A rapid spread of the Stony Coral Tissue Loss Disease outbreak in the Mexican Caribbean

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Caribbean reef corals have experienced unprecedented declines from climate change, anthropogenic stressors and infectious diseases in recent decades. Since 2014 a highly lethal, new disease, called stony coral tissue loss disease (SCTLD), has impacted many species in Florida. During the summer of 2018 we noticed an anomalously high disease prevalence affecting different coral species in the northern portion of the Mexican Caribbean. We assessed the severity of this outbreak in 2018/2019 using the AGRRA coral protocol to survey 82 reef sites across the Mexican Caribbean. Then, using a subset of 14 sites we detailed information from before the outbreak (2016/2017) to explore the consequences of the disease on the condition and composition of coral communities. Our findings show that the disease outbreak has already spread across the entire region, affecting similar species (with similar disease patterns) to those previously described for Florida. However, we observed a great variability in prevalence and tissue mortality that was not attributable to any geographical gradient. Using long-term data, we determined that there is no evidence of such high coral disease prevalence anywhere in the region before 2018, which suggests that the entire Mexican Caribbean (~450 km) was afflicted by the disease within a few months. The analysis of sites that contained pre-outbreak information showed that this event considerably increased coral mortality and severely changed the structure of coral communities in the region. Given the high prevalence and lethality of this disease, and the high number of susceptible species, we encourage reef researchers, managers and stakeholders across the Western Atlantic to accord it the highest priority for the near future.

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Abstract

Caribbean reef corals have experienced unprecedented declines from climate change, anthropogenic stressors and infectious diseases in recent decades. Since 2014 a highly lethal, new disease, called stony coral tissue loss disease (SCTLD), has impacted many species in Florida. During the summer of 2018 we noticed an anomalously high disease prevalence affecting different coral species in the northern portion of the Mexican Caribbean. We assessed the severity of this outbreak in 2018/2019 using the AGRRA coral protocol to survey 82 reef sites across the Mexican Caribbean. Then, using a subset of 14 sites we detailed information from before the outbreak (2016/2017) to explore the consequences of the disease on the condition and composition of coral communities. Our findings show that the disease outbreak has already spread across the entire region, affecting similar species (with similar disease patterns) to those previously described for Florida. However, we observed a great variability in prevalence and tissue mortality that was not attributable to any geographical gradient. Using long-term data, we determined that there is no evidence of such high coral disease prevalence anywhere in the region before 2018, which suggests that the entire Mexican Caribbean (~450 km) was afflicted by the disease within a few months. The analysis of sites that contained pre-outbreak information showed that this event considerably increased coral mortality and severely changed the structure of coral communities in the region. Given the high prevalence and lethality of this disease, and the high number of susceptible species, we encourage reef researchers, managers and stakeholders across the Western Atlantic to accord it the highest priority for the near future.

Keywords: White plague; Coral mortality; disease prevalence; Reef monitoring; Long-term data, Reef functioning

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Introduction

Over the past four decades, coral reefs have experienced declines in condition and function, which has been attributed to coral disease, overfishing and herbivore loss, eutrophication, sedimentation, and climate change (Jackson et al., 2014; Hughes et al., 2017). For the Caribbean in particular, diseases have caused devastating declines in living coral cover of more than 50% to 80% within a few decades (Aronson & Precht, 2001; Jackson et al., 2014). The region-wide outbreak of the white-band disease in the late 1970s led to a substantial loss of the major reef-building corals *Acropora palmata* and *Acropora cervicornis* (Gladfelter, 1982; Aronson & Precht, 2001), it is estimated that nearly 80% of the population was lost during this event (Gladfelter, 1982; Aronson & Precht, 1997). In the late 1990s the white-pox disease, apparently caused by a human-related pathogen, further decimated the populations of *Acropora palmata* (Patterson et al., 2002). In addition, the increase in the incidence of the yellow-band disease in the 1990s affected the populations of *Orbicella* spp., which are the second most important primary reef-building species that tend to dominate many fore-reef zones (Cervino et al., 2001; Gil-Agudelo et al., 2004). Although less evident in the literature, multiple events of white-plague disease outbreaks during the last decades have also substantially decimated the populations of a range of species (Weil, 2004; Harvell, 2007; Precht et al., 2016). It has been suggested for some sites that white-plague disease may have a greater impact on the Caribbean than other diseases (Croquer et al., 2005). Due to the fact that the most severely impacted coral species are also major reef-building corals, disease outbreaks in the Caribbean have largely contributed to the substantial changes in spatial heterogeneity and ecological functionality of Caribbean reefs, along with their capacity to provide important ecosystem services to humans (Alvarez-Filip et al., 2009; Aronson & Precht, 2001; Weil, 2004). Furthermore, diseases have also impacted populations of other key components of Caribbean ecosystems. In the decade of the 1980s, *Diadema antillarum* virtually vanished from the region in the span of only two years due to a non-identified disease outbreak that reduced the populations of this important herbivore and bioeroder in Caribbean reefs (Lessios et al., 1984).

Although Caribbean reef-related diseases were first reported in the early 1970s, our knowledge of their pathology, etiology, and epizootiology (i.e. what are the main drivers that potentially trigger a disease outbreaks) of most coral reef diseases is still limited. However, it is likely that increasing pressures in the form of climate change and coastal development will increase disease prevalence and the effects of diseases on coral communities. For instance, coral diseases are likely to be exacerbated in a context of rapidly increasing sea surface temperatures, as thermal stress has been linked to coral disease outbreaks (Bruno et al., 2007; Randall et al., 2014; van Woesik & McCaffrey 2017). In addition, coral diseases have also been related to stressors such as excess nutrients from sewage or high levels of sedimentation (e.g. Sutherland et al., 2010, Bruno et al., 2003).

