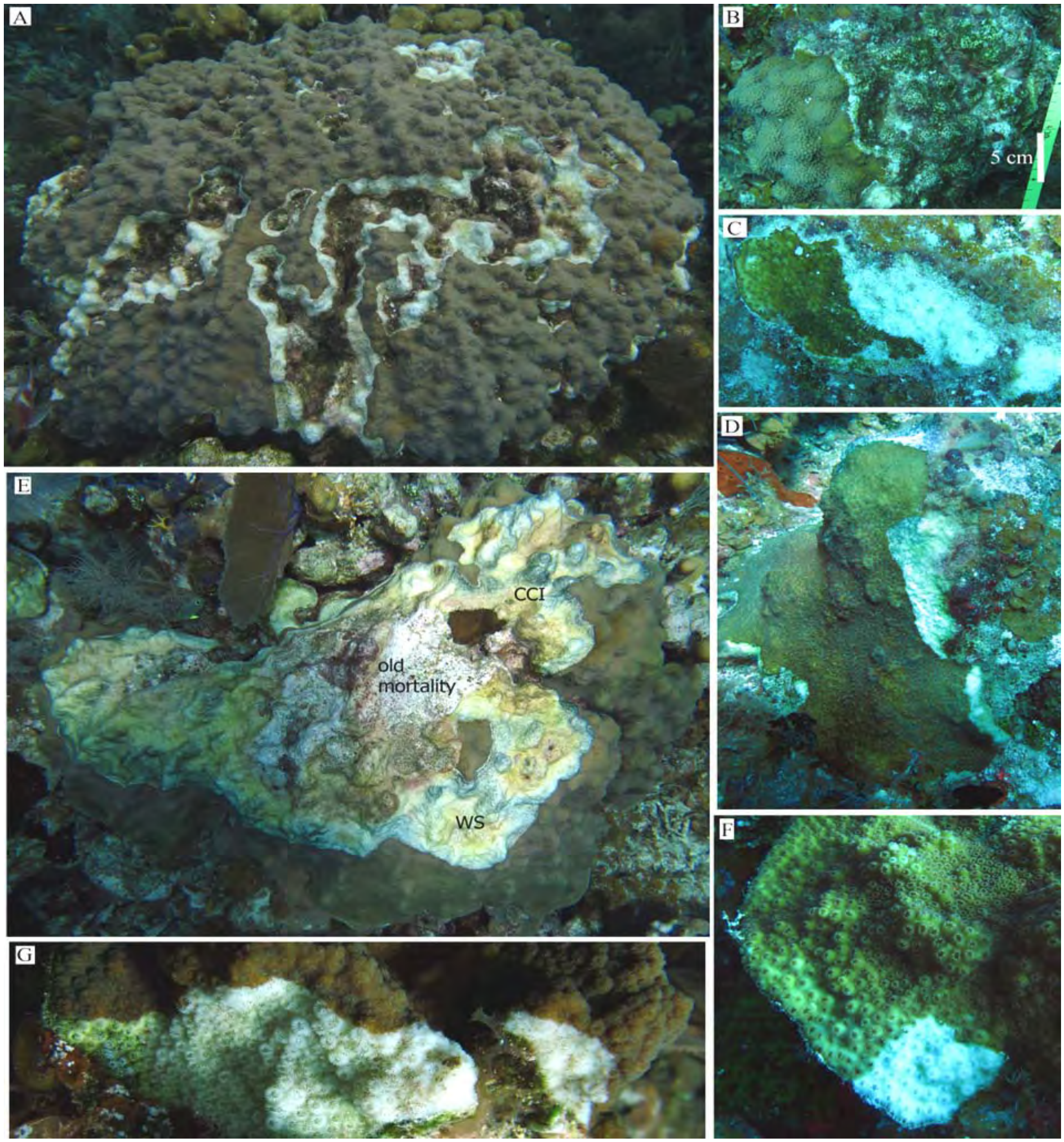


Fig. 17. White plague lesions on *Montastraea annularis* (complex).*A.* Large, 100-200 year old colony with extensive recent tissue loss advancing outward from depressions within the colony. B. Small colony of *M. faveolata* that has lost over 50% of its tissue. Recent tissue loss is restricted to a narrow band immediately adjacent to live tissue. Previously denuded portions of the colony are overgrown by turf and macroalgae C. Small *M. franksi* colony with extensive (>50%) recent tissue loss. D. Characteristic progression of white plague across a small colony of *M. franksi, w*ith tissue loss ensuing from the right to left in a near linear manner. Older tissue-denuded skeleton is colonized by *Lobophora* (brown macroalgae), cyanobacteria and turf algae. E. Large colony of *M. faveolata* that has lost about 70% of its tissue within the last one to two weeks. A small area of the colony in the center previously died and is colonized by crustose coralline algae (CCA). The black pigmentation visible on the exposed skeleton is from ciliates (Caribbean ciliate infection). F. Small colony of *M. franksi* with a recent lesion. G. Two ramets of *M. franksi* with white plague. Tissue loss is progressing at similar rates across both lobes.

