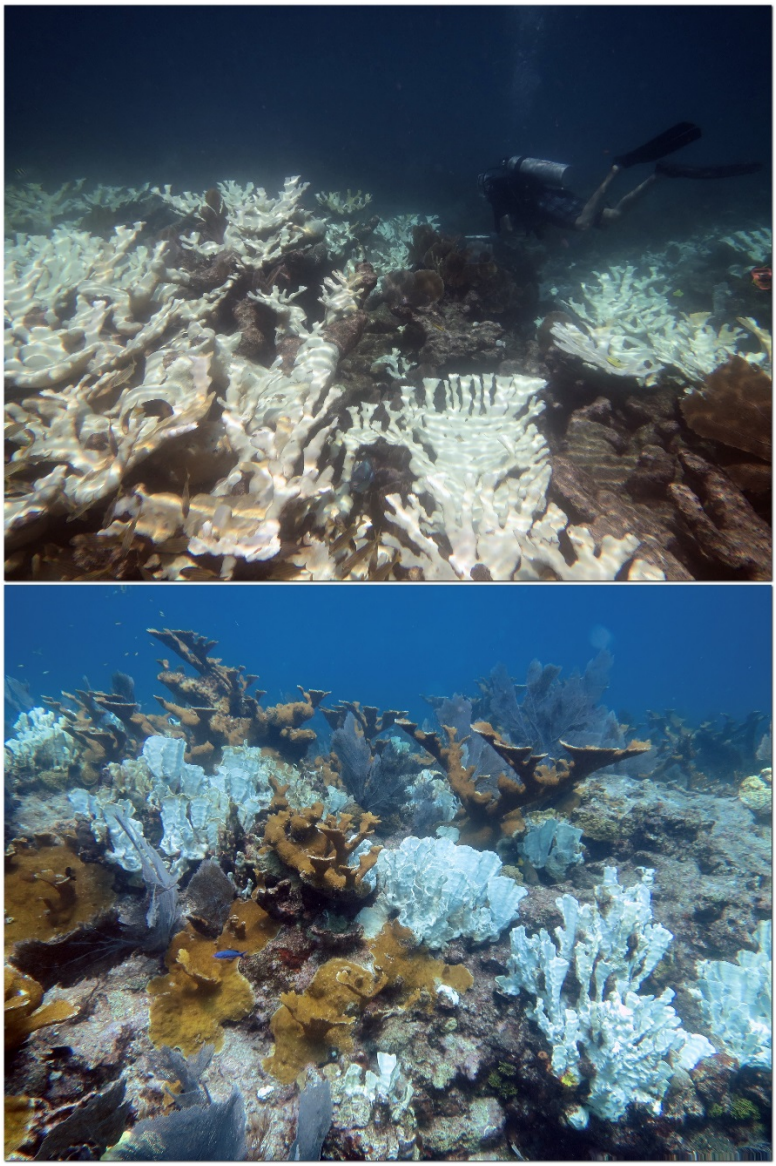
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Quick Look Report: 2014 *Acropora palmata* Bleaching Event in the Upper Florida Keys



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Intro/Preface

During summer 2014, we observed bleaching among many coral species in the upper Florida Keys. As water temperatures continued to rise, increasing numbers of coral species were observed with bleached tissue. In mid to late August, we observed bleaching affecting acroporid corals (Fig. 1) at various sites. Based on these informal observations, we undertook additional surveys of our 7 existing *Acropora palmata* monitoring sites (Fig. 2). This report describes the nature of the bleaching event along with preliminary data on the progression and impact of this event on the *A. palmata* at these sites. While the Florida Keys reefs have experienced moderate bleaching events in the past decade, this is the first bleaching event to affect local *A. palmata* since the 1998 El Niño-associated bleaching event (Miller et al. 2002). The only other extensive description of bleaching affecting *A. palmata* is from the US Virgin Islands during the Caribbean-wide thermal bleaching event in 2005 ([1]Rogers and Muller 2012).

Methods

Observations reported here were made at seven long-term *A. palmata* demographic monitoring sites (Fig. 2), each of which include three to five 150m^2 fixed study plots in *A. palmata* habitat. All plots have been routinely surveyed since at least 2010 (most since 2004). In each study plot, all colonies are mapped and surveyed annually, and a randomly selected subset of tagged colonies in each study plot is surveyed for size and condition three times per year.

Tagged colonies in all study plots were assessed for bleaching between 9/11/14 and 9/19/14 (termed 'initial survey'; Fig. 3) and a subset of plots was revisited at 3-5 week intervals through late November to track progression. Additionally, all study plots were surveyed in June 2014 (before bleaching event) and Feb 2015 (5 months after bleaching peak) as part of the long term monitoring effort. Temperature loggers (HOBO Pendant) deployed at most sites during this event logged water temperature every 30 min.

Colonies were photographed at each assessment, and later the images were scored for % live tissue, active tissue loss, bleaching presence and severity. Bleaching severity was ranked on a qualitative scale (by a single observer) from 0 for normal colored tissue to 5 indicating completely bleached but intact tissue. Bleaching was often not uniform over an individual colony, thus, colonies were subdivided into three parts: 1) tips/margins, 2) upper surfaces and 3) undersides/shaded portions (Fig. 4). Each part was ranked for bleaching severity independently. The ranks for all three parts were then averaged to give a 'bleaching severity' (BLS) score for the entire colony (Fig. 5). Bleaching prevalence was calculated as the percentage of live tagged colonies with any degree of bleaching. A live area index (LAI) was calculated for each colony (average colony dimension squared x % live) and summed for the subset of tagged colonies at each assessment. This index was compared between the June 2014 survey and the February 2015 surveys to determine the loss of live tissue area over the course of the bleaching event.

[1] Rogers C, Muller E. 2012. Bleaching, disease and recovery in the threatened scleractinian coral *Acropora palmata* in St. John, US Virgin Islands: 2003–2010. Coral Reefs. 31(3):807-819.

Results

Event progression and recovery

The early stages of this event were not well documented and the timing likely varied between sites. However, some scattered/patchy paling in *A. palmata* was observed in mid-August (8/15-18), and by late August (8/25) bleaching was more severe and more common (Fig. 3). Fully bleached colonies were observed on Molasses Reef on 9/4. Because the extent of bleaching varied on a small spatial scale and the same sites were not visited in rapid succession at this early stage, it is impossible to pinpoint a precise peak. However we know colonies that were partly bleached on 8/25 were observed more severely bleached on 9/19. Colonies observed at other sites as partly or fully bleached on 9/11 were showing signs of recovery (or mortality) by 9/29 suggesting the peak was likely between 8/25 and 9/11/2014. Daily average water temperature (Fig. 3) rose above 30°C by mid-July and remained above 30°C through mid-September. One exception occurred on 8/5 when water temperatures dropped by at least 1 degree (to 29.9°C at three of the sites) for a single day. Average reef temperatures were also above 31°C for the better part of a month (late July to late August).

Many severely bleached colonies rapidly lost most or all of their live tissue within ~3 weeks of the initial observation (Fig. 6). Over this same time period, by early October, mildly bleached portions of colonies began to recover their normal color, while the more severely bleached portions remained bleached. This trend continued through October and by mid-November only a few of the surviving colonies had pale portions remaining (Fig. 7); the remainder were normal in color or long dead. In February 2015, ~5% of live colonies were observed with slightly pale areas of tissue. However, this is a typical 'baseline' level in this population and most likely not related to the bleaching event.

Bleaching prevalence and severity

Bleaching prevalence (percent of live colonies displaying any degree of bleaching; Fig. 6) varied widely between sites. Elbow Reef had the lowest prevalence of bleaching while Grecian Rocks, Carysfort and Key Largo Dry Rocks had the highest, with nearly all colonies were bleached. Severity of bleaching for each tagged colony at the initial survey (Fig. 8) also varied widely between study plots at the same site (Fig. 5), between colonies in a single study plot (Fig. 9) and even within a single colony (Fig. 4).

Tissue Loss

Rapidly progressing tissue loss that is normally associated with disease was observed throughout the event on colonies of varying condition. In some cases it was observed on the most severely bleached parts of colonies (Fig. 10) suggesting the tissue had succumbed to temperature stress, but it was also observed to affect the more mildly bleached or recovering parts of colonies (Fig. 11). At plot EL3 (surveyed 9/17) where only the mildest bleaching was observed, large areas of recent mortality were observed that were not likely related to bleaching (Fig. 12). Based on algal colonization it appeared as though these dead areas had died approximately 2 weeks prior. Similarly, colonies at one study plot on Carysfort (surveyed 9/17; Fig. 13) were severely bleached and actively losing tissue, but also had signs of older tissue mortality that, based on algal colonization of the dead skeleton, had occurred up to 5 weeks prior to that survey indicating that mortality started earlier at that site compared to the others. It is unknown whether this was heat stress alone, or if a pathogen or other stressor coincided with the bleaching event.

Between June 2014 and February 2015 an average of 25% (+/- 27% SD) of (tagged) colonies in the study plots died completely (Fig. 14a). However, this does not account for the colonies with severe partial tissue mortality that retained only small remnants of live tissue. Based on the total LAI summed for the subset of tagged colonies at the February 2015 survey, the total live area decreased by 1/3 from the June 2014 survey, averaged across all sites (Fig. 14b). Like bleaching prevalence and severity, tissue loss varied widely on a local scale. Grecian Rocks suffered the greatest loss of live *A. palmata* tissue area compared to the other sites observed in this study.

Variability in bleaching response

Water temperature differences between sites may explain some of the variability in bleaching severity and prevalence. For example, daily average water temperature at Elbow Reef, one of the least affected in terms of severity, was consistently lower from mid-July to mid-August and the peak in daily average temperature was also lower than at the other sites. In contrast, Key Largo Dry Rocks and Grecian Rocks typically had higher daily average temperatures than the other sites through this time period, and these sites suffered severe bleaching and mortality. Note that temperature data are not available from June through September at Molasses or French Reefs, however the CMAN readings from Molasses Reef (which historically align very well with our readings at that site) suggest that temperatures there were lower also, and this site was less affected than others too.