In 2014, a new emergent coral disease, the Stony Coral Tissue Loss Disease (SCTLD), was first reported off the coast of Miami-Dade County, Florida in September 2014, just after an intense bleaching event during the summer of the same year (Precht et al., 2016; Precht, 2019; FEDP, 2019). Since then, the SCTLD has gradually spread through the Florida Reef Tract (FEDP, 2019) and began to reach other regions in the Caribbean (AGRRA, 2019). In Florida, regional declines in coral density approached 30% loss and live tissue loss was upward of 60% as a result of the disease outbreak (Walton et al., 2018). The cause of the disease is still unknown but it is affecting more than 20 species of corals (FEDP, 2019), usually in a specific order, with highly-susceptible species showing initial signs of infection, followed by intermediate-susceptible species (FEDP, 2019). The most evident symptom is the display of multiple lesions that provoke rapid tissue loss, leading to the exposure of bright white skeletons that are rapidly covered by turf, macroalgae or sediment. Highly susceptible species include *Pseudodiploria strigosa*, *Dendrogyra cylindrus, Meandrina meandrites, Dichocoenia stokesii, Montastraea cavernosa* and *Eusmilia fastigiata* (Precht et al. 2016; Precht, 2019; FEDP 2019). According to early reports, the SCTLD has not shown seasonal patterns linked to warming or cooling ocean temperatures, contrary to previous white plague diseases that have subsided in winter months as temperatures cooled (Harding et al 2008; Miller et al 2009; FEDP 2019).

On July 2018, following alerting reports issued by local divers, and in collaboration with the authorities of the Parque Nacional Arrecife de Puerto Morelos, we found a reef near Puerto Morelos, in the northern Mexican Caribbean, that had a severe outbreak of a coral disease affecting similar species and exhibiting similar patterns as those previously reported in Florida (Fig. 1). Since then, we set out to survey other reefs in the Mexican Caribbean and found that the disease outbreak spread quickly across the region. Here we document the impact of the SCTLD on coral communities in the Mexican Caribbean by (i) quantifying the disease prevalence at 82 sites; and (ii) describing how this disease has modified the condition and composition of coral communities at 14 sites, using detailed information from before the onset of the outbreak.

Materials & Methods

Data for this region-wide assessment was produced by the Healthy Reefs Initiative (HRI), the Comisión Nacional de Áreas Naturales Protegidas (Mexican Commission for Protected Areas; CONANP) and the Biodiversity and Reef Conservation Laboratory, UNAM. A total of 82 sites were surveyed for this assessment over the period July 2018 - April 2019 (Table S1). All sites were surveyed using the AGRRA coral protocol (Lang et al. 2012).

At each site, coral communities were surveyed by replicating 2 to 16 belt transects of 10x1 m. The following data were recorded for each coral colony within the transect: species name, colony size (maximum diameter, diameter perpendicular to the maximum and height), percentage of bleaching, percentage of mortality (new, transition and old) and the presence of SCTLD and other diseases (Lang et al., 2012). We then calculated the SCTLD prevalence at each site and for all coral species. For this study, we also recorded colonies with 100% mortality for which death could be attributable to the SCTLD (i.e., recent or transient mortality was still evident; see Fig. 1). To provide a clearer picture of the magnitude of the problem, we focused on exploring geographical and temporal trends for the 11 most 'highly susceptible species', which we defined as those that presented more than 10% of SCTLD prevalence across all surveyed sites (Fig. 2; Table S2).

To identify whether the SCTLD outbreak may have started earlier than the summer of 2018, a variety of published and unpublished sources were used to provide a yearly estimate of disease prevalence at a regional level. Datasets were obtained from AGRRA, the HRI, CONANP monitoring protocols and scientific sources (publications and researchers), and are being systematized in the Coral Reef Information System of the Biodiversity and Reef Conservation Laboratory, UNAM (Table S1). Since the main intention of this exercise was to provide a regional perspective of disease prevalence, we only used years for which enough geographical representation exists. In other words, we included years with information from at least 15 sites distributed in at least three of the main sub-regions identified for the Mexican Caribbean (Northern Quintana Roo, Central Quintana Roo, Southern Quintana Roo, Cozumel and Banco Chinchorro; Rioja-Nieto & Álvarez-Filip, 2019). In total, we present data for 7 time periods: 2005/2006, 2009, 2011/2012, 2014, 2016, 2017, and 2018/2019. Some years were combined into one period, as they were part of the same monitoring campaign (i.e. sites were surveyed only once within each period).

In 2016 and 2017 we conducted an extensive effort to survey coral reefs systems through the Mexican Caribbean (e.g. Suchley & Alvarez-Filip, 2018; Perry et al., 2018). Although surveying the condition of coral communities was not part of the objectives of those campaigns we assessed coral communities in some sites using the AGRRA methodology (see above). In 2018 and 2019 we revisited 14 of these sites to compare how coral condition and coral community composition changed from before the SCTLD outbreak to after the onset of the outbreak (in 2018/2019). To describe patterns of coral mortality between periods, we first calculated the proportion of healthy, afflicted and dead colonies for each period (2016/2017 and 2018/2019). As described above, for this analysis we only considered the 11 most 'highly susceptible species'.