Fig. 18

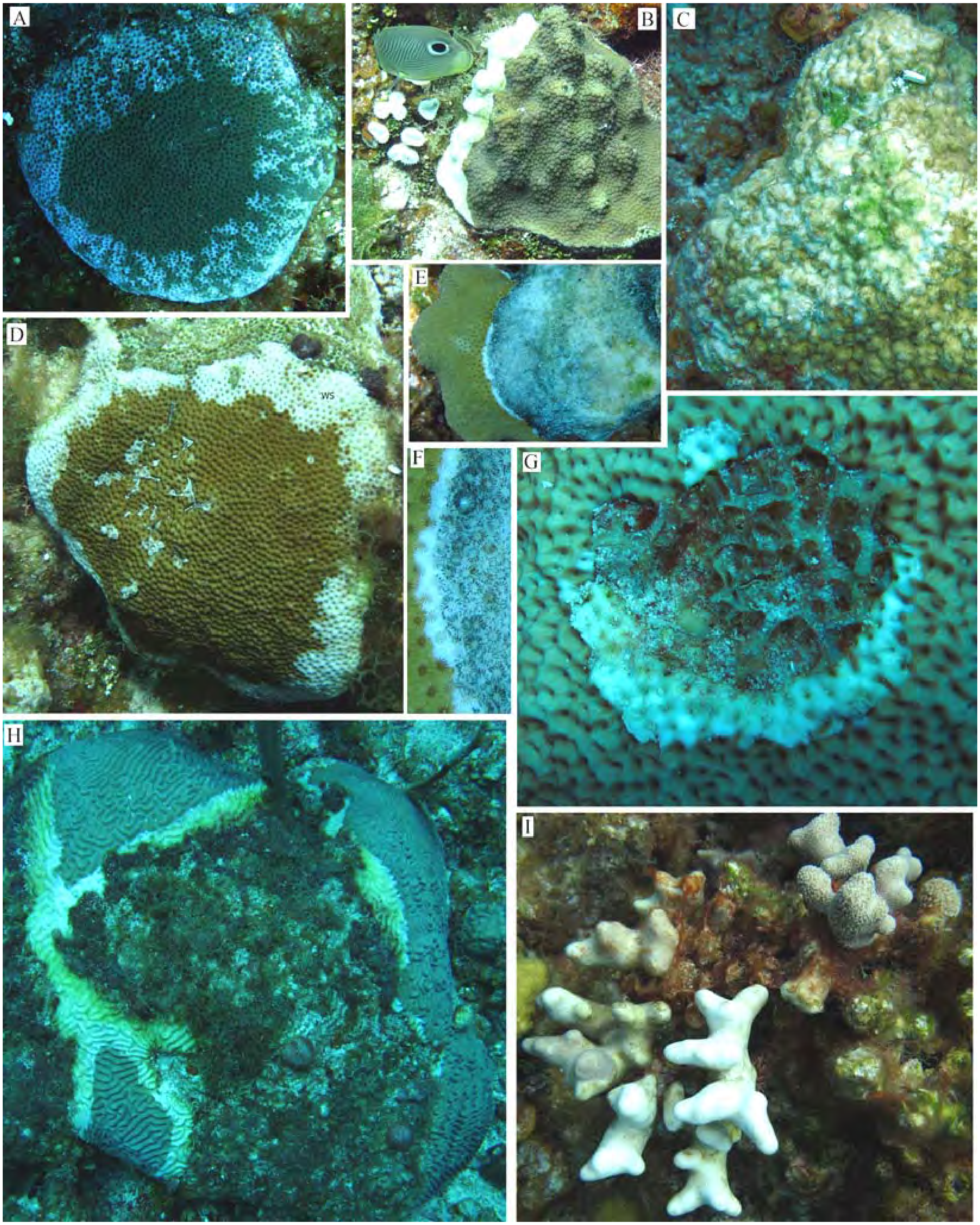


Fig 18. White syndromes in other massive and branching corals. A. *Siderastrea siderea* with recent tissue loss advancing from the perimeter of the colony inward. Tissue loss is diffuse and serpiginous. B. White plague killed a small *Eusmilia fastigiata* colony and has spread to *M. faveolata*. A four eye butterflyfish is scavenging dying tissue from *E. fastigiata*. C. *Porites astreoides* with diffuse tissue loss and bleaching. The tissue exhibits thinning and irregular tissue loss, similar to that described as mottling syndrome (Flower Gardens National Marine Sanctuary, Texas; Borneman 2006). D. Possible white plague on *S. siderea*. Tissue loss initiated at the perimeter of the colony and has progressed inward over about 20% of the corallum. The lesion edge is irregular. E. Colony of *M. faveolata* with a white syndrome. Over 60% of the colony has recently died and the exposed skeleton is colonized by ciliates. A narrow band of recent tissue loss is visible, separating live tissue from a blackened area of corallites of ciliates. F. Close-up of (E) illustrating the narrow white band of tissue loss separating live tissue from the ciliates. G. Close-up of a small patch of recent tissue loss on *S. siderea*. Tissue loss initiated at the margin of a small (4 cm) circular patch of old mortality (colonized by *Dictyota and turf algae*) and has advanced outward nearly 2 cm. H. Large colony of *Diploria strigosa* affected by white plague. Over half the colony died several months ago and older denuded skeletal surfaces are colonized by dense macro and turf algae. Recent tissue loss has divided the colony into three isolates. I. White plague on *P. porites*. White branches in the lower portion of the photos died within the last 3 days and the disease is advancing over adjacent branches. Older dead portions of the colony are colonized by filamentous algae, macroalgae and cyanobacteria.

Fig. 19 Pigmented band diseases. A. black band disease (BBD) on *S. siderea*. The disease has advanced about 10 cm over the last several weeks. B. Cyanobacterial infection in *D. labyrinthiformis*. A narrow red band visible near the arrow is progressing a few mm per day. C. A black pigmented band of ciliates (Caribbean ciliate infection, CCI) separating live tissue from algal colonized skeleton. D. Multiple black band lesions in a large colony of *D. strigosa*. Nearly 70% of the coral has died over the last two to three months. E. Caribbean ciliate infection on *M. faveolata*. Ciliates are slowly consuming coral tissue at the outer perimeter of the lesion; denuded areas of the colony, adjacent to the ciliates, were killed months prior, as evidenced by the colonization of skeletal areas by CCA. F. CCI on *A. palmata*. Tissue loss began at the base and is spreading upward. Red band disease in *A. agaricites*. H. Cyanobacteria have colonized previously denuded parts of the *M. meandrites* colony. They do not appear to be killing remaining tissue.

Fig. 20. Caribbean yellow band disease (CYBD). A. individual ramet of *M. annularis* with a new YBD infection. Darker area in the center of the yellow blotch was affected first and is beginning to die, while the outer pale yellow band has fewer zooxanthellae than adjacent tissue but is still living. B. Older case of YBD. Several lobes were progressively killed over the last 6-12 months (upper right and left), while the central lobe was first affected within the last 3-4 months. C. A single ramet of *M. annularis* with a characteristic yellow band. The disease advances about 1 cm per month. The upper right portion of the colony (colonized by turf algae) was progressively killed over the last 6-8 months. Recent tissue loss is restricted to a small (2 cm) isolated patch of tissue (arrow).D. Large colony of *M. annularis* with CYBD. The larger lobe in the center has lost about 60% of its tissue and it continues to be slowly killed by CYBD; approximately 30% of the remaining live tissue on that lobe is affected by the disease and a new center of infection has appeared in the upper left. E. Close-up of a ramet of *M. annularis* with CYBD. The arrow indicates recent tissue loss, while pale uyellow tissue (L) is still alive. F. Small colony of *M. faveolata* with CYBD. The center of the colony died and the disease is now advancing in two directions.

Fig. 21. *Acropora cervicornis* and *A. palmata*. A. Seemingly healthy *A. cervicornis* colony. Close inspection reveals small white lesions at the base of two branches. Close-up shown in (D). B. Sexual recruit of *A. cervicornis*. Colony was found on Cayman Brac on a reef with no other *A. cervicornis* colonies. C. Sexual recruit of *A. palmata*. E., H. White syndrome on *A. cervicornis.* Nearly 90% of each colony died within the last few days. F. G. White patch disease on *A. palmata*. I. *Acropora* framework. Flattened skeletons are colonized by crustose coralline algae, *Peysonellia*, *Lobophora,* and other algae. No living *A. palmata* remains on this reef.

Fig. 19

Fig. 20

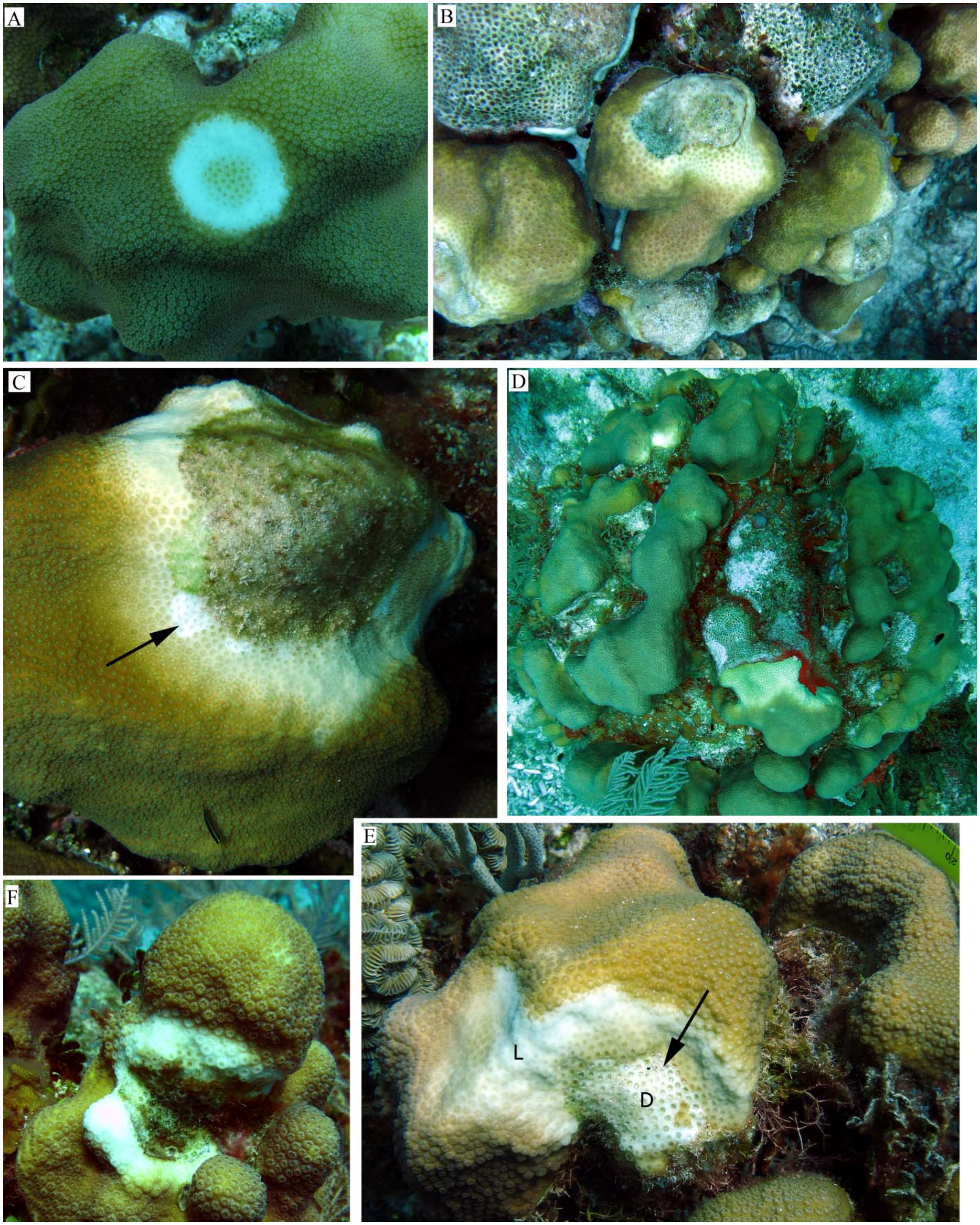
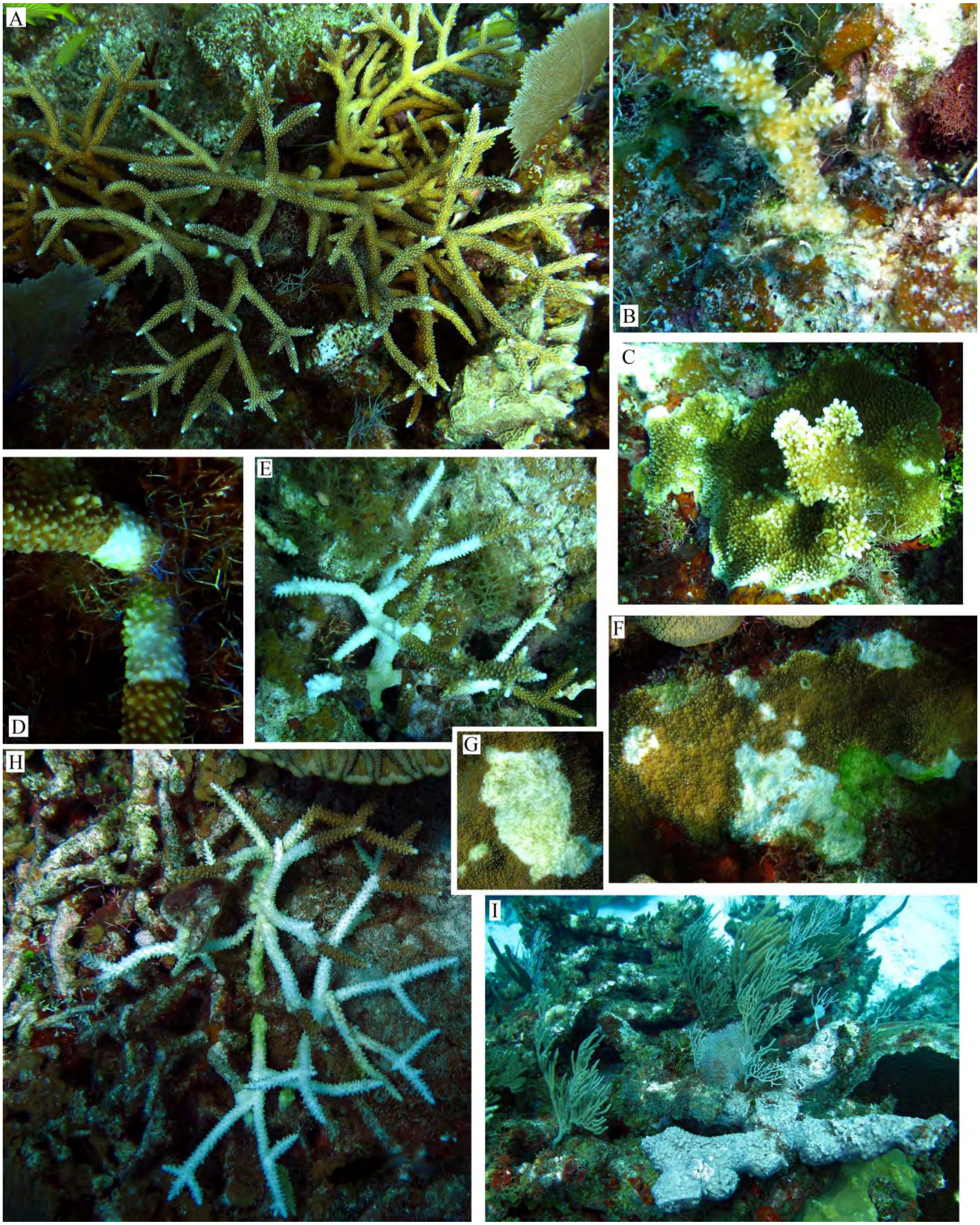