Variability in bleaching was also observed within a reef site. Only one temperature logger is deployed per reef site (except Key Largo Dry Rocks where there is one on both the fore reef and back reef), so we cannot say for sure whether temperatures differ enough within one reef to explain the observed plot-to-plot variability. However, similar variability in bleaching response was observed WITHIN some of the 150m^2 study plots (Fig. 9) where it is very unlikely that temperature differences could account for differences in bleaching response. The study plots range in depth from 1 to 6m, however neither the deeper nor the shallower plots within a reef site were consistently more severely bleached. Grecian Rocks Plot 3 (the shallowest study plot, where the tops of the colonies are at times less than a meter from the surface) fared better than the deeper plots at that site. At Carysfort Reef the study plot at 2m depth (CF2; Fig. 13) experienced dramatic bleaching and mortality.

Even if water temperatures did differ enough on this spatial scale to explain the within reef site variability, it does not explain the differences observed between colonies in the same plot (Fig. 9). Variability on this spatial scale is often attributed to differing susceptibility of the various coral genotypes. However, variability between colonies of the same genet (Fig. 15) was observed indicating that, like temperature stress exposure, differences in genotypic susceptibility do not fully explain the observed variability in bleaching response.

Insolation or water flow are factors that may explain (either directly or indirectly) some of the variability between colonies in the same plot as well as between different areas on the same reef. Colonies in sheltered or shaded areas often retained more color (Fig. 16) and recovered more quickly than some of the more exposed parts of the colonies. It is possible that the tissue and zooxanthellae are less stressed in these shaded areas or that different strains or genotypes of zooxanthellae are harbored in these areas.

Other sites

Horseshoe Reef and Turtle Rocks, two thriving *A. palmata* stands, have survived this event. Turtle Rocks is only surveyed annually, and due to its remote location we were not able to make observations during the event. However, it was visited in February 2015 and based on informal estimates may have lost approximately 1/3 of its live area since July 2014. Given that there are still large, healthy colonies there, and based on the past robust performance of this stand, it is likely to recover. No monitoring is conducted at Horseshoe Reef but it was visited in early August, prior to the peak, and mid-September, after the peak, and again in November. At the September visit, some colonies were partly bleached (Fig. 17) but the majority had only minor bleaching at the tips and disease-like tissue loss was present but not substantial. No dramatic losses were observed at the November visit.

Conclusions

- Throughout summer 2014, water temperatures on upper Florida Keys reef sites were ~1^{o}C higher than in the past 4 summers
- Substantial bleaching in *A. palmata* was observed to begin in late August
- Rapid mortality of the more severely bleached colonies was observed
- Less severely affected colonies recovered by November
- Substantial disease-like rapid tissue loss affected recovering colonies as well as colonies which had not bleached
- Overall loss of 1/3 of the live *A. palmata* tissue area from upper Florida Keys reef sites during this event
- Carysfort, Key Largo Dry Rocks and Grecian Rocks suffered dramatic losses.
- High variability in the bleaching response of colonies was not clearly attributable to variation in temperature exposure nor to coral genotype-specific sensitivity as previously described.

Acknowledgments

NOAA's Coral Reef Conservation Program (2006–2010) and NOAA Fisheries' Southeast Regional Office, Protected Resources Division, NSF grant OCE-0825979 and permitted by Florida Keys National Marine Sanctuary (FKNMS-2010-130).

Figures



Figure 1 Extensive bleaching observed in a dense stand of *Acropora palmata* (elkhorn coral) at Grecian Rocks on 9/11/2014.

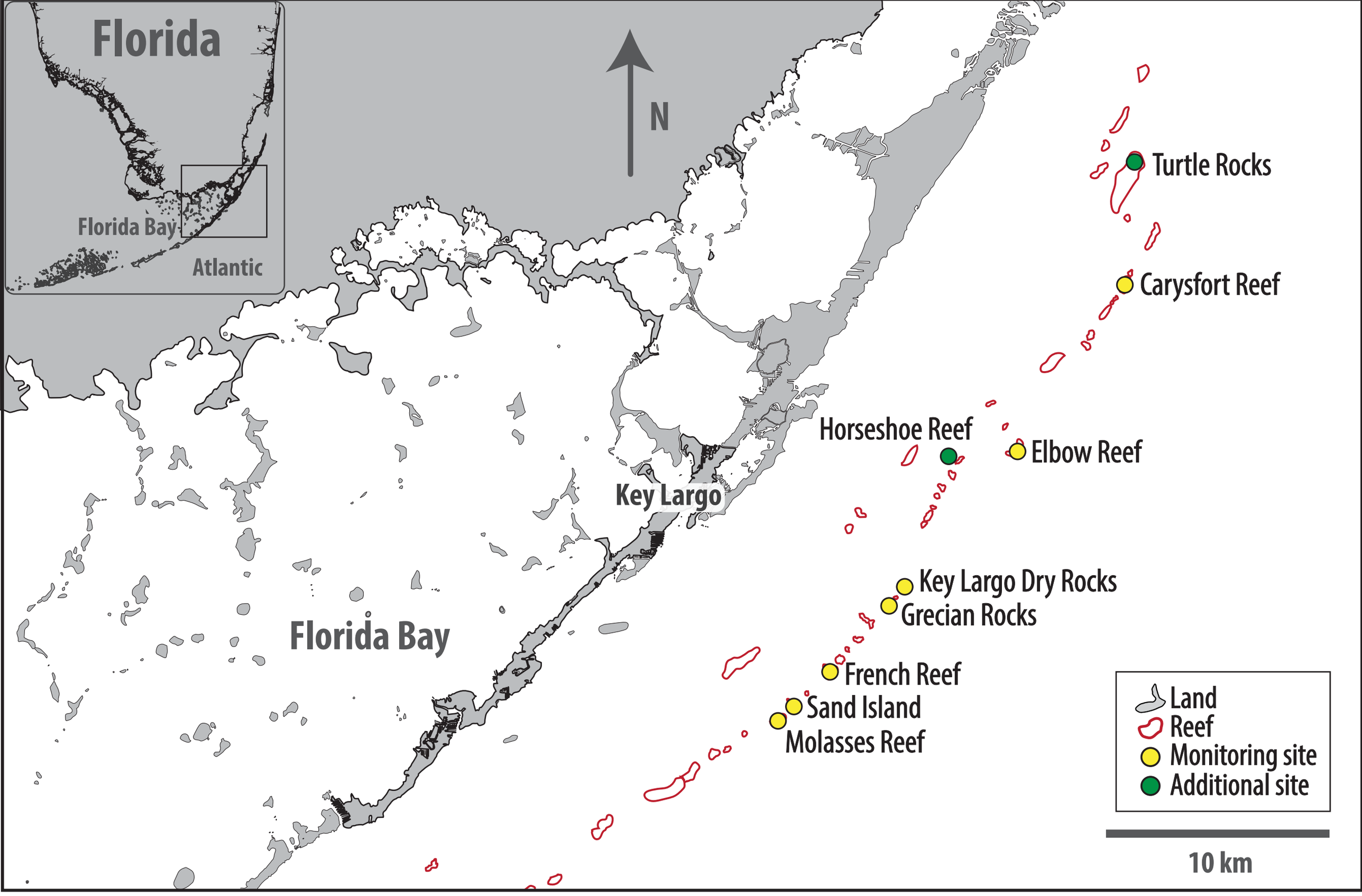


Figure 2 Fixed monitoring plots are located in shallow (1-6m depth) *Acropora palmata* habitat at 7 reef sites in the upper Florida Keys.