The variation in the overall coral community composition (including all recorded species) between 2016/2017 and 2018/2019 was investigated with non-metric multidimensional scaling (nMDS) based on Bray-Curtis similarities of square root transformed coral cover species data in Primer v6 (Clarke & Gorley., 2006). The matrix was created using the relative abundance of each healthy, afflicted and dead colony for each coral species, for each period. The relative abundance of each coral species was used as the variable, the sites as the samples and the before and after period as the factors. A one-way Analysis of Similarities (ANOSIM) was used to test the significance of these groupings (9999 permutations), using the time period as a factor. We then infer the width of the coral community of each reef zone per year as the total area within a polygon delineated by the exterior points (the convex hull). Consequently, we also used standard ellipse area (SEA) as a more representative measure for comparing the coral community space between reefs zones in each time period. Briefly, the standard ellipse is to bivariate data as standard deviation is to univariate data. The standard ellipse of a set of bivariate data is calculated from the variance and covariance of the two axes and contains approximately 40% of the data (Jackson et al., 2012). To compare the total area for each time period, we used the Bayesian standard ellipse area corrected for sample size (SEAc) estimated and plotted using the SIBER routine for the SIAR package in R (Parnell et al., 2015) and the overlap of the reef zones was calculated as the proportion of SEAc overlapping (Jackson et al., 2011).

Results & Discussion

Here we describe how the SCTLD affected 82 reef sites distributed along 450 km in the Mexican Caribbean coast. More than 40% of the sites had a SCTLD prevalence of 10% or more and nearly a quarter had a disease prevalence of more than 30% (Fig. 3); this should be taken as a conservative value, since many sites were surveyed when the SCTLD outbreak was only starting (i.e., only a few colonies of a few species were afflicted by the disease; Fig. 3). However, we observed a great variability in prevalence that was not attributable to any geographical gradient or seasonality (Fig. 3). For example, the SCTLD was first observed in Cozumel’s windward coast in October 2018 (as in most of the surveyed sites in the mainland); however it was not until December 2018 that the disease reached the reefs in the leeward side of Cozumel, followed by rapid spreading during the winter. This observation contrasts with the idea that the disease is linked to thermal stress (van Woesik & McCaffrey, 2017; Walton et al., 2018). Overall, the presence of the SCTLD in the Mexican Caribbean during 2018/2019 was well above the 5% disease prevalence that has been identified as habitual for Caribbean reefs (Weil, 2004; Ruiz-Moreno et al., 2012); and just slightly lower than what has been reported for Florida a few years after the start of the SCTLD outbreak (Walton et al., 2018). During the last 13 years, disease prevalence in the Mexican Caribbean was below 10%, reaching its lowest point in 2016-2017, just one year before the SCTLD outbreak in this region, with only 1% (Fig. 4). Similarly throughout the Florida Reef Tract, the prevalence of disease before the first SCTLD reports was below 2%, but this prevalence doubled after the region-wide outbreak (Walton et al., 2018).

Disease-outbreak events have been a major driver of decline for coral reefs in the Caribbean, however, these events have decimated the populations of only a few species (e.g. white-band and white-pox in *Acropora palmata* and *Acropora cervicornis*). Therefore, the severe effects of the SCTLD have no precedent in the recent history of the Caribbean yet several species have been severely affected by this disease (FEDP, 2019). Our field surveys revealed that 24 out of 46 recorded species presented symptoms of SCTLD, the following being the most affected (i.e. % disease prevalence): *Dendrogyra cylindrus* (57%), *Pseudodiploria strigosa* (40%), *Meandrina meandrites* (38%), *Eusmilia fastigiata* (33%), *Siderastrea siderea* (26%), *Diploria labyrinthiformis* (25%), among others (Fig. 2, Table S2). As in Florida, we have also observed that some of the most susceptible species have disappeared from long-term monitoring sites. Potentially, this emergent disease has even driven local-extinction events of species such as *Meandrina meandrites and D. cylindrus*, species that have vanished from several reef sites on the mainland coast of our study region. In fact, a recent study suggests that *D. cylindrus*, a rare species for hundreds of thousands of years, has a high likelihood to become extinct in the coming years due to this outbreak disease (Chan et al., 2019). We still found healthy colonies of *M. meandrites and D. cylindrus* at Chinchorro Bank and Cozumel Island, but some more recent surveys (not included in this study) revealed that colonies from these two species are increasingly being afflicted by the SCTLD in these two sub-regions.

Although there are some differences between the lists (and ranking) of afflicted species identified for the Mexican Caribbean (this study) and those reported for Florida (e.g. Precht et al., 2016 and Walton et al., 2018), the overall pattern is similar. Many of the species that remained as important reef-building corals, after the declines of *Acropora* and *Orbicella,* are being severely affected by the SCTLD (Gonzalez-Barrios & Alvarez-Filip, 2018; Fig. 2). Complexity-contributing species that exhibited significant declines include *P. strigosa*, *D. labyrinthiformis*, *C. natans* and *M. cavernosa* (Fig. 2). In contrast, we found very low disease prevalence on non-framework building species such as *Agaricia agaricites* and *Porites astreoides* - species that are increasingly becoming dominant in many Caribbean reefs (Perry & Alvarez-Filip, 2019). *A. agaricites* and *P. astreoides* has been described as intermediate susceptible species to the SCTLD (FEDP, 2019), and are very abundant across reef sites in the Mexican Caribbean (Table S1; Gonzalez-Barrios & Alvarez-Filip, 2018). Therefore, the decline in the abundance of several species due to the SCTLD is likely to further increase the dominance of *A. agaricites* and *P. astreoides* in the region. This may have started to become apparent already. The relative abundance of these two species represented 46% of the surveyed colonies in 2016 and 2017, yet by 2018/2019 they accounted for 52% of the total number of recorded coral colonies. However, this is a preliminary observation and further studies should assess coral communities once the SCTLD has already passed its peak in the region. Overall, these findings suggest that the ultimate consequence of the SCTLD outbreak may be a further decrease on the physical persistence and ecological functionality of coral reefs (Alvarez-Filip et al., 2013; Perry et al., 2015; Perry & Alvarez-Filip, 2019).