Fig. 21



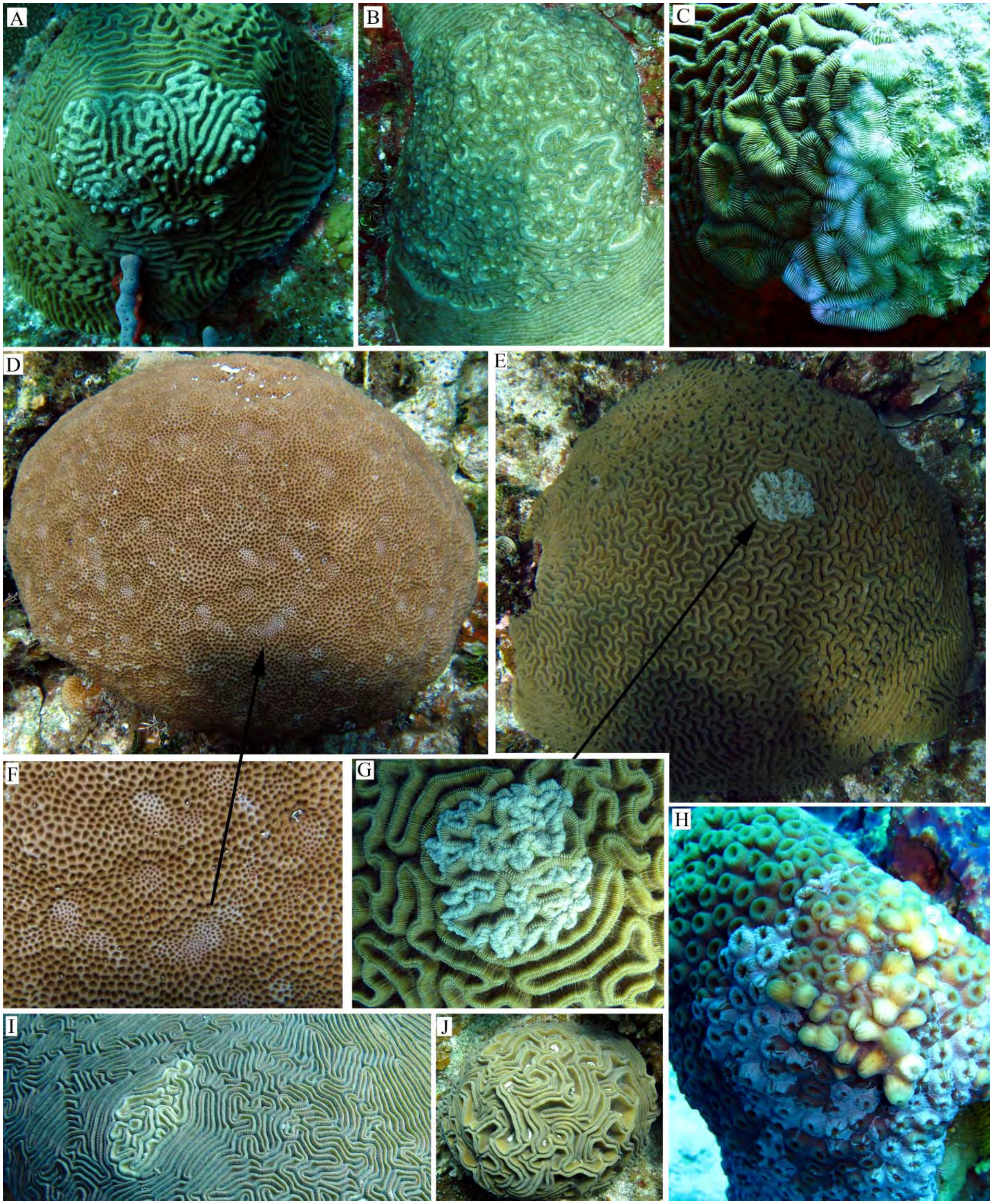


Fig. 22. Growth anomalies (GAs). A large growth in *D. strigosa*. Structure appears normal (ridges and valleys) and pigmentation is intact, but everything is exaggerated in size. B. Irregular growth in *D. strigosa*. C. Growth anomaly in *C. natans*. Colony is affected by a white syndrome which is advancing in a linear manner across the GA. D, F. Small depressed areas in the colony consisting of corallites of reduced size, dispersed across the *S. siderea* colony. E, G. Growth anomaly in *C. natans*. H. Abnormally large corallites in *M. cavernosa*. I . Growth anomaly in *D. labyrinthiformis*. J. Irregular pattern of ridge and valley development in *D. labyrinthiformis*.

In addition to coral diseases, the tunicate *Trididemnum* and the sponges in the genus Cliona (*Cliona delitrix* and the brown *Cliona langae/aprica* complex) were an important source of coral mortality and these taxa overgrew denuded coral skeletons, inhibiting resheeting of tissue remnants and new colonization of skeletal surfaces by coral recruits (Fig. 23).

Obvious predators of corals included a gastropod (*Coralliophila abbreviata*) (Fig. 24), the fireworm (*Hermodice carcunculata*), and parrotfish (Fig. 25). In general, these were responsible for minimal coral colony mortality, but they do have the potential to cause substantial partial mortality. In most corals with fish bites, lesions were small and both recent and healing lesions were noted. Snails were of most concern to areas dominated by *Acropora*, as these had higher densities of snails per coral, snails were larger (mean size 36 mm (n=86) vs. 24 mm (n=67) on massive and plating corals.

Another nuisance species observed on these reefs was the damselfish, *Stegastes planifrons*. This species formerly was most common in *A. cervicornis* thickets, but with the loss of these corals the fish have relocated to massive corals and other taxa. They tend to create lesions through repeated biting, and these become colonized by filamentous algae which can overwhelm the colony over time (Fig 26).