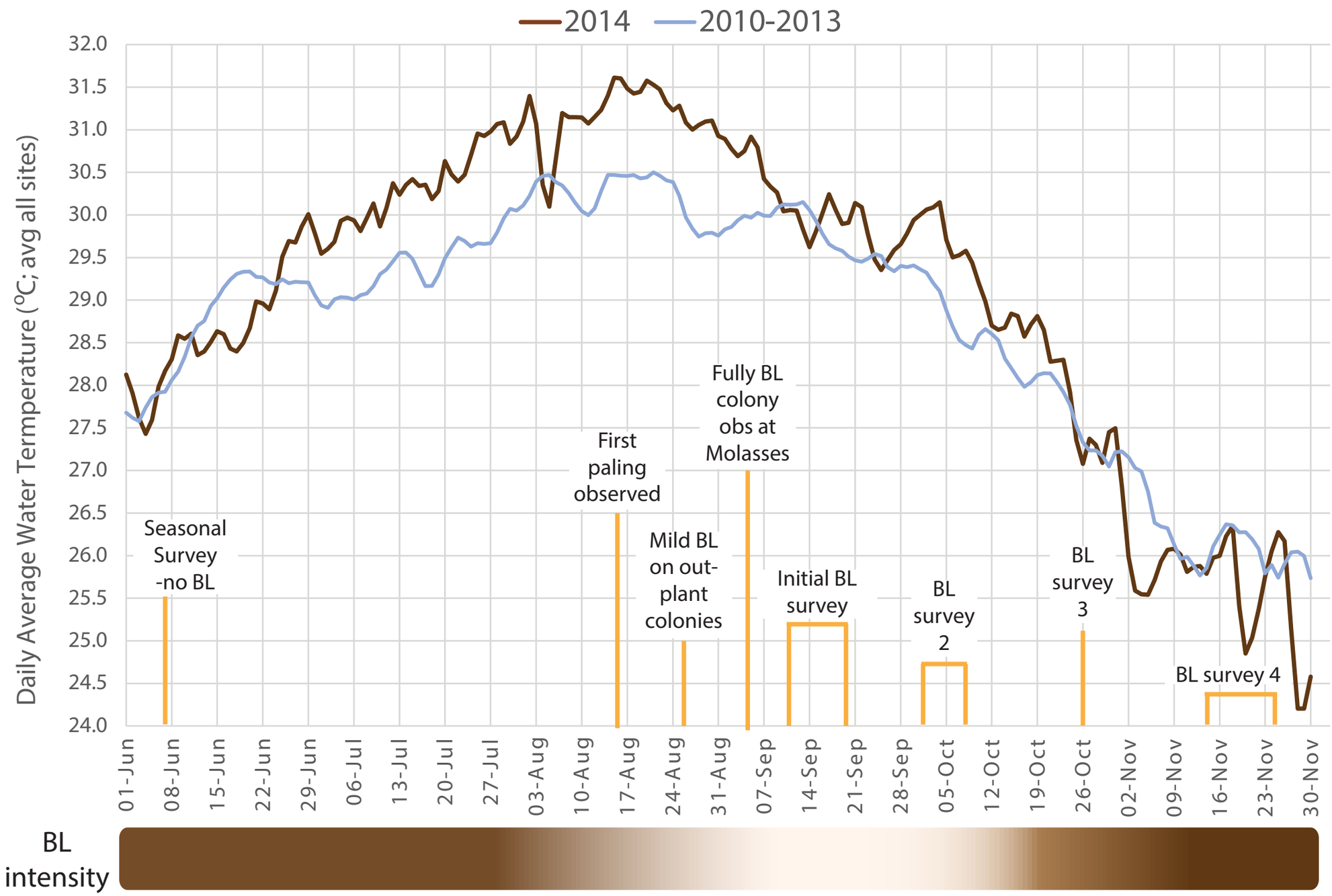


Figure 3 Daily average water temperature averaged for all survey sites from June through November of 2014 and averaged for the same sites over the previous 4 years (2010-2013). A timeline of informal observations of *Acropora palmata* bleaching (BL) in the upper Florida Keys are shown along with the survey timing. The shaded bar along the bottom depicts the approximate event timing shown in the bar along the bottom (white indicates peak bleaching). Note these observations only pertain to *A. palmata*, other coral species were observed bleached earlier (late July, early August).

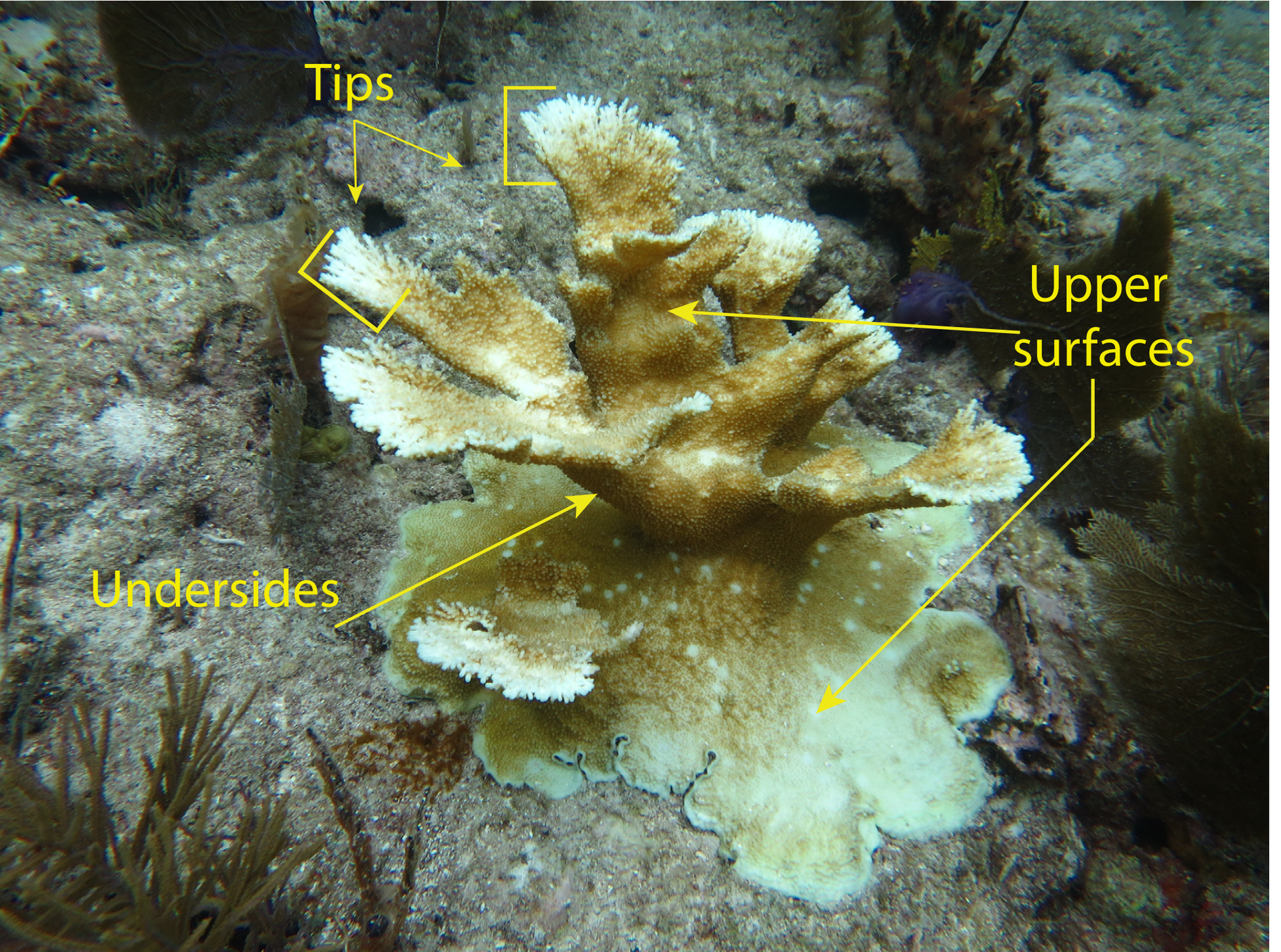


Figure 4 For assessing bleaching severity in *Acropora palmata*, colonies were subdivided into three parts; branch tips, top surfaces, and shaded undersides (understory) with each part being assessed independently. Note that growing tips are typically white so this was taken into account when assessing the tips. In cases where one of the parts did not exist or had no live tissue, no rank was assigned to that part. For example If all branch tips were dead, no severity ranking was assigned to tips. For encrusting colonies where no branches were present, the margins of the colony were ranked as tips, though because these colonies do not have undersides, no rank was assigned for undersides.

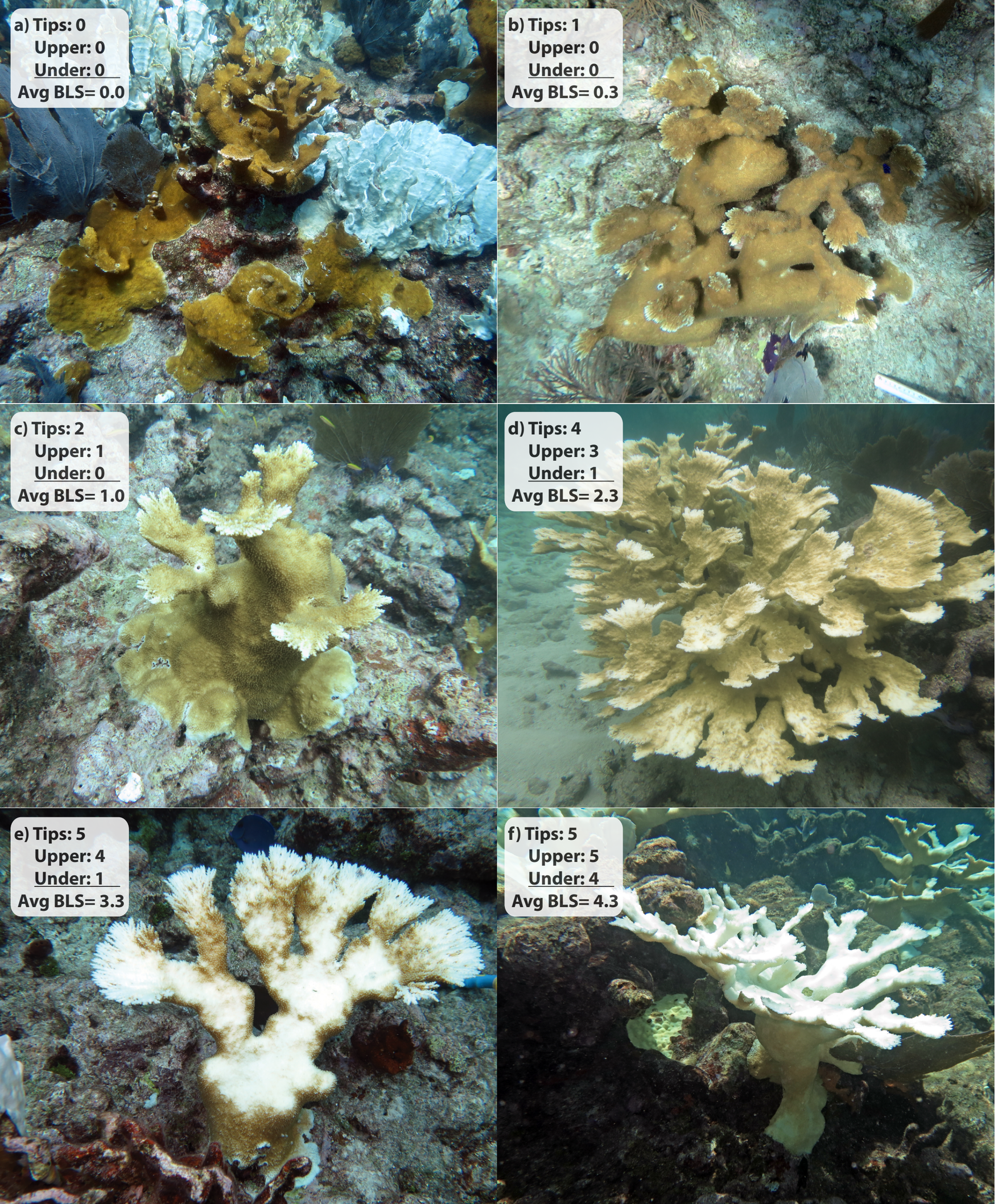


Figure 5 Examples of *Acropora palmata* colonies with bleaching severity (BLS) scores ranging from 0 (a) indicating no observable color loss to 4.33 (f) indicating a severely bleached colony. For each tagged colony, the degree of bleaching on the branch tips, upper surfaces (see Fig. 4) and undersides were ranked independently from 0 to 5. The scores for each colony were averaged to get a BLS score for each colony. For the mildest bleaching, only the branch tips were mildly bleached (b) so the tips were ranked 1 while the tops and undersides were ranked 0 yielding a BLS of 0.3.