The analysis of sites that contained pre-outbreak information showed that this outbreak event considerably increased coral mortality and severely changed the structure of coral communities in the region. In total we surveyed 3,059 coral colonies for both periods (2016/2017 and 2018/2019) of the highly susceptible species. In the pre-outbreak period 99.5% of the coral colonies were healthy, but in the 2018-2019 the prevalence reached 25.9%, while another 12.9% of the colonies were already dead as a consequence of the SCTLD (Fig. 5). All the colonies exhibited similar symptoms to those in colonies from Florida, with rapid tissue loss occurring within a period of just a few weeks in the most extreme cases, leaving the white skeletons exposed that were colonized by macroalgae or covered by sediment shortly after. Additionally, our percentage of afflicted colonies by the SCTLD is similar to what was observed in Florida between 2014-2015, where they registered a 30% proportion of afflicted colonies (Precht et al., 2016). The coral community composition of those 14 sites changed considerably between the pre-outbreak surveys and 2018/2019. The one-way ANOSIM showed significant differences between sampling periods ($R = 0.461$, $p < 0.001$). To support this observation, the width (space occupied by the community) of the coral community was compared between sampling periods using the standard ellipse area (SEAc) which is a measure of the space occupied by the community (see methods). The analysis revealed that the period of 2018/2019 had the largest SEAc, compared to the pre-outbreak surveys (Table 1) with an overlapping of 0%, which means that the coral community composition of pre-outbreak surveys is different from the coral community composition of 2018/2019 surveys. This is particularly explained by the sudden increase of afflicted colonies and the number of dead colonies, especially from the species *Meandrina meandrites*, *Pseudodiploria strigosa*, *Diploria labyrinthiformis* and *Eusmilia fastigiata*. This massive disease-outbreak is a clear example of how coral diseases are a driver of change of coral communities (Harvell et al., 2007).

The SCTLD outbreak reached the north of the Mesoamerican Reef System in 2018, affecting most of the coral reefs throughout the 450 km of the Mexican Caribbean coast in less than a year with a non recognizable geographical pattern, contrasting to the gradual spread across Florida Reef Tract between 2014 and 2019 (FDEP, 2019). The extremely rapid geographical progression of the SCTLD across the Mexican Caribbean could be explained, at least in part, by the rapidly decreasing quality of sea water in the region. The Mexican Caribbean coast has experienced dramatic coastal development over the last decades. Over 10 million tourists visit the region annually and the local population has grown exponentially (Suchley & Alvarez-Filip, 2018). Consequently, coastal waters of the region have experienced eutrophication and increased sedimentation levels (Murray, 2007; Baker et al., 2013; Hernández-Terrones et al., 2015). Eutrophication resulting from inadequate wastewater treatment has been previously identified as a major driver of declining reef condition in the region (e.g. Suchley & Alvarez-Filip, 2018). In addition and more recently, the Mexican Caribbean coast has regularly experienced a massive influx of drifting *Sargassum* that accumulates on the shores and rapidly decomposes, resulting in near-shore murky-brown waters that rapidly increases nutrient concentration in the water column and reduces light, oxygen and pH levels (van Tussenbroek et al., 2017). These sargassum-brown-tides have been proven to have drastic consequences on near shore seagrass meadows and coral communities (van Tussenbroek et al., 2017), given the amount of *Sargassum* reaching the coast, these negative effects are likely to disseminate further offshore, reaching coral reefs (usually located 0.5-3 km from the coast). Further research is needed to fully comprehend the relationship between rapidly changing water quality in the Mexican Caribbean and the susceptibility of reef corals to diseases; however, chronic nutrient enrichment has already been related to coral diseases and bleaching under experimental conditions (Vega Thurber et al., 2013).

Conclusion

The Caribbean region is a well-known ‘disease hot-spot’ because of the fast emergence, high prevalence and virulence of coral-reef diseases and syndromes (Weil, 2004). These events have deeply marked the community composition of Caribbean reefs by decimating populations of important reef-building coral species like *A. palmata*, which has not fully recovered from these events (e.g. Rodríguez-Martínez et al., 2014). However, the SCTLD is likely to become the most contagious and deadly coral disease ever recorded. A total of 29 species, including rare and important reef-building coral species, have been reported to be affected by the SCTLD (this study; Precht et al., 2016; Walton et al., 2018; FDEP, 2019), but even more concerning is the fact that this disease is covering a wide geographic range that is rapidly expanding. Recently, reports of the SCTLD have also been issued for Jamaica, St. Maarten, the Dominican Republic and St. Thomas in the U.S. Virgin Islands (AGRRA, 2019). The ultimate consequences for the wider Caribbean are yet to be seen; however, our findings suggest that this event has the potential to further decrease physical persistence and ecological functionality of coral reefs at a regional scale (Perry & Alvarez-Filip 2019). Amelioration or eradication intervention have only partially succeeded in impeding the spread of the SCTLD disease across Florida and Mexico, in part because the disease is spreading more rapidly (weeks) than our capacity (scientists, managers, stakeholders) to respond to these types of events (e.g. Precht, 2019). Given the high prevalence and lethality of this disease, and the high number of susceptible species, we encourage reef researchers, managers and stakeholders across the Caribbean to accord it the highest priority for the near future.

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Figure legends

Figure 1. Two colonies of *Pseudodiploria strigosa* observed the 3rd of July, 2018 at a fore-reef reef site in Puerto Morelos, Mexico. One colony (front) shows the classic symptoms of the Stony Coral Tissue Loss Disease, while the other one died shortly before the photo was taken (recent and transient mortality). A Foureye Butterflyfish (*Chaetodon capistratus*) is feeding on the edge of the lesion on the colony at the front. This was a common observation during the course of this study. Photo credits: Lorenzo Álvarez-Filip.