Fig 23. Organisms overgrowing important reef building corals. A. *Trididemnum solidum*, an encrusting tunicate overgrowing a large *Montastraea faveolata* colony. B. The encrusting sponge, *Anthosigmella varians* has overgrown a *D. strigosa* C. The encrusting brown gorgonian *Erythropodium caribaeorum* overgrowing *D. srigosa*. D. Closeup of red bioeroding sponge *Cliona delitrix* on *S. siderea*. E. *Siphonodictyon coralliphagum* on *S. siderea*. F. *Cliona delitrix* covering over half a *D. strigosa* colony. G. *Cliona langae/aprica* complex overgrowing *S. siderea*.

Fig. 24. Predators of corals. A-E, H. Predation by the corallivorous gastropod *Coralliophila abbreviata*. G. Fireworm (*Hermodice carunculata*) predation. F. Lesions caused by repeated bite marks from the yellowtail damselfish, *Microspathodon chrysaurus*.

Fig 25. Parrotfish lesions on scleractinian corals. A. Individual bite marks on *M. faveolata*. Each pair of lesions represents the upper and lower jaw. B. Repeated bits on *A. palmata* by the stoplight parrotfish, *Sparisoma viride*. C. and D. Spot biting on *M. annularis*. On e or multiple parrotfish take individual bites from a colony. Colonies often have lesions in various stages, including recently denuded bite marks and recovering lesions. F. Focused biting by *S. viride* on *M. faveolata*. The harem of fish began biting on a ridge at one end of the colony and progressively denuded skeleton and tissue along that ridge. F. Removal of branch ends in *P. porites* by *S. viride*. G. Spot biting on *S. siderea*. The skeleton of this coral is much harder; as a result, parrotfish bites are generally shallow and heal quickly. H. Focused biting in *M. faveolata* by *S. viride.*