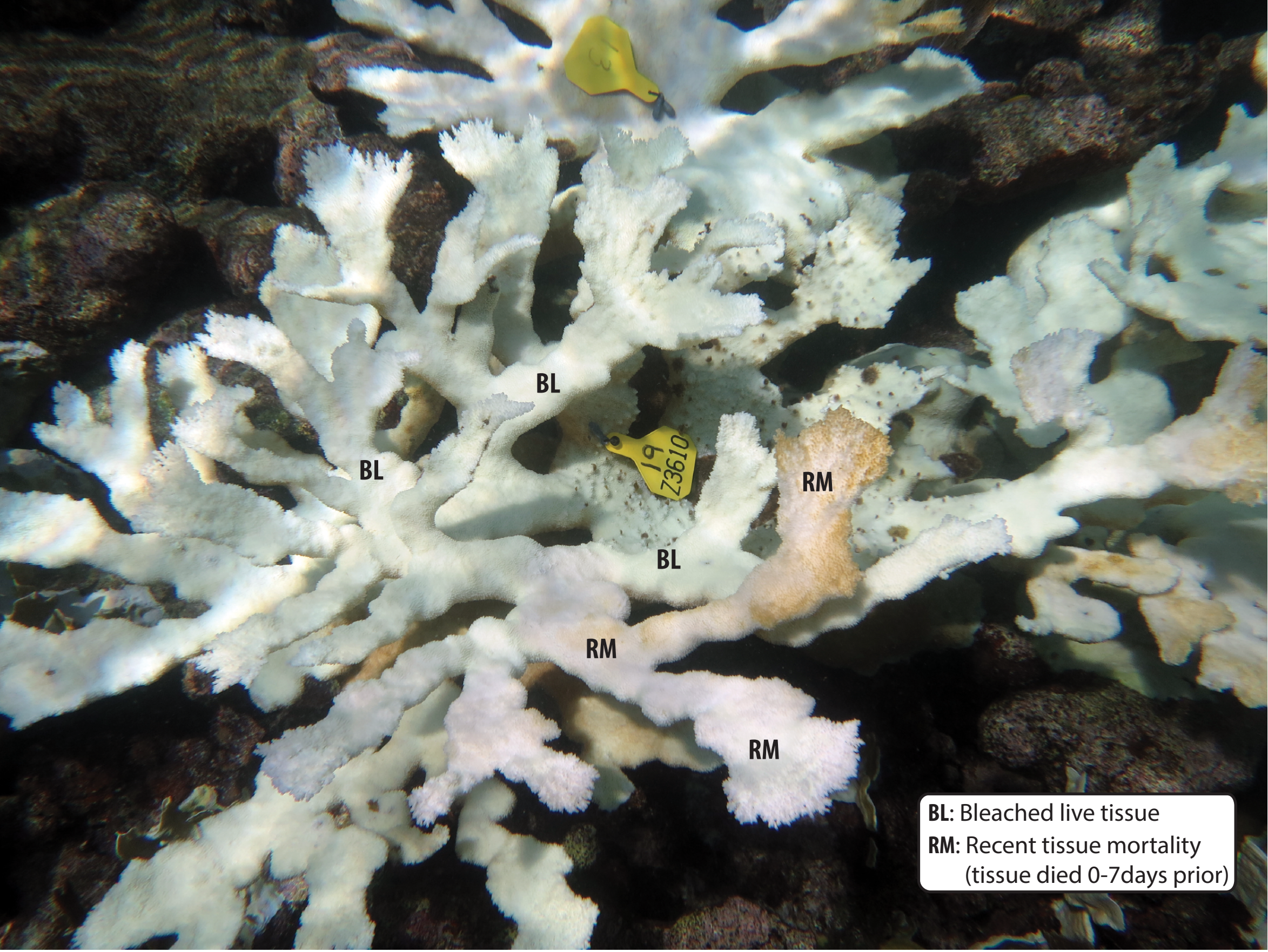


Figure 6 *Acropora palmata* colony at Grecian Rocks on 9/11/14 with severe bleaching (BL) and recent tissue mortality (RM). The light brown on some RM areas is from the growth of filamentous algae indicating that this area has been dead a few days longer than the bright white RM areas on this colony.

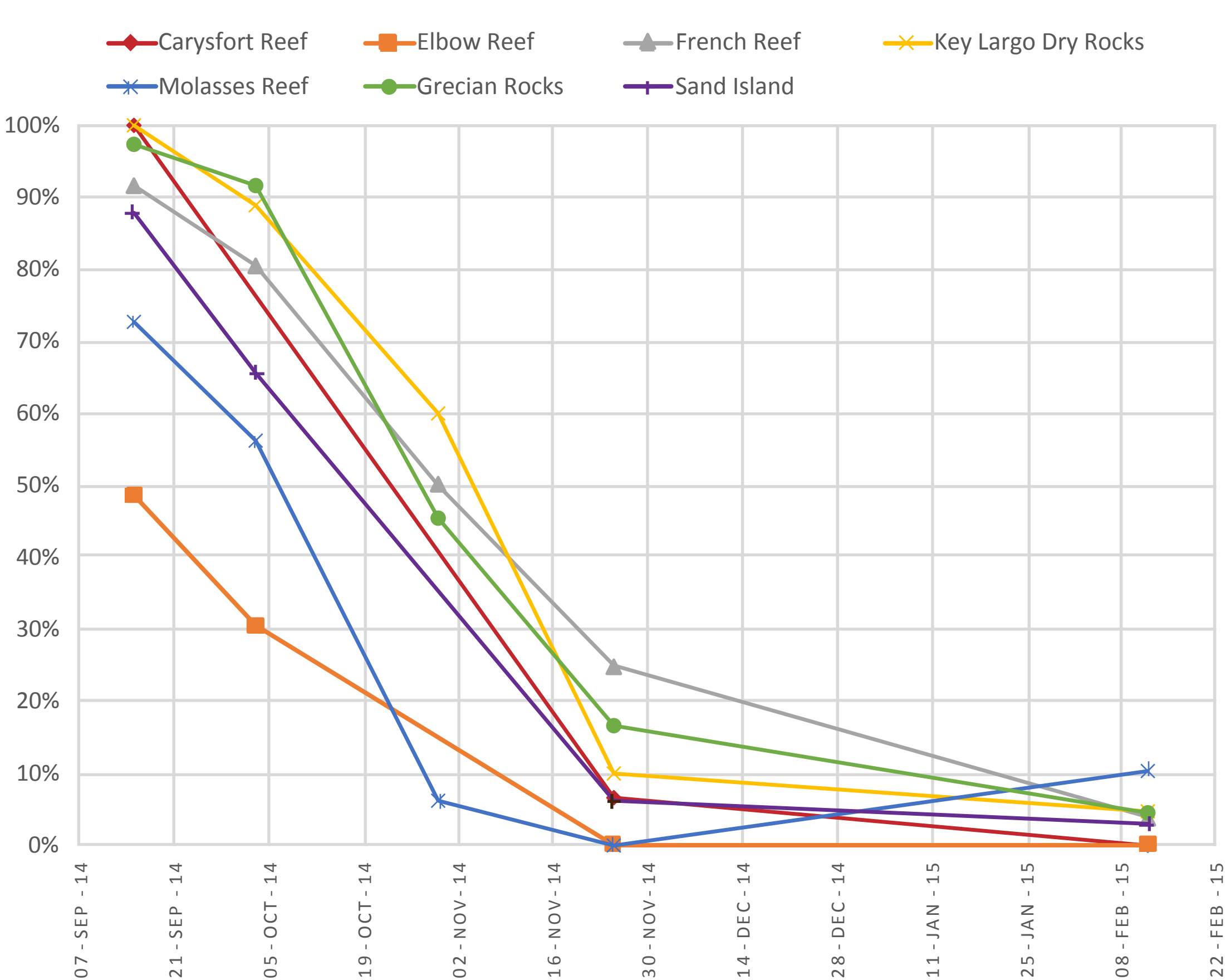


Figure 7 Prevalence of bleaching (any intensity of bleaching included) among tagged *Acropora palmata* colonies over time in fixed plots at the seven reef sites. All sites were observed in June 2014 and bleaching prevalence was within or below typical background levels (~5%). Note that Elbow Reef only includes plots EL1-3 as EL4-5 were only surveyed at the initial September 2014 survey and the February 2015 survey.