Figure 2. Prevalence (%) of the Stony Coral Tissue Loss Disease for the 11 most susceptible species across 82 reef sites in the Mexican Caribbean (n = number of colonies). For this figure, we include coral colonies with total mortality but for which death could be attributable to the SCTLD (exposed bright white skeletons; see Fig. 1).

Figure 3. Prevalence of the Stony Coral Tissue Loss Disease in the Mexican Caribbean. Dots represent the location of the 82 surveyed reefs and the colours represent the SCTLD prevalence for the 15 most afflicted species (see methods and Fig. 2). Data on this figure was collected by the Healthy Reefs Initiative, the Comisión Nacional de Áreas Naturales Protegidas (Mexican Commission for Protected Areas; CONANP) and the Biodiversity and Reef Conservation Laboratory, UNAM. Please note that reef sites were surveyed at different times (between July 2018 and April 2019).

Figure 4. Disease prevalence (%) of the 11 most susceptible species to the Stony Coral Tissue Loss Disease (STCLD) from 2005/2006 to 2018/2019 in the Mexican Caribbean. From 2009 to 2014 black-band disease was the most abundant coral disease and was mainly recorded in *Siderastrea siderea* in Cozumel.

Figure 5. Proportion of healthy, afflicted and dead colonies of the highly susceptible species in 2016/2017, before the onset of the Stony Coral Tissue Loss Disease Outbreak (SCTLD) in the Mexican Caribbean, and in 2018/2019 when the SCTLD was spread across many sites in the region.

Figure 6. Coral community composition for the study sites before and after the disease. Non-metric multi-Dimensional Scaling (nMDS) analysis displaying degree of similarity of the community composition across 24 sites in the Mexican Caribbean for the coral cover by species. The blue triangles represent the sites before the disease (2016-2017) and the grey circles represent the sites after the disease (2018-2019). Dotted lines: convex hull total area (TA). Solid lines: standard ellipse area corrected for small sample sizes (SEAc).

Figure 1

Two colonies of *Pseudodiploria strigosa* observed the 3rd of July, 2018 at a fore-reef reef site in Puerto Morelos, Mexico.

One colony (front) shows the classic symptoms of the Stony Coral Tissue Loss Disease, while the other one died shortly before the photo was taken (recent and transient mortality). A Foureye Butterflyfish (*Chaetodon capistratus*) is feeding on the edge of the lesion on the colony at the front. This was a common observation during the course of this study. Photo credits: Lorenzo Álvarez-Filip.

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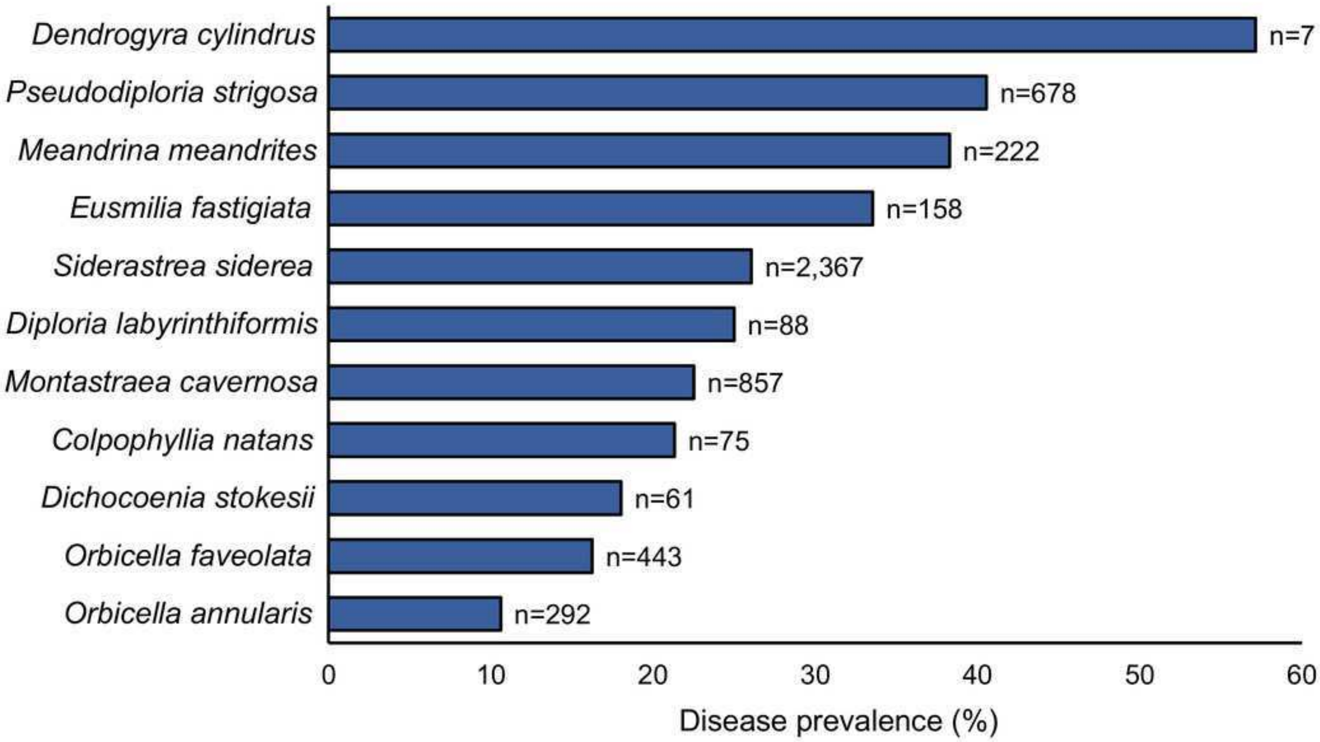
For this figure, we include coral colonies with total mortality but for which death could be attributable to the SCTLD (exposed bright white skeletons; see Fig. 1).