Fig. 23

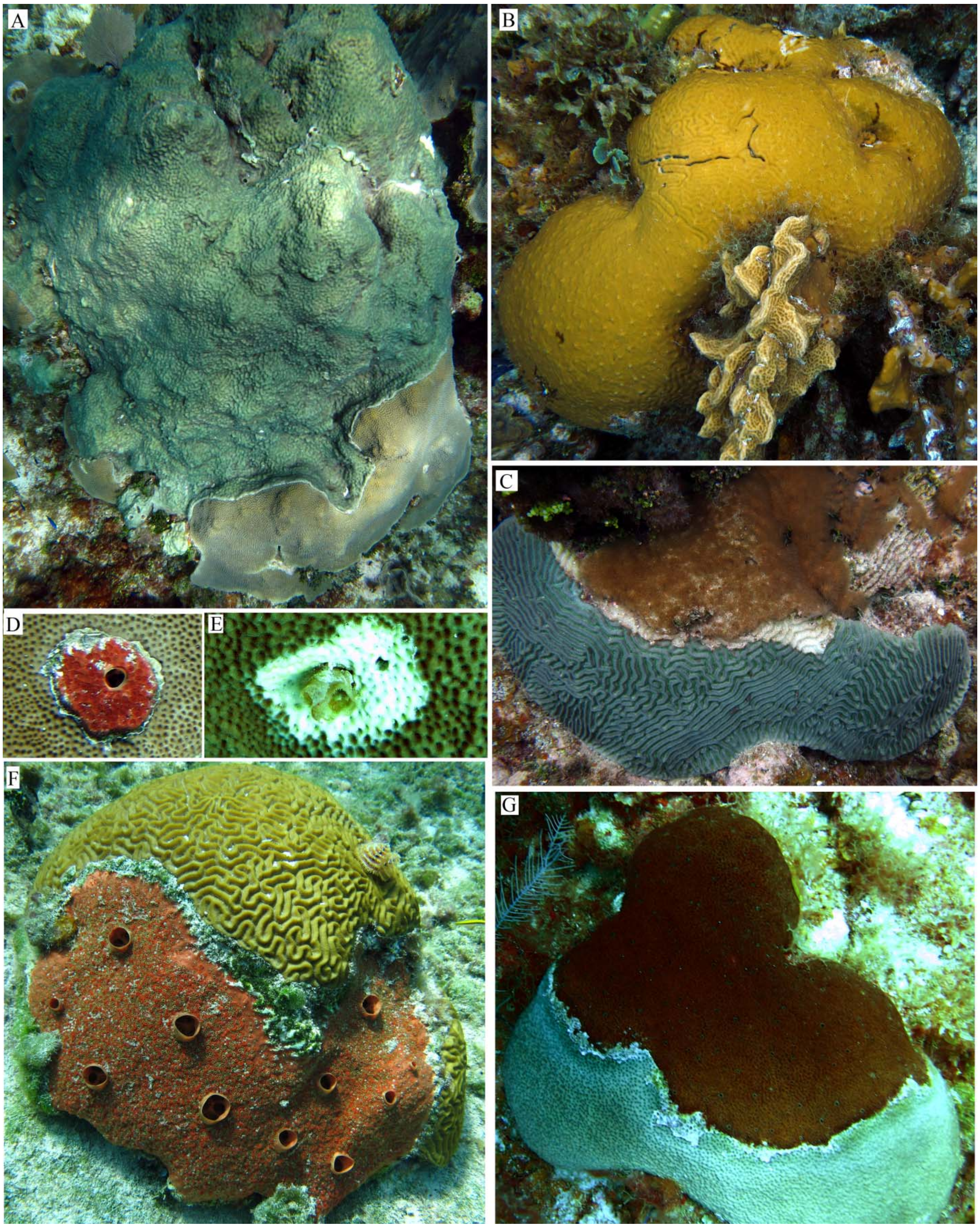


Fig. 24

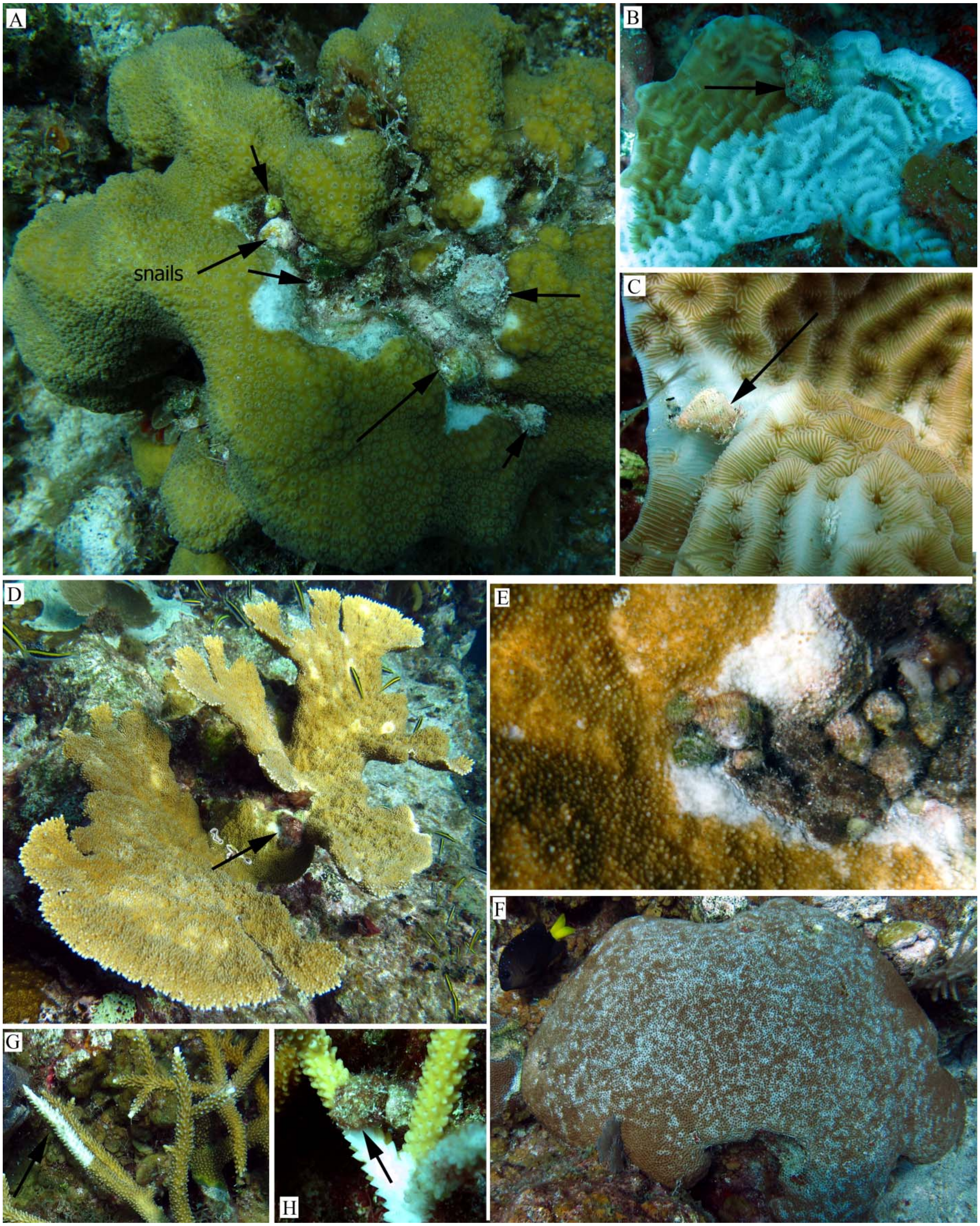
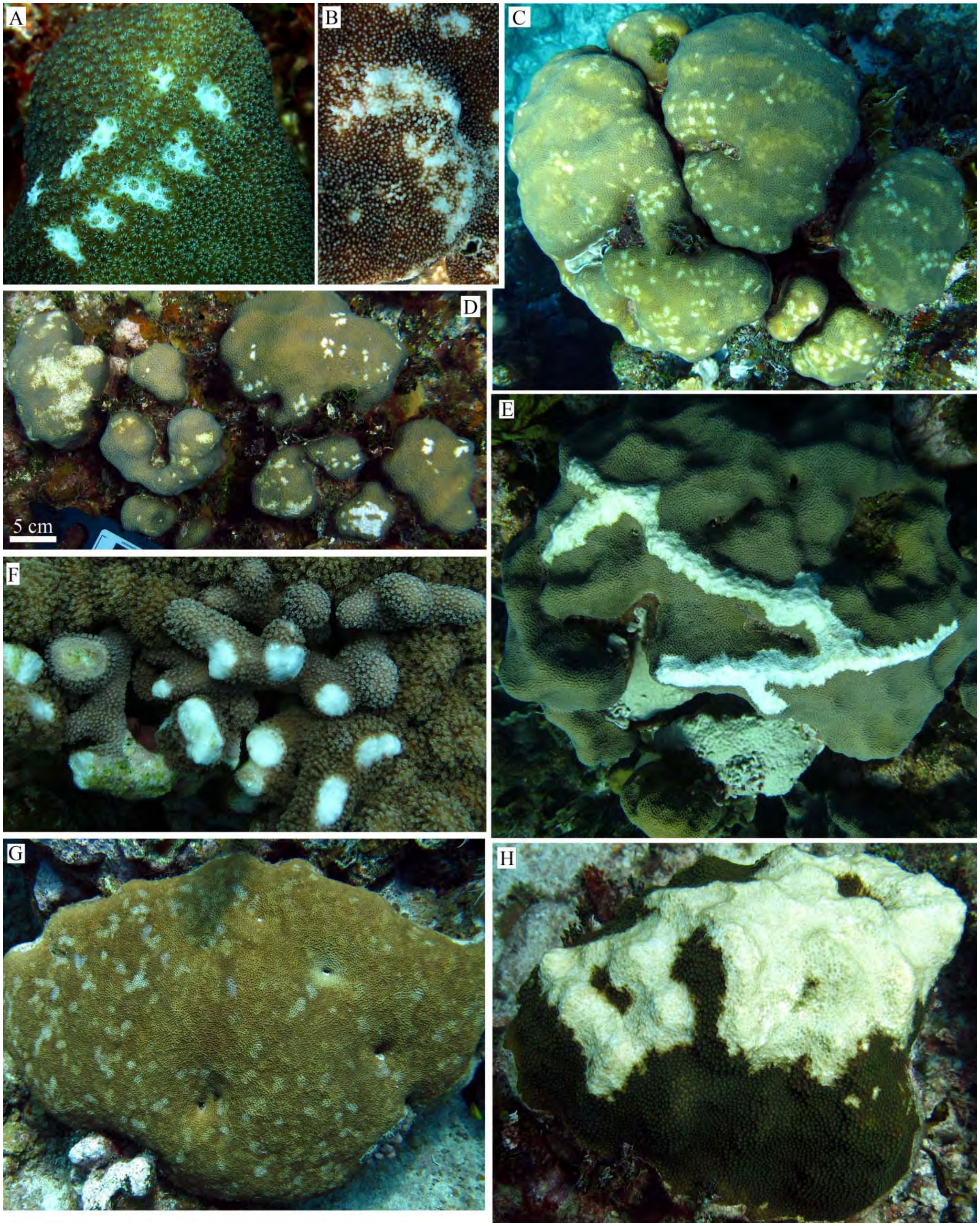


Fig. 25



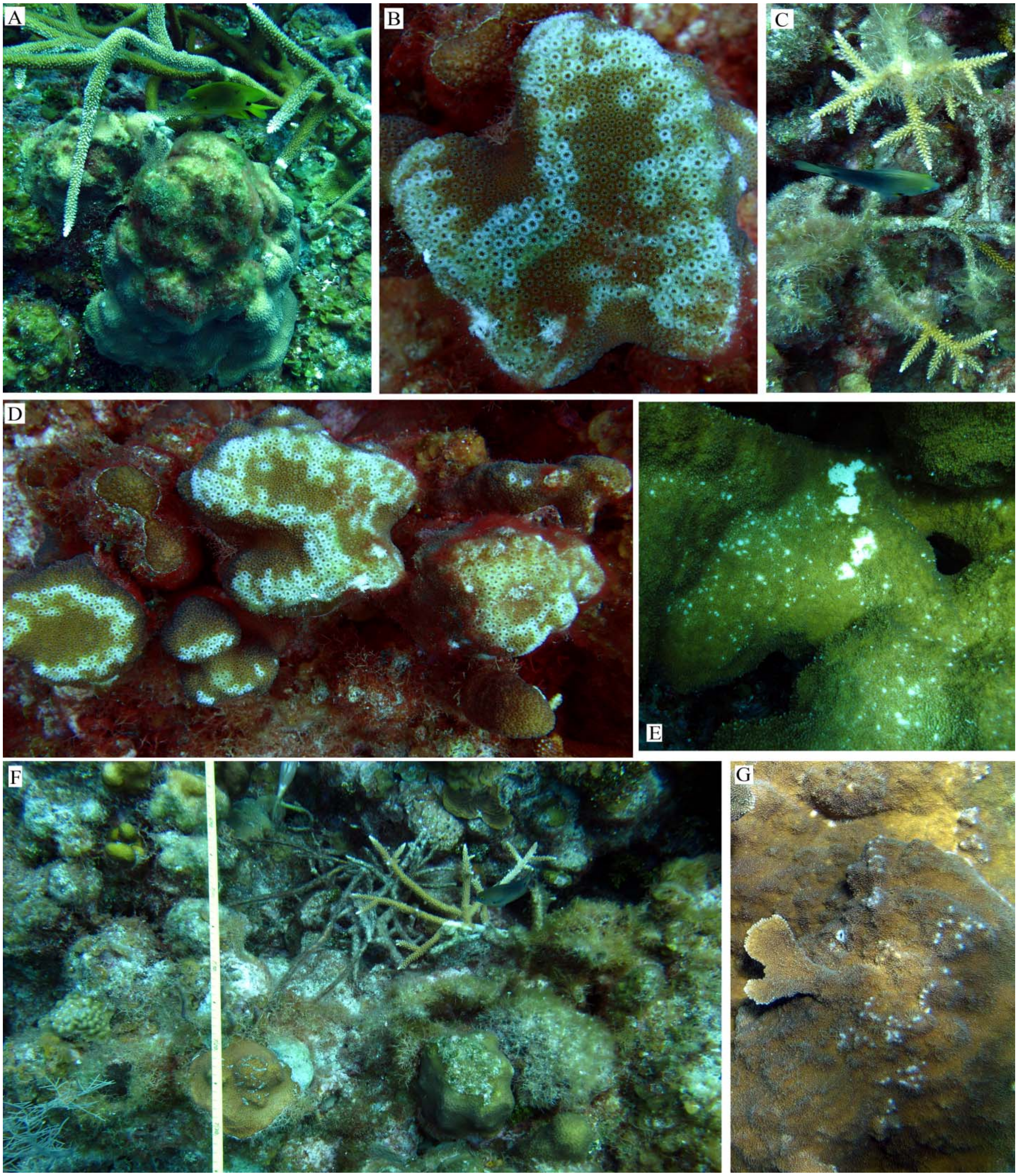


Fig. 27. Lesions on reef building corals created by *Stegastes planifrons* (three spot damselfish). A. Three spot damselfish territory among *M. faveolata* and *A. cervicornis* . Nearly half the *M. faveolata* colony has been killed and colonized by algae. B. Close-up of multifocal lesions caused by repeated damselfish bites on *M. annularis*. The damselfish established a large territory and associated algal lawn affecting multiple lobes of *M. annularis,* as shown in D. C. *Stegastes planifrons* territory among a small A. *cervicornis* colony. Filamentous algae has colonized dead portions of the staghorn coral branches. E. Damselfish bite marks on elkhorn coral, *A. palmata*. F. Three spot damselfish territory with algal lawn development extending over *A. cervicornis* and *M. annularis*. G. Close-up of small, multifocal bite marks from *Stegastes planifrons* on a colony of *A. palmata*.