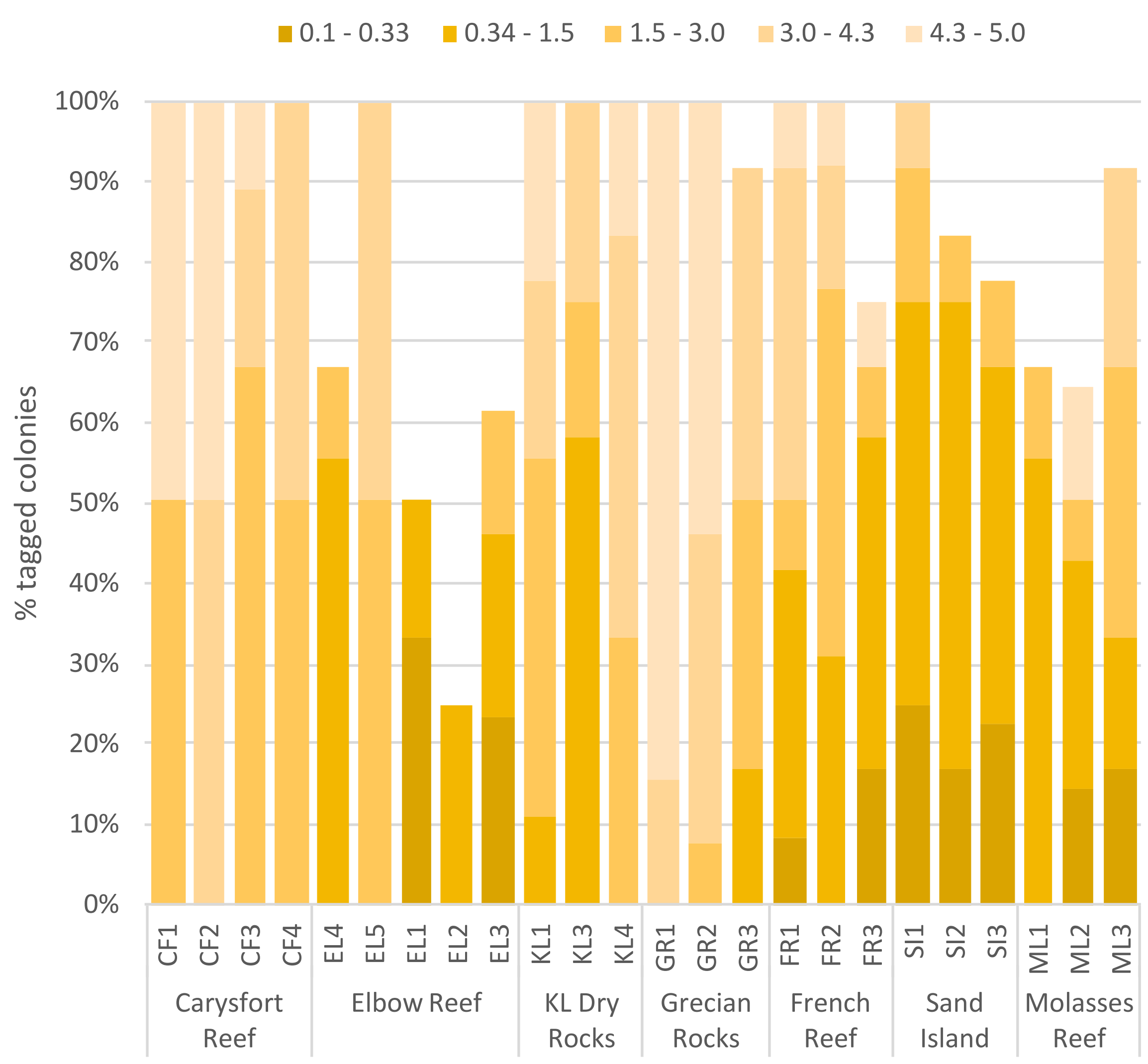


Figure 8 Bleaching prevalence and severity frequency (ranked 0-5 with 5 being fully bleached) among live tagged *Acropora palmata* colonies at the mid-September (initial) survey of all study plots at the 7 sites. Height of the bar indicates the prevalence of bleached colonies at that study plot.

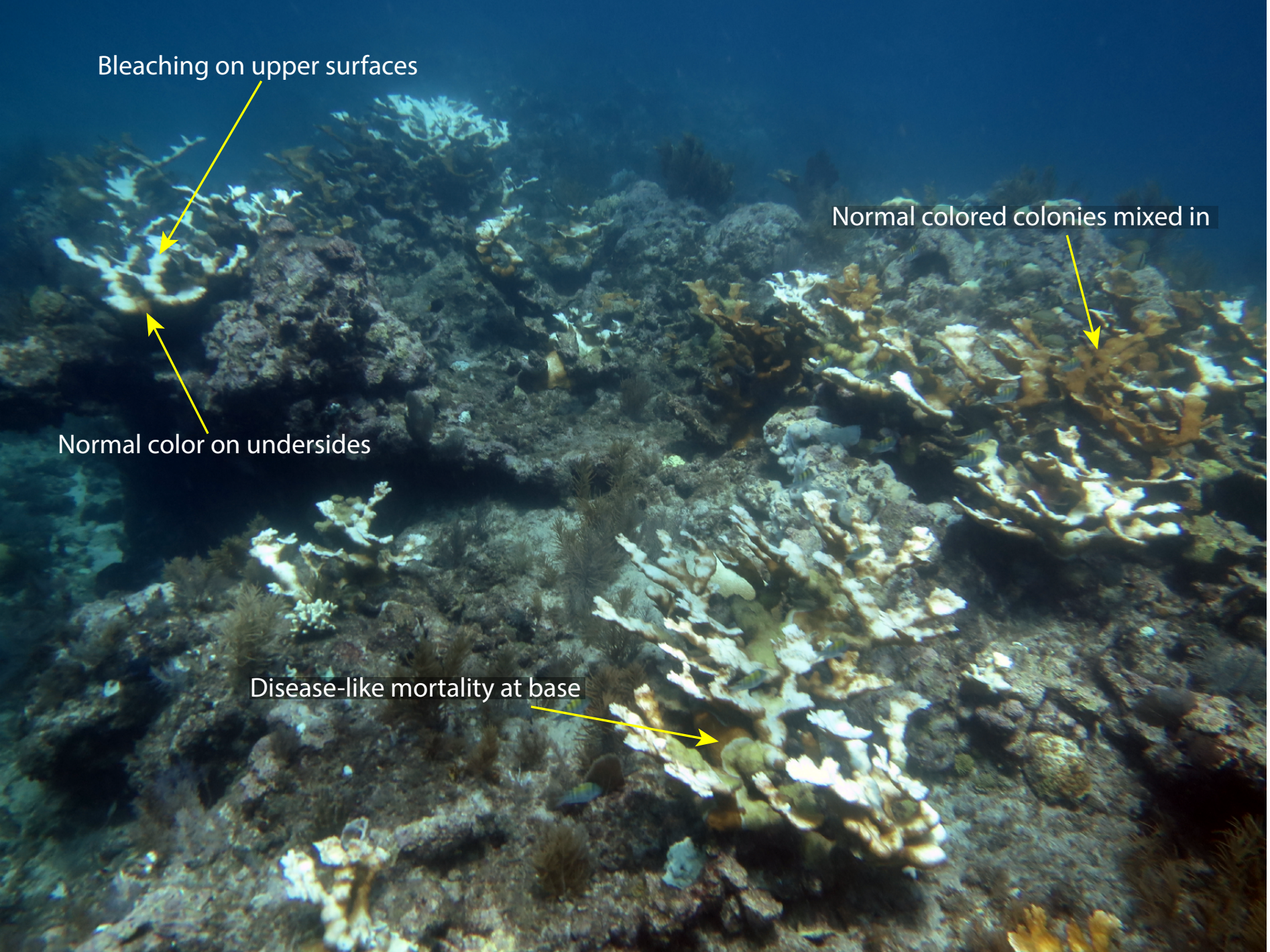


Figure 9 Wide range of *Acropora palmata* colony conditions observed on a small spatial scale (French Reef 9/18/2014). Some colonies retained their normal color throughout the event. Others bleached on part of the colony (typically the top surfaces) while other parts were normal color or only pale (typically the shaded portions). Tissue mortality similar to disease was often observed progressing across areas of normal colored tissue on colonies that had never been observed to bleach as well as colonies that had bleached but already regained normal tissue color.

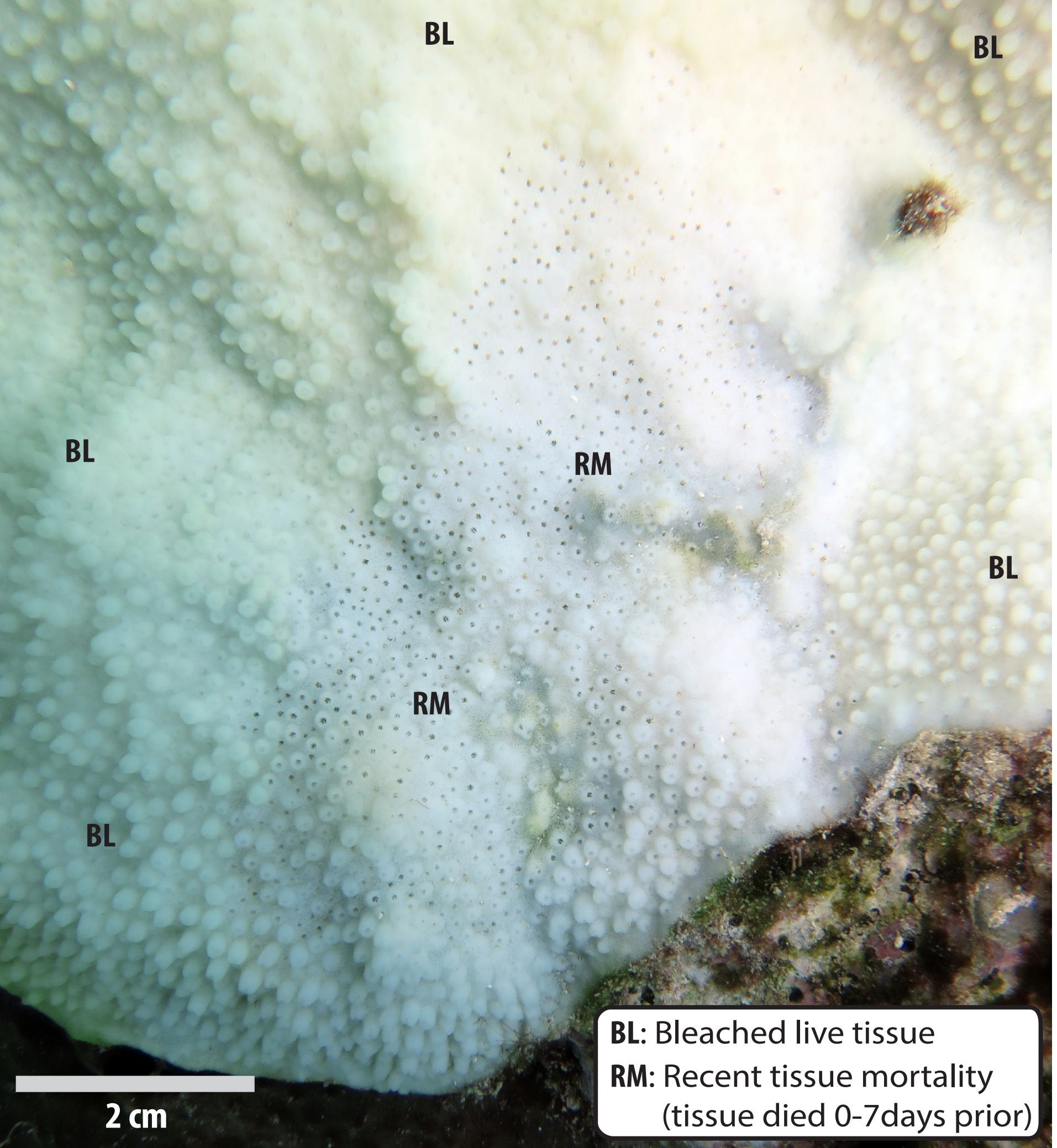


Figure 10 Close-up showing intact bleached *Acropora palmata* tissue along with freshly exposed skeleton where tissue has recently (within 0-2 days) died.