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Prevalence of the Stony Coral Tissue Loss Disease in the Mexican Caribbean.

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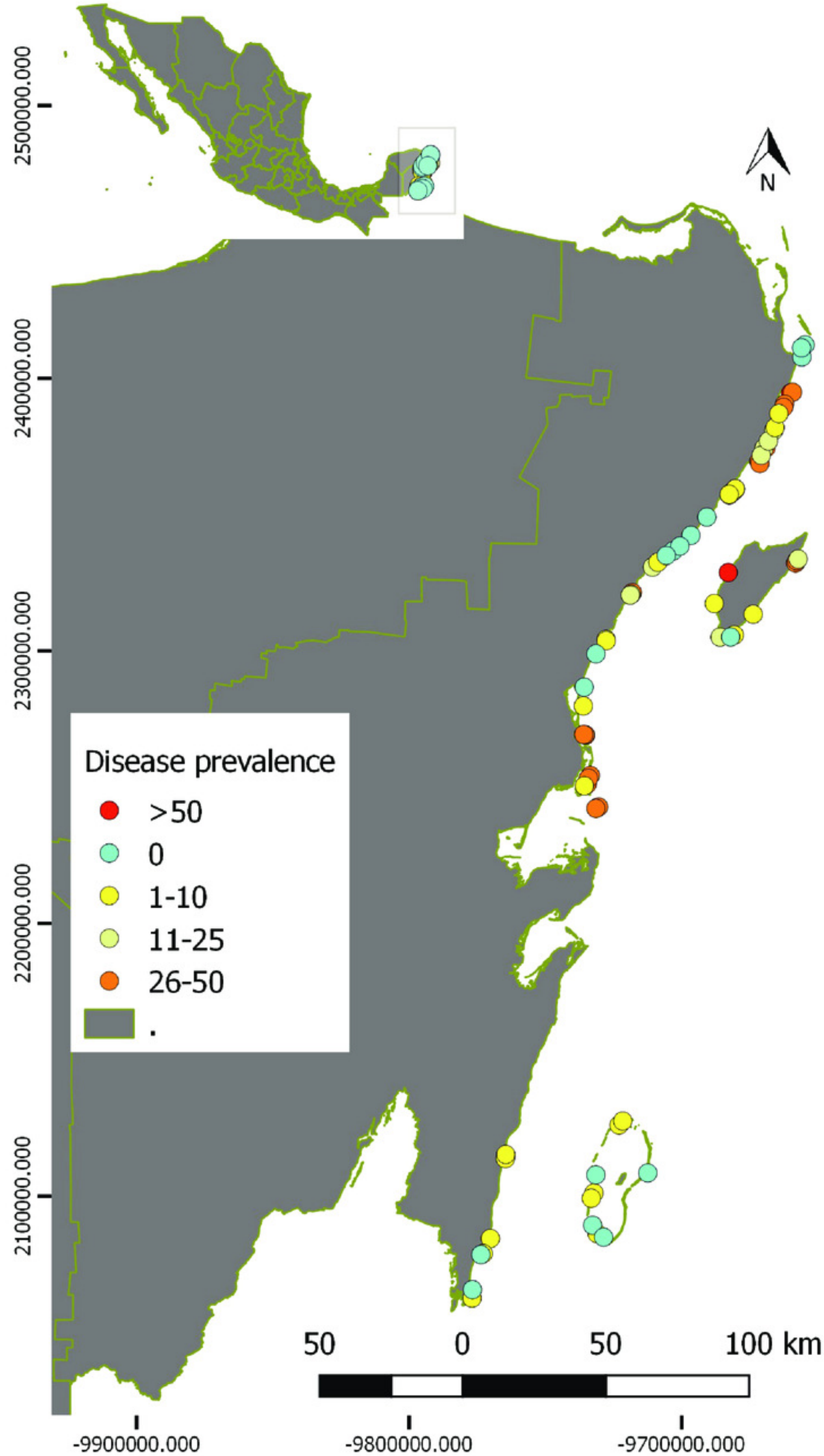