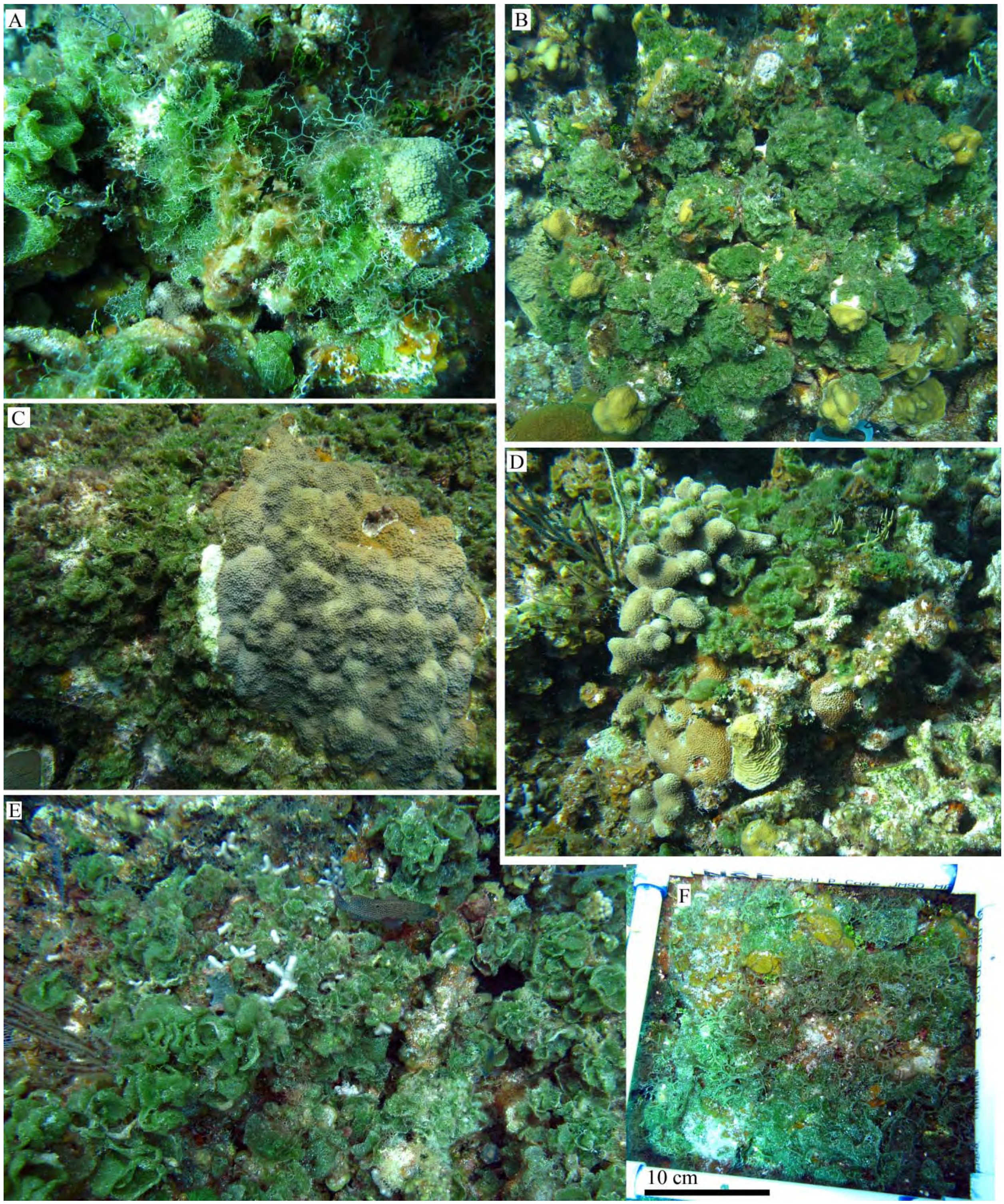


Fig 28. *Macrodictyon* algal bloom on Cayman Brac. A. Close-up of a colony of *M. annularis* that has been smothered by this algae. Small remnants of live tissue protrude from the algae. B. Large *M. annularis* colony encrusted with *Macrodictyon*. Small ramets of *M. annularis* are surviving. C. *M. faveolata* encircled with *Macrodictyon*. Colony is affected by white plague, which emerged at the margin of the colony adjacent to the macroalgae and is progressing inward. D. *Macrodictyon* on *Porites* and *Agaricia* skeletons. E. A large area of reef with few living corals and over 90% cover of *Macrodictyon*. F. A representative 25 X 25 cm quadrat along a belt transect showing the poor substrate quality and absence of coral recruits.

4. **Fish community structure**

Belt transects (30 m X 2 m) were used on Little Cayman (14 locations,162 transects), Cayman Brac (12 sites, 156 transects) and Grand Cayman (11 locations, 132 transects) to characterize the abundance and size structure of 106 species of fish in 18 functional groups. In all transects, 18,436 fish were documented, with 6549 on Little Cayman reefs, 6389 on Cayman Brac reefs and 5498 on Grand Cayman reefs. An average of 40-44 fish were recorded along each transect (approximately 1.3 fish per m), with no significant differences observed between islands for fish density. The size structure of fishes was fairly similar in all locations, with minor differences noted in Grand Cayman surveys. On Grand Cayman fewer fish were recorded in the smallest size class (0-5 cm) and largest (over 30 cm), while these reefs had a larger proportion of fishes between 11-30 cm (Fig. 29).

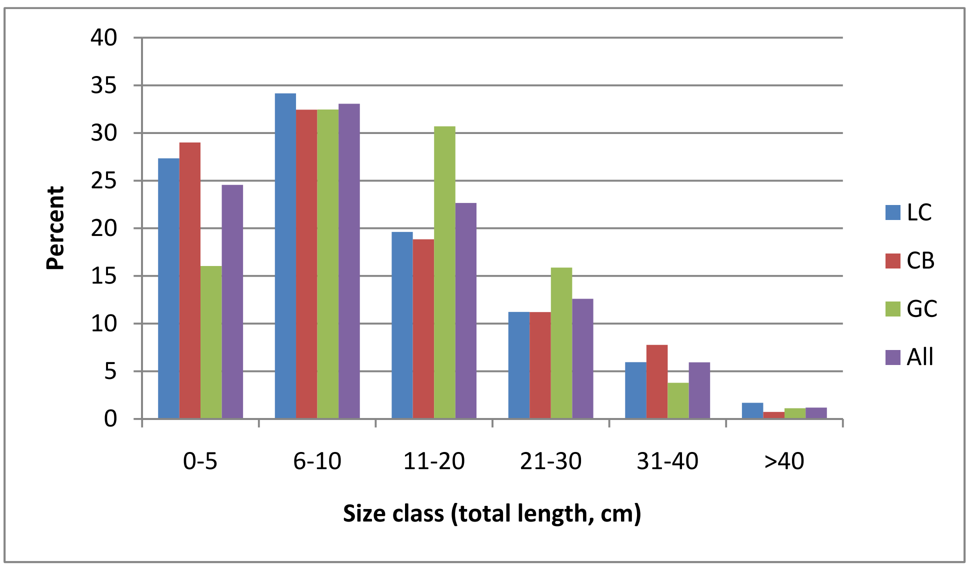


Fig. 29 Total length of fish recorded in belt transects on reefs off the Cayman Islands. All species are pooled into six size classes for Little Cayman (LC), Cayman Brac (CB), Grand Cayman and all reefs (All).

Parrotfish were the most common fish recorded in the transects (38% of all fish), although most (79%) were 20 cm or smaller in total length. Surgeonfish were the next most abundant group (22%). While many groupers were seen, 71% of these were 20 cm or smaller in total length. Other predators, including snappers, jacks, and barracuda had a higher proportion of individuals that were over 20 cm length, but the total numbers of each of these fish was fairly low. The size structure of the major functional groups (pooled for all reefs) is shown in table 5.

Table 5 . Numbers of fishes recorded along belt transects in each size class, broken down into 19 functional groups. Other includes 27 species.

	Total numbers of fishes						
Size (cm)	**0-5**	**6-10**	**11-20**	**21-30**	**31-40**	>**40**	Sum
Angelfish	43	48	12	13	18	1	135
Butterflyfish	89	373	62	0	0	0	524
Grunt	0	106	533	457	317	10	1423
Parrotfish	1772	1852	1864	1138	305	54	6985
Grouper	16	121	196	79	23	32	467
Snapper	0	4	118	223	112	78	535
Surgeonfish	1545	1475	683	277	20	0	4000
Triggerfish	4	125	180	72	44	0	425
Moray	0	0	0	0	1	0	1
Wrasse	342	664	342	22	12	2	1384
Filefish	13	8	1	2	2	0	26
Porgy	0	0	4	7	0	1	12
Porcupinefish	0	0	1	0	2	2	5
Jack	0	20	41	16	17	3	97
Barracuda	0	0	0	0	0	11	11
YT damselfish	65	269	100	0	0	1	435
lionfish	1	3	0	0	0	0	4
Other	636	1027	40	18	221	25	1967
Sum	**4526**	**6095**	**4177**	**2324**	**1094**	**220**	**18436**

When examined by island, there were some notable differences in the size structure of certain functional groups. For parrotfish, Cayman Brac had a much higher proportion of juveniles and small IP fish (0-5 cm) and fewer fishes from 6-20 cm, while Grand Cayman was the opposite: fewer small fish and more intermediate-sized (6-20 cm) parrotfish (Fig 30). In all locations, there were relatively few large terminal phase males.