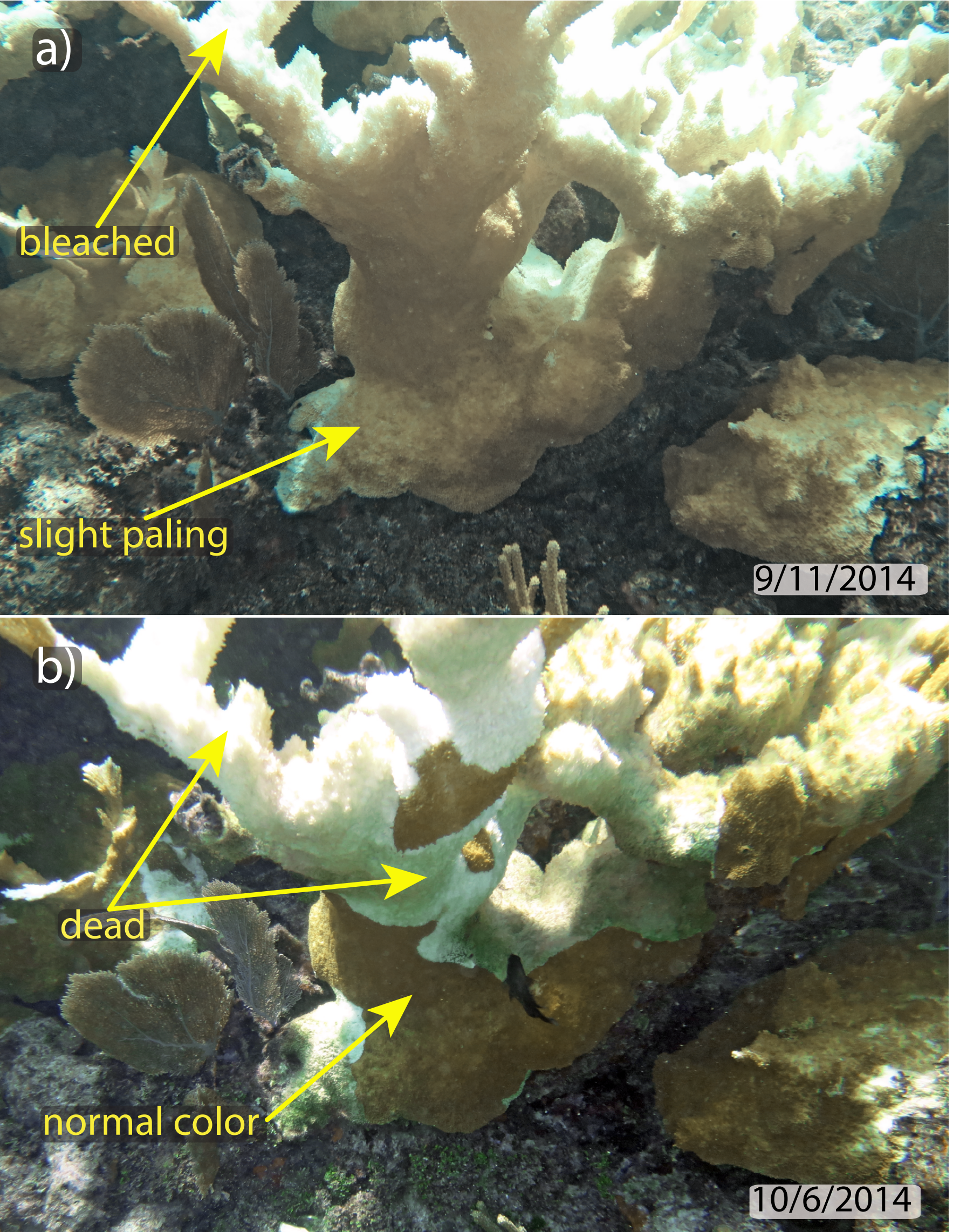


Figure 11 *Acropora palmata* colony at Grecian Rocks a) on 9/11/2014 with bleached upper surfaces and slight paling on the underside; and b) 26 days later the underside had regained normal color yet was rapidly losing tissue from both the still bleached areas on upper surfaces and from the apparently recovering underside.



Figure 12 *Acropora palmata* colony at Elbow Reef (plot EL3) on 9/17 with large area of tissue mortality. Based on the light algal colonization of the dead skeleton, this area is estimated to have died approximately 2 weeks prior and because the algal colonization is uniform it is apparent that this area died over a period of days rather than a slowly progressing tissue loss as is observed with white band disease.

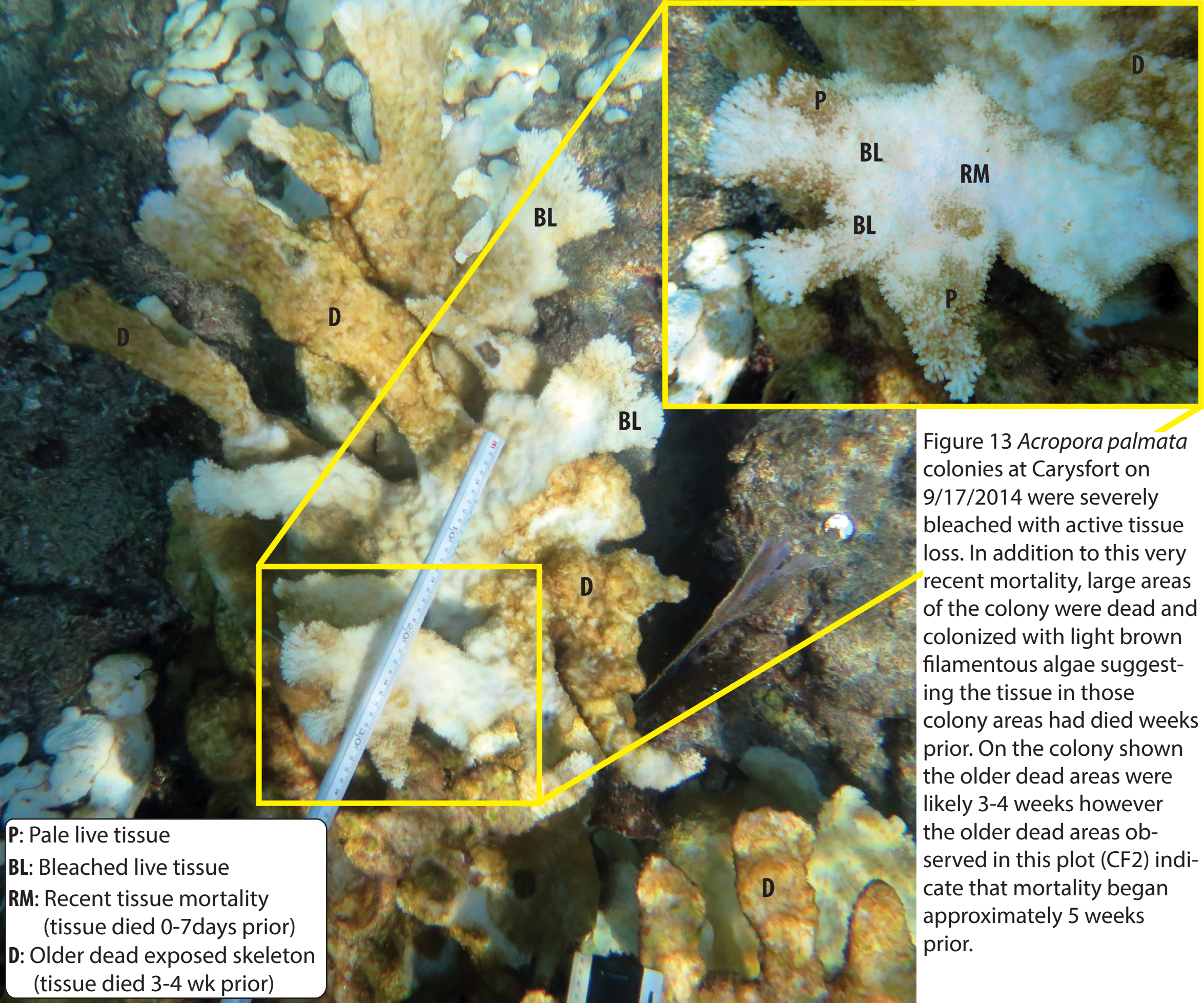
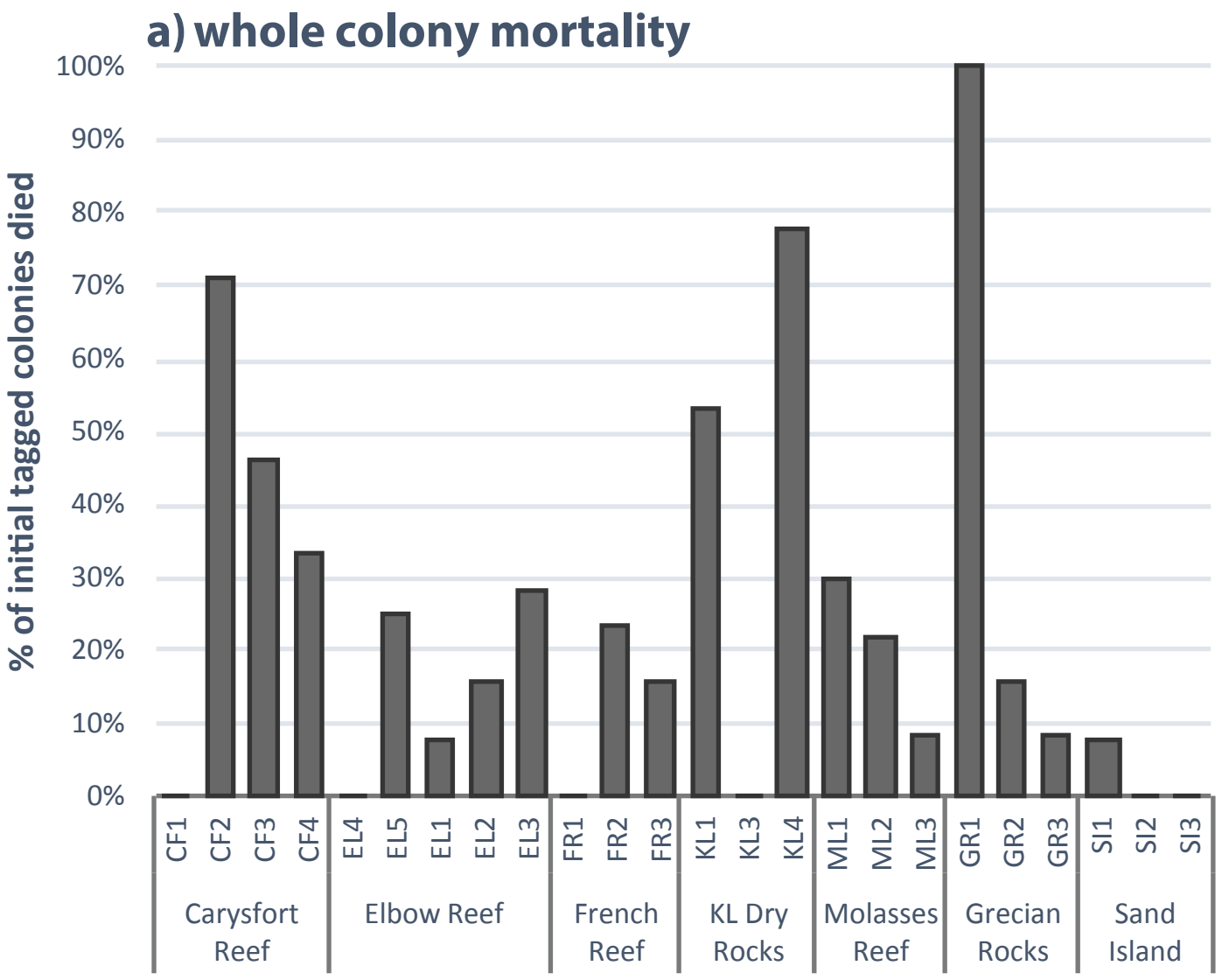


Figure 13 *Acropora palmata* colonies at Carysfort on 9/17/2014 were severely bleached with active tissue loss. In addition to this very recent mortality, large areas of the colony were dead and colonized with light brown filamentous algae suggesting the tissue in those colony areas had died weeks prior. On the colony shown the older dead areas were likely 3-4 weeks however the older dead areas observed in this plot (CF2) indicate that mortality began approximately 5 weeks prior.



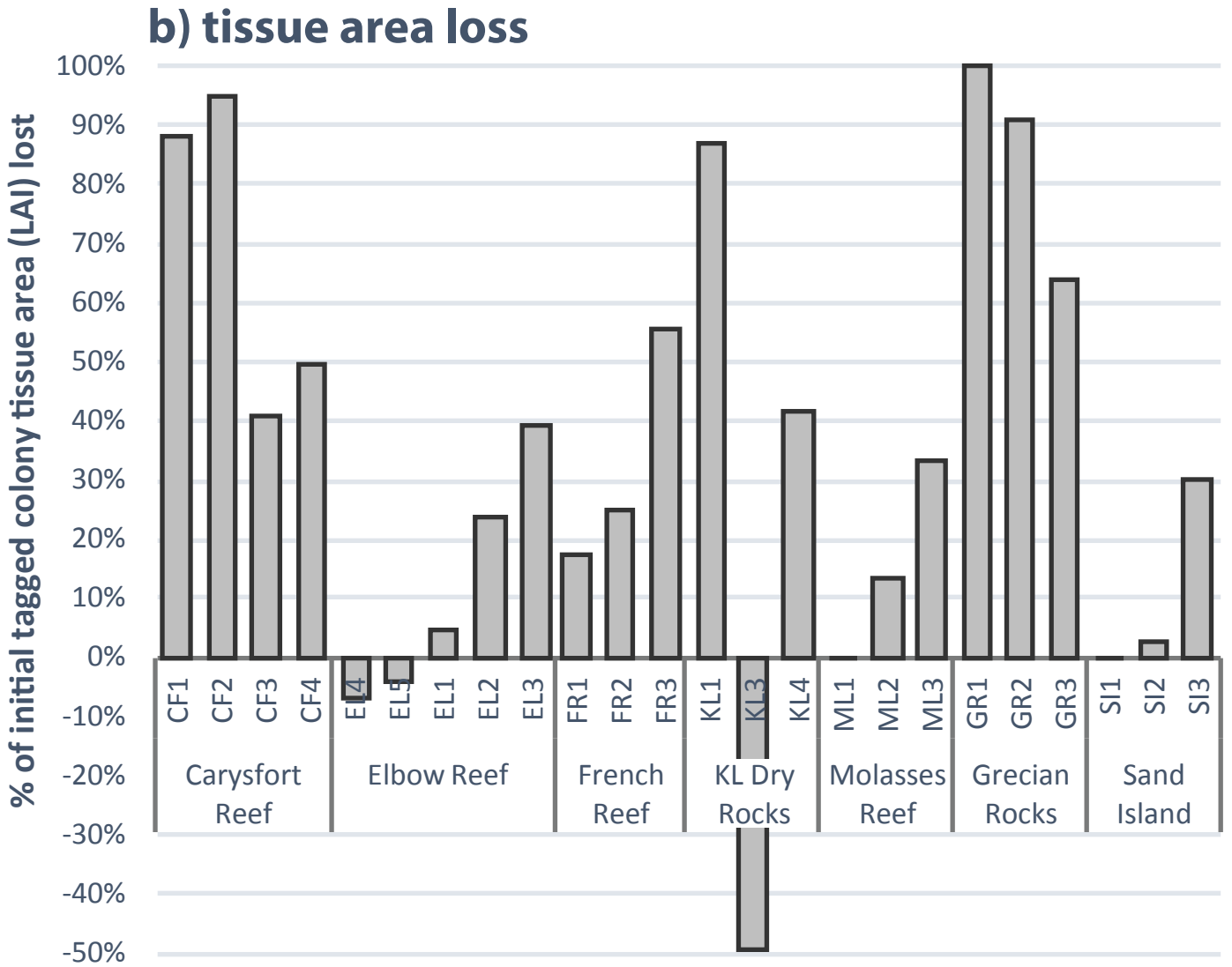


Figure 14 *Acropora palmata* loss between June 2014 and February 2015 shown as a) percent of individual tagged colonies that were alive in June and completely died (lost all live tissue area) before the February survey; and b) percent of total live tissue area (LAI) lost from all tagged colonies either as partial or total mortality between June and February. Note that the large percent increase in LAI (negative loss) shown at study plot KL3 resulted from growth of the small (<40 cm) colonies at that study plot. Note that plots CF1, CF4 and EL5 have very few (2-4) extant colonies even prior to bleaching so the percentages should be interpreted with the small sample size in mind.

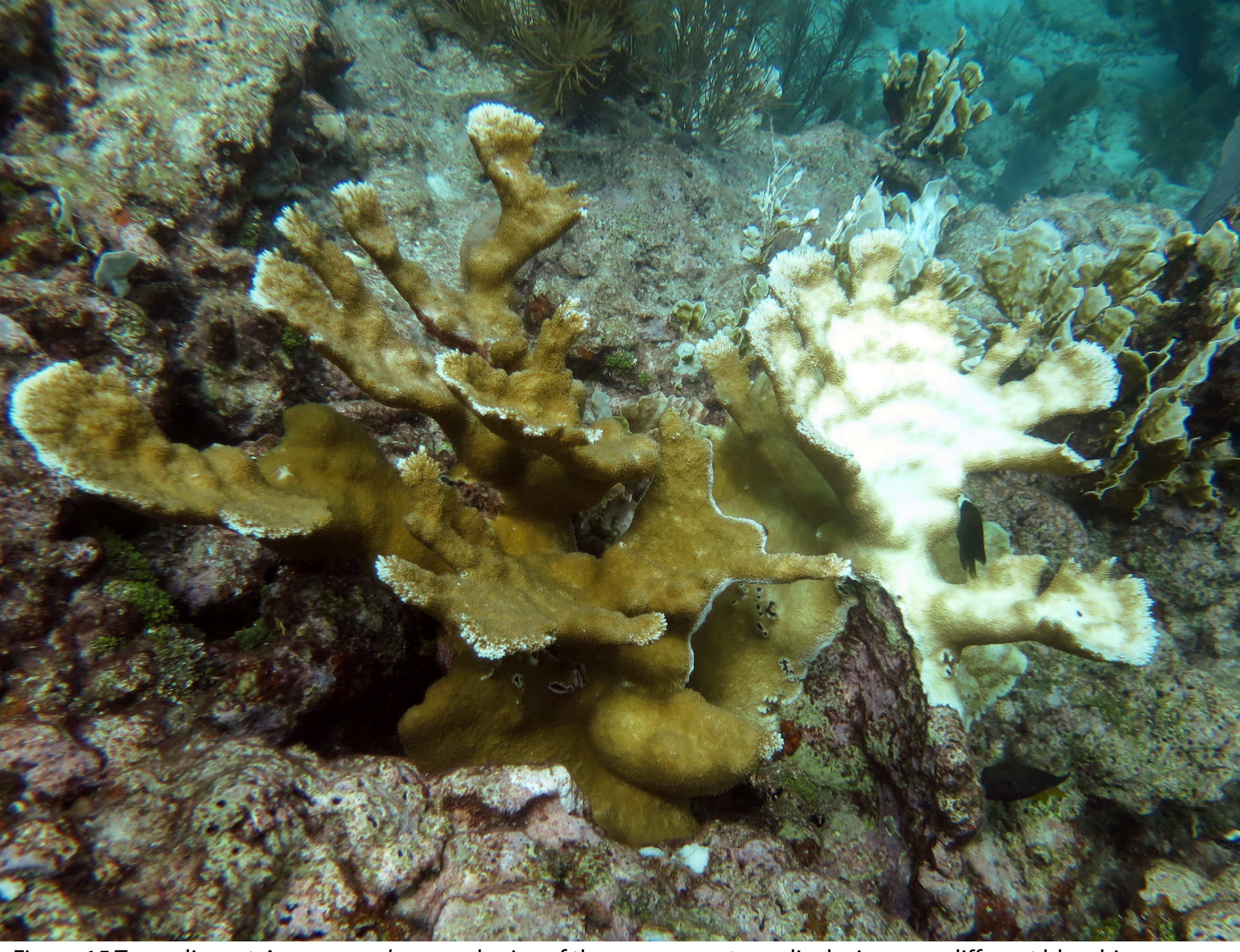
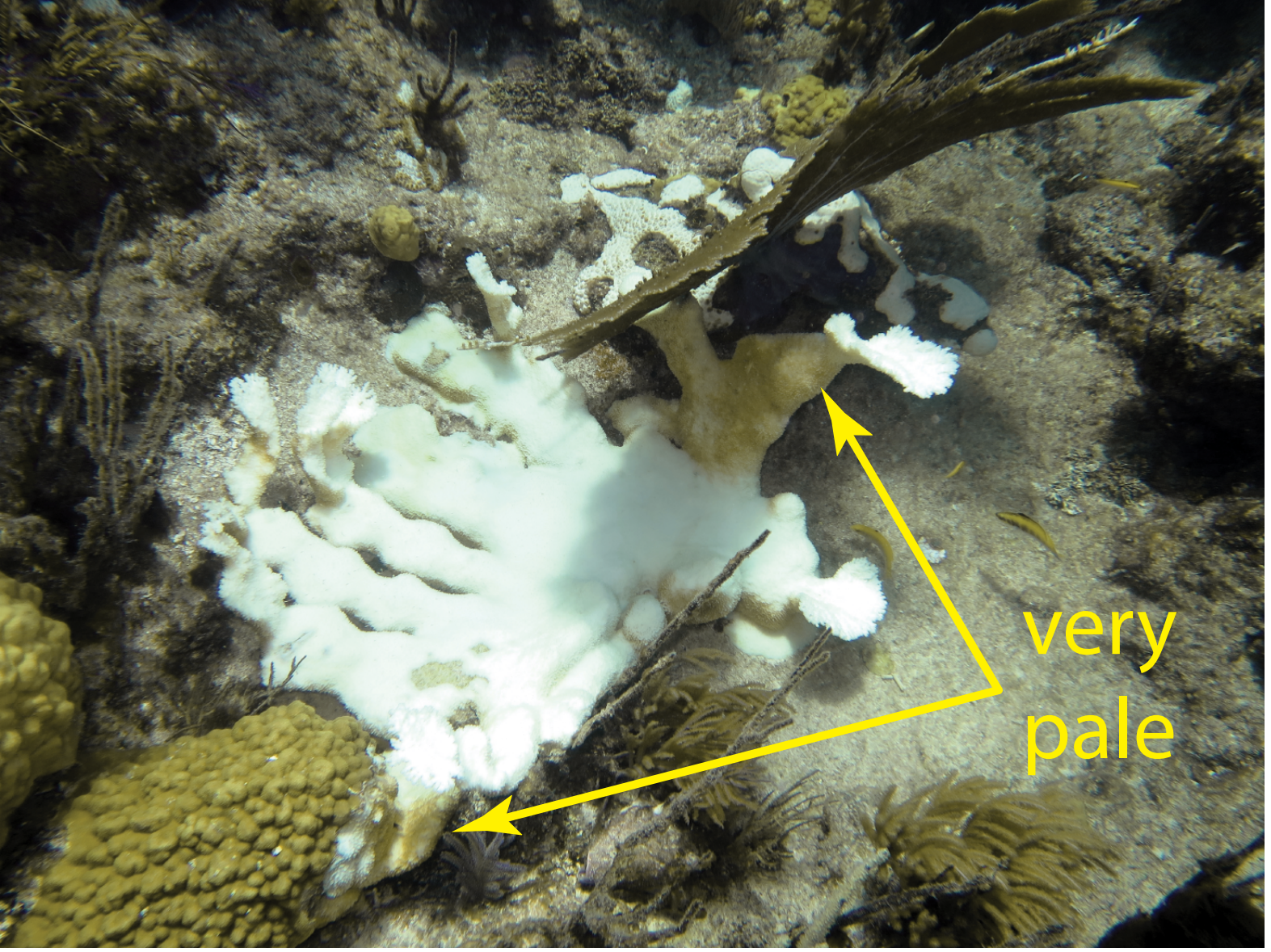


Figure 15 Two adjacent *Acropora palmata* colonies of the same genotype displaying very different bleaching response.



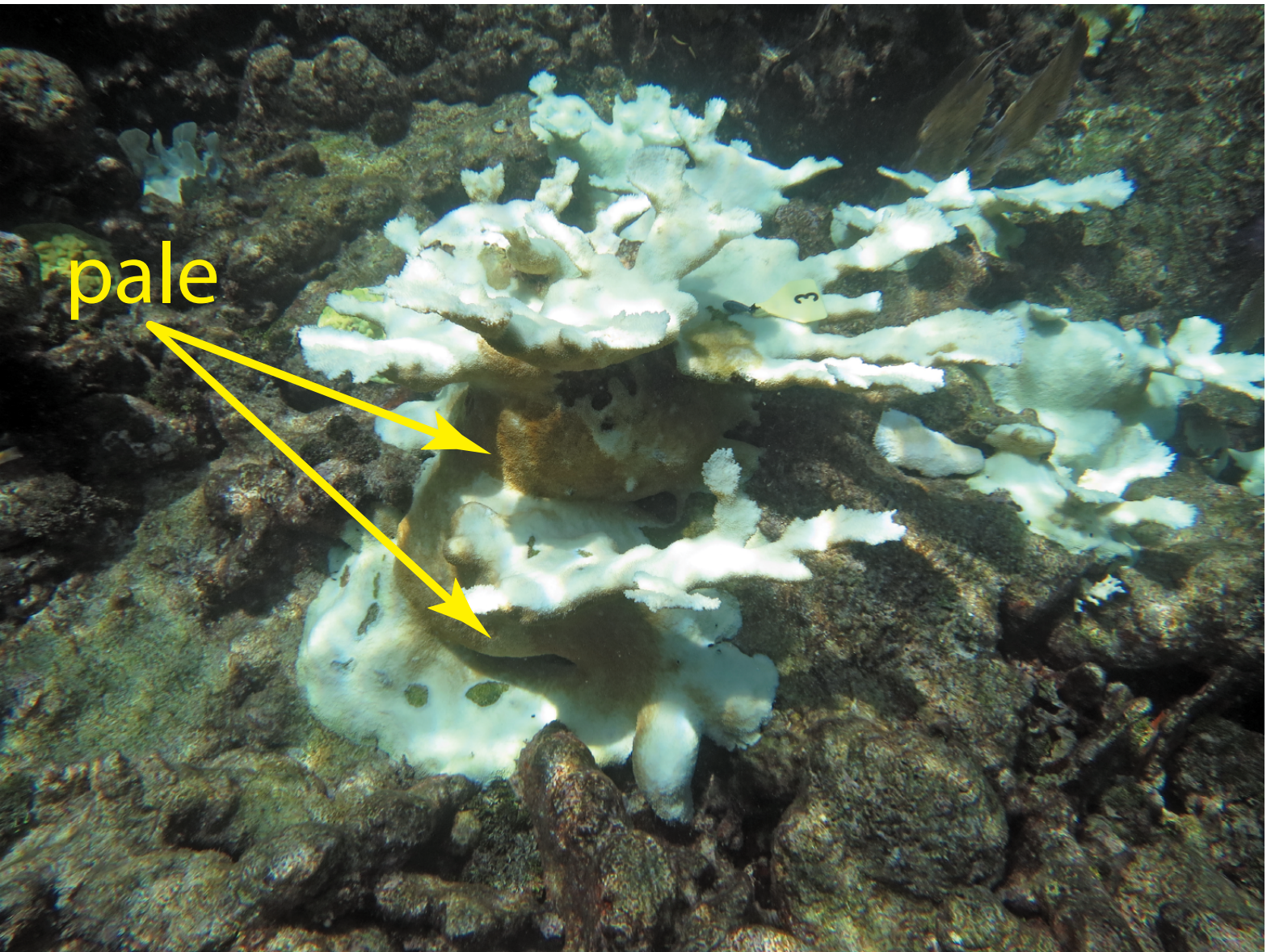


Figure 16 Shaded portions of some *Acropora palmata* colonies retained more color (pale) compared to other neighboring fully bleached parts of the colony. Photos of both of the colonies shown were taken around noon so the shadows show areas of the colony that remain sheltered through the more intense sunlight of the day.



Figure 17 Thicket of *Acropora palmata* colonies at Horseshoe Reef had only mild bleaching in mid-September 2014. Only a small portion (~10% of tissue area) had more moderate to severe bleaching.