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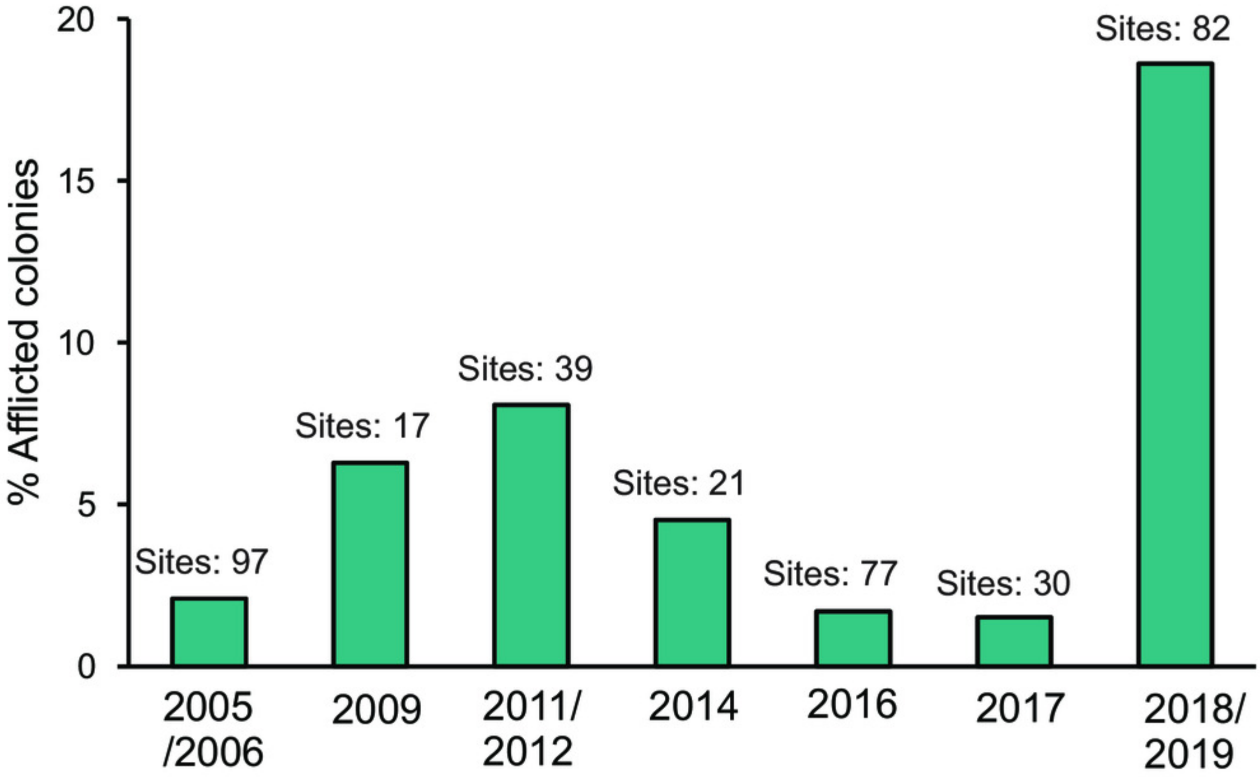
From 2009 to 2014 black-band disease was the most abundant coral disease and was mainly recorded in *Siderastrea siderea* in Cozumel.



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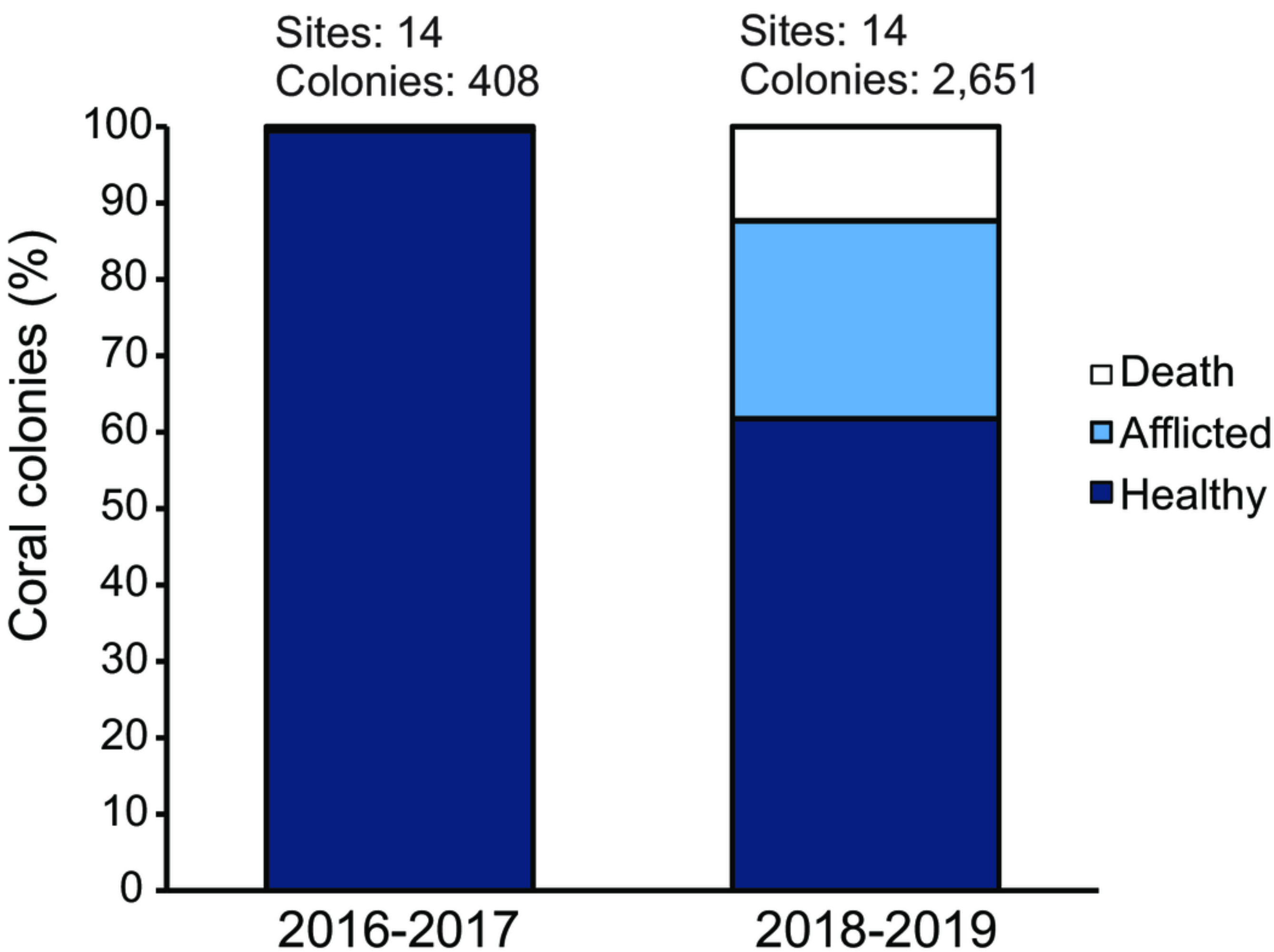

Figure 6

Coral community composition for the study sites before and after the disease.