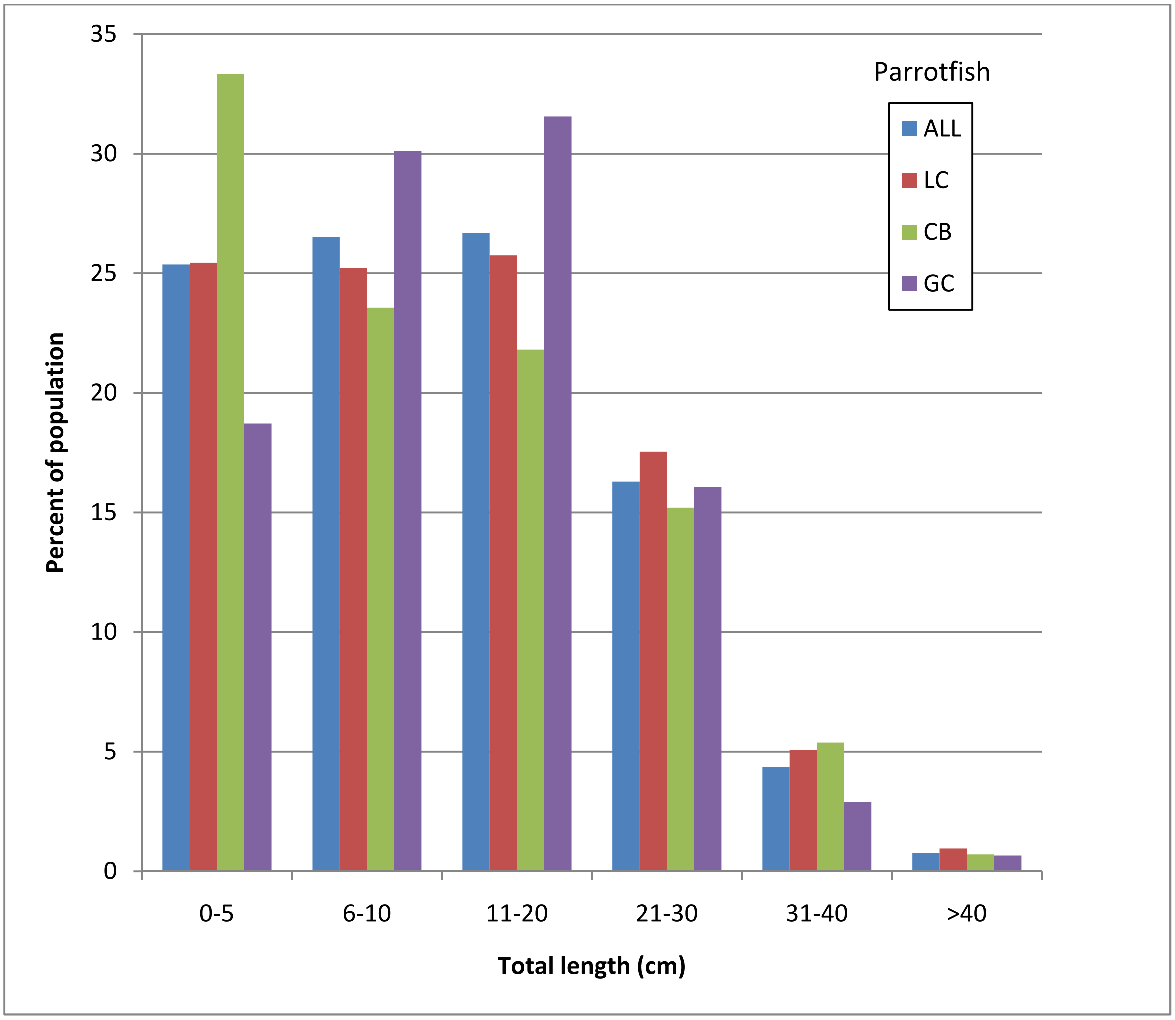


Fig. 30 Size structure of parrotfish on Cayman Island reefs.

Grouper were observed on most reefs at low abundances. Most fish were small to intermediate and consisted of hinds, graysbys and coneys. Little Cayman and Cayman Brac had a higher number of large grouper (> 30 cm), while Grand Cayman had more fish in the 21-30 cm size class (Fig. 31).

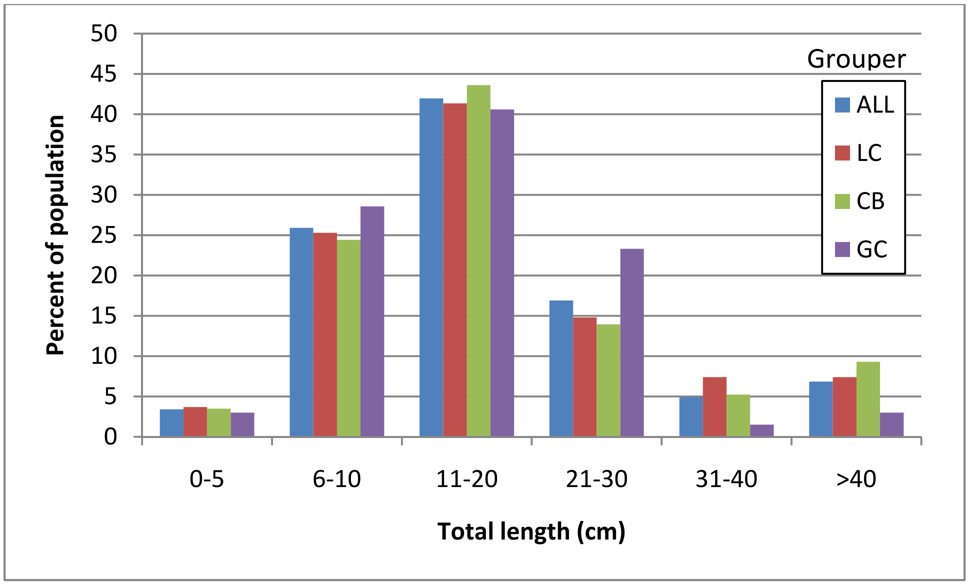


Fig. 31. Size structure of groupers on Cayman Island reefs.

Snapper populations were characterized by a near absence of fish less than 10 cm in length. Little Cayman reefs had a higher proportion of large snappers than the other islands, especially for fish >40 cm in length. As observed with other species, snappers on Grand Cayman were significantly smaller in size, with most between 11-30 cm total length (Fig. 32).

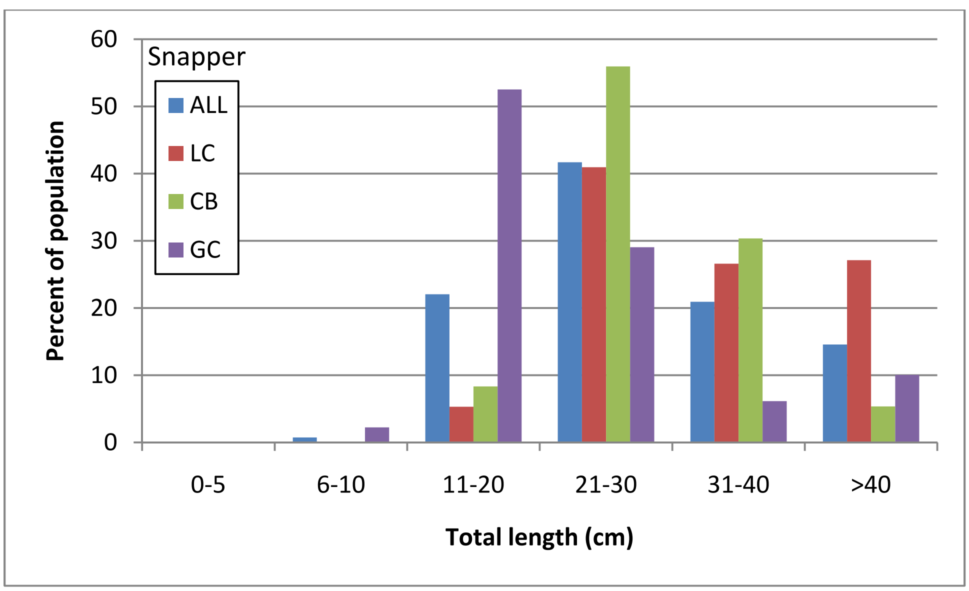


Fig. 32. Size structure of snappers on Cayman Island reefs.

Coral Reef Resilience

Cayman Island reefs showed numerous positive signs of high resilience, but there were also several factors present known to degrade resilience. It appears that the 2009 bleaching event was most severe on Grand Cayman reefs, with recovery still on-going (as evidenced by the large number of pale and partially bleached corals still seen on these reefs), while newly bleached colonies were not observed. Direct impacts from bleaching to the colonies (in terms of bleaching –associated mortality) appears to have been fairly low, as considerable recovery of pigmentation was noted and bleaching- related tissue loss was minimal. However, the bleaching event is likely to have affected the health and resistance of the corals. Surviving colonies that bleached and recovered may not have had adequate energy reserves to reproduce in 2010 and/or 2011 at their fullest extent. In addition, the bleaching event appears to have been a precursor to the white plague outbreak that followed and was still active in June 2010.

As seen in reefs around the Caribbean, Cayman Island reefs have experienced a substantial decline in the most important frame building corals, *M. annularis* complex. Approximately 1/3 of the living *M. annularis* tissue was lost since the 2009 bleaching event and mortality was still ongoing primarily due to white plague, at the times of these surveys. White plague appears to be having the greatest long-term consequences for the larger corals in the population, especially *Montastraea* spp,, as these are older and more important in terms of reef growth and future recruitment events (i.e. larger corals produce more gametes). Even though there has been widespread mortality, there are many remaining *M. annularis* colonies in good health. In addition, a large percent of the colonies hit by disease experienced partial mortality but they are still alive, having been reduced to tiny remnants of live tissue that are likely to be non-reproductive. If conditions remain suitable, these remnants can continue growing, and ultimately will reach a size necessary for successful spawning.

In addition to concerns of coral disease, the high cover of macroalgae is worrisome, especially on Cayman Brac where reef substrates have been carpeted by dense growths of *Microdictyon*. The high abundance of macroalgae could be due to a low abundance of herbivores and/or nutrient input. *Diadema* were seen on the reefs, but at very low numbers (Fig. 33). In fact, there were few reefs with more than five or six urchins sited by the entire team. The reefs contained fairly large populations of herbivorous fishes, but most individuals were small and they tended to be dominated by species that are browsers (surgeonfishes) and scrapers (scarid parrotfish). Many of these species show a higher preference for filamentous algae and turfs, and not the dominant, problematic macroalgal taxa (e.g. *Dictyota, Lobophora and Microdictyon*) seen during these surveys. Nutrient input is another cause of increases in fleshy macroalgae (and other plants), but most reefs off Little Cayman and Cayman Brac are located off relatively undeveloped coastlines and land-based pollution and run-off is minimal. Some sites in Grand Cayman are likely to be more influenced by coastal development, sedimentation and nutrient run-off, especially reefs located off areas where dredging, canal extension and building is occurring.

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Appendix 1: Scientific Team and responsibilities

Name	Duty
Dr. Andrew Bruckner	Lead scientist; benthic assessments including coral belt transects, point intercept, resilience assessments
Glynnis Roberts	Fish assessment
Tauna Rankin	Fish assessment
Eric Borneman	Benthic coral surveys
Amanda Williams	Point intercept transects; recruitment quadrats
Amber Little	Point intercept; recruitment quadrats (LC and CB only)
Flower Moye	Point intercept; recruitment quadrats (LC and CB only)

Appendix 2

Surveyor:	Site Name:		Reef Type:	Reef Zone:
Date:	Day #: Site #:	Latitude:	Subzone/Habitat	
Start Time:	Bottom Temp.: °C/ °F	Longitude:		
Start Depth: ft/ m		Site Comments:		
End Depth: ft/ m		Transect Comments:		

All ≥ 4 cm Corals

Species Code	# Isolates	Maximum (cm)			% Bleach (P, BL)	% Partial Mortality			Disease	Predation overgrowth	Comments
		Length	Width	Height		New	Trans	Old			

Appendix 3

Surveyor:	Site:	Date:	Time:	Temperature: °C/ °F

Compass Bearing:	Start Depth: ft/ m	End Depth: ft/ m									Quadrats	
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Compass Bearing:	Start Depth: ft/ m	End Depth: ft/ m									Quadrats	
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Compass Bearing:	Start Depth: ft/ m	End Depth: ft/ m									Quadrats	
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Substrate codes

DC = dead coral
RDC = recently dead coral
BL = fully bleached
HG = hardground
R = rubble
S = sand
C = live coral
I = invert

Coral codes

use first letter of genus
and three letters of species

Condition

ID disease, predation, bleaching, other compromising feature

Algae codes

m = macroalgae
t = turf
cca=crustose coralline
e = erect coralline
cy = cyanobacteria
TS = turf + sed.

Special algae

Dic = dictyota
Lob = lobophora
Mic = microdictyon
Hal = halimeda
Peys = Peyssonellia

Invert

Gorg = seafan
Octo = soft coral
Anem = anemone
Paly = palythoa
Tun = tunicate
SP = sponge
RSP = rope sponge
TSP = tube sponge
BSP = barrel sponge
ESP = encrusting sponge

AINV = aggressive invert

Nuisance species

Eryth = Erythropodium
Paly = Palythoa
Clidel = Cliona delitrix
Clio = Cliona (brown)
Tridi = Trididemnum
Chon=Chondrilla sponge

Appendix 4

Location:	**Date/Time:**					
Depth:	Transect No.					
Dir:	cm total length					
Min:	**0-5**	**6-10**	**11-20**	**21-30**	**31-40**	**>40**
Angelfish						
French						
Gray						
Rock Beauty						
Queen						
Butterflyfish						
Foureye						
Banded						
Spotfin						
Reef						
LongSnout						
Grunt						
Porkfish						
White						
Bluestriped						
French						
Tomtate						
Smallmouth						
Caesar						
Spanish						
Sailors Choice						
Margate						
Parrotfish						
Stoplight (IP)						
Stoplight (TP)						
Redfin (IP)						
Redfin (TP)						
Redband (IP)						
Redband (TP)						
Princess (IP)						
Princess (TP)						
Striped (IP)						
Striped (TP)						
Queen (IP)						
Queen (TP)						
Redtail (IP)						
Redtail (TP)						
Midnight						
Rainbow						
Greenblotch						
Blue						
Porgy						
Jolthead						
Sheepshead						
Saucereye						
Moray eel						
Lionfish						

Name/Buddy:			**Dive No:**			
	0-5	**6-10**	**11-20**	**21-30**	**31-40**	**>40**
Seabass						
Tiger						
Red Hind						
Graysby						
Nassau						
Black						
Rock Hind						
Coney						
Yellowfin						
Yellowmouth						
Snapper						
Schoolmaster						
Gray						
Mahogany						
Yellowtail						
Lane						
Cubera						
Mutton						
Dog						
Surgeonfish						
Ocean Surgeon						
Doctorfish						
Blue Tang						
Queen Trigger						
Black Durgon						
Whitespot file						
Scrawled filefish						
Orangespot File						
Chub						
Yellowtail Damsel						
3spot Damsel						
Spanish Hogfish						
Barracuda						
Bar Jack						
Blue Runner						
Hogfish						
Slippery dick						
Yellowhead wrasse						
Puddingwife						
Porcupine						
Baloonfish						
Burrfish						
Cowfish						
Trunkfish						
Bar jack						
Permit						
Other						

Appendix 5

Date: *Site:* *Collector:*

	Variable	#	***Comments***
1-Cover	H/S Coral cover		
	Fleshy Algae		
	Turf/sediment		
	Turf algae		
	CCA		
	Cyanobacteria		
	Hardground		
	Rubble		
	Sediment		
2. Physical attributes	Sponge		
	Topographic complexity - micro		
	Topographic complexity -		
	Sediment texture		
	Sediment layer		
	Temperature		
	water movement		
	deep water (30-50m)		
	depth of reef base		
	wave energy/ exposure		
	depth (m)		
	aspect		
	slope (degrees)		
	phys. shading		
	canopy corals		
	Visibility (m)		
	Exposed low tide		
	Ponding/pooling		
5-Anthropogenic	Nutrient input		
	Development		
	Pollution (chem)		
	Pollution (solid)		
	Turbidity/Sedimen		
	Physical damage		
	Fishing pressure		
	Destructive fishing		
	Other		

Site

Description, sketch, etc.

	Lionfish			
	Diadema			
	Lobster			
3-Bleaching/Mortality	Bleaching			
	Mortality-new			
	Mortality-old			
	Recovery-old			
	Coral disease			
4-Coral associates	Obligate feeders			
	Branching residents			
	Competitor			
	Bioeroders (external)			
	Bioeroders (internal)			
	Corallivores (negative)			
	Recruits/m2			
3- Coral Gene	*Largest corals*			
	Other			

Dom/Abun/Comm/Uncomm/Rare

Acer		Dcliv		Ppor		Efas		Malc	
Apal		Dstr		Past		Mang		Mcom	
Aaga		Dlab		Pfur		Mmir		Ffra	
Alam		Mann		Pdiv		Mdec		Isin	
Aten		Mfav		Sint		Mfor		Irig	
Aga		Mfr		Sbou		Mpha		Lcuc	
Cnat		Mcav		Shya		Mfer		Mare	
Dcyl		Mmea		Ssid		Mlam			
Dstoc		Scol		Srad		Mali			