Spread of the new coral disease "SCTLD" into the Caribbean: implications for Puerto Rico

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The ongoing deterioration and significant decline in live coral cover and diversity in coral reef communities worldwide is strongly associated with increasing water temperatures linked to Global Climate Change, aided by anthropogenic activities (Harvell et al. 2004, 2007, 2009; Weil and Rogers 2011; Maynard et al. 2016; Woodley et al. 2016). In the Wider Caribbean, major community structure and function decline was marked by two region-wide, concurrent, highly virulent disease epizootics in the early 1980's. These events almost wiped out two foundational scleractinian species (*Acropora palmata* and *A. cervicornis*), and the keystone sea urchin *Diadema antillarum*. White band disease (WBD) affected the acroporids and was caused by a complex of vibrio bacteria (Gil-Agudelo et al. 2006). The *Diadema* mass mortality had all the trademark characteristics of a virulent, transmissible, bacterial or viral infection, but the putative pathogen (pathogens) was never identified (Lessios 2016). Populations of both acroporids and sea urchins suffered over 95% mortalities throughout the wider Caribbean (Gladfelter 1982; Lessios et al. 1984a,b; Aronson and Precht 2001; Lessios 2016), followed by a cascade of ecological consequences (significant loss of live coral cover, primary productivity, spatial complexity, biodiversity and fecundity; loss of ecological functions, increase in algal cover and biomass, etc.), ending in a shift from coral- to algal-dominated communities and the loss of ecological services to other tropical marine communities and to human beings (Aronson and Precht 2001; Weil and Rogers 2011). Several other disease-induced mass mortalities of other cnidarians, as well as of massive, plate and nodular reef-building genera, have in the last 30 years resulted in additional loss of biomass, diversity and live coral cover on many Caribbean reefs (Miller et al. 2009; Weil et al. 2009a; Weil and Rogers 2011; Bastidas et al. 2011; Weil et al. 2017).

More recently, a presumed new "white-plague type" disease, killing large numbers of corals in a short time, was reported from southeastern Florida in 2014 (Precht et al. 2016; Walton et al. 2018). It followed dredging operations (2013-2015) in the Port of Miami channel, that resulted in high sedimentation and turbidity near "ground zero" (Miller et al. 2016), and came after Summer-Fall high thermal anomalies that led to extensive bleaching across the Florida Reef Tract (Manzello 2015; Walton et al. 2018). Therefore, it is possible that the pathogen(s) could have been released from sediment disturbance, or that pathogen virulence and/or host susceptibility were affected by the high temperatures, or both. Often new disease outbreaks occur following a change in host-parasite biological or ecological relationship, the introduction of a novel pathogen(s) in susceptible host populations, the emergence of newly evolved pathogens and/or changes in environmental conditions that alter the microbiome/host physiological equilibrium, fostering increased pathogen virulence, transmissibility and coral mortality (Daszak et al. 2000, 2001; Harvell et al. 2007, 2009; Weil and Rogers 2011; Woodley et al. 2016; Aeby