Non-metric multi-Dimensional Scaling (nMDS) analysis displaying degree of similarity of the community composition across 24 sites in the Mexican Caribbean for the coral cover by species. The blue triangles represent the sites before the disease (2016-2017) and the grey circles represent the sites after the disease (2018-2019). Dotted lines: convex hull total area (TA). Solid lines: standard ellipse area corrected for small sample sizes (SEAc).

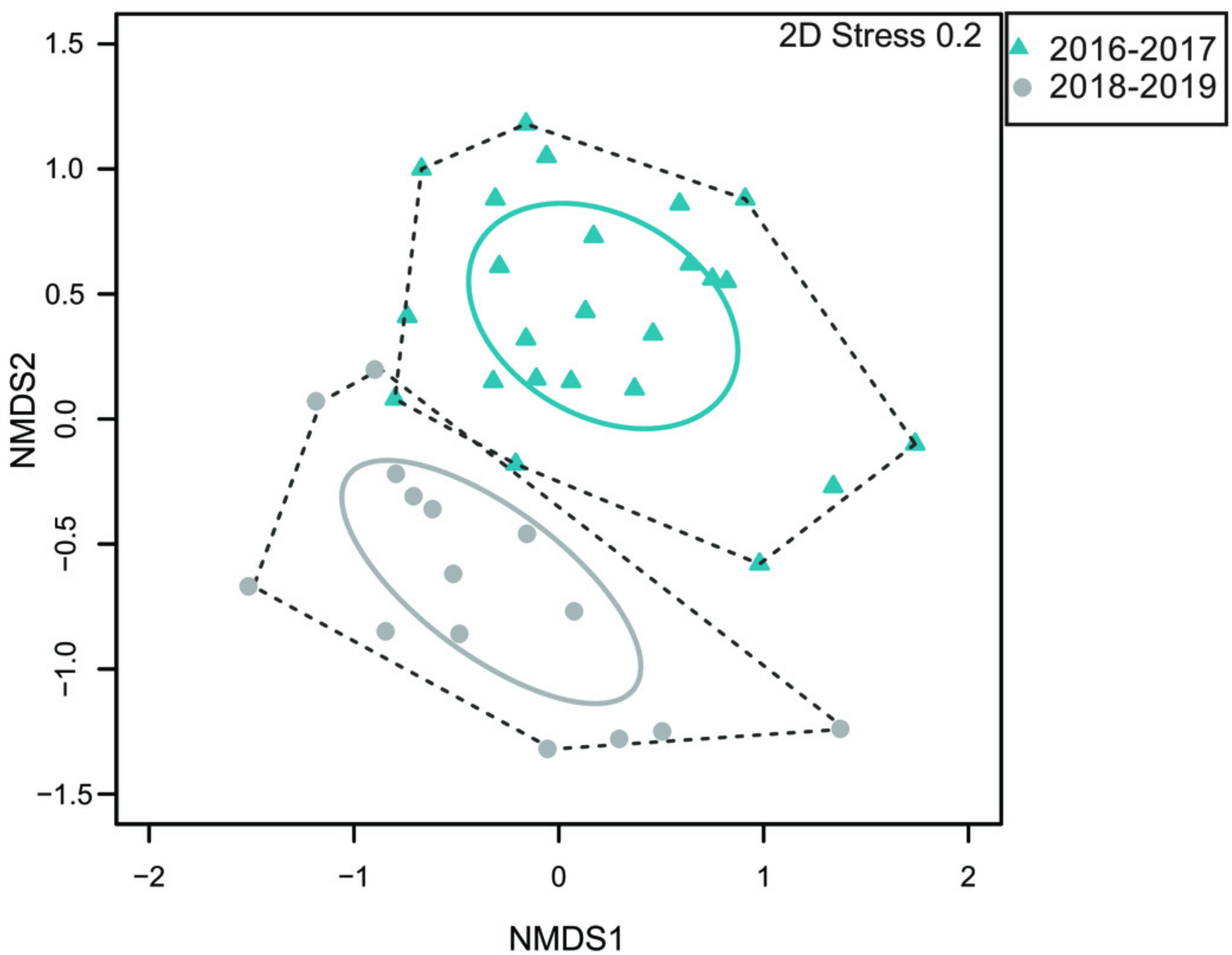

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Table 1(on next page)

Overlap of the coral community composition before and after the SCTLD in the Mexican Caribbean.

Convex hull total area (TA), Bayesian standard ellipse area (SEA), Bayesian-corrected estimate of the standard ellipse area (SEAc), overlap in SEAc between reef zones for 2016/2017 (before the SCTLD outbreak) and 2018/2019 (during the SCTLD outbreak) and the percentage of overlap with SEAc of the reef zone between years and within the same year.

Table 1. Overlap of the coral community composition before and after the SCTLD in the Mexican Caribbean. Convex hull total area (TA), Bayesian standard ellipse area (SEA), Bayesian-corrected estimate of the standard ellipse area (SEAc), overlap in SEAc between reef zones for 2016/2017 (before the SCTLD outbreak) and 2018/2019 (during the SCTLD outbreak) and the percentage of overlap with SEAc of the reef zone between years and within the same year.

Period	Convex hull total area units^2	SEA units^2	SEAc units^2	SEAc overlap units^2 (%)
2016/2017	2.04	0.80	0.86	0(0%)
2018/2019	2.79	0.88	0.92	0(0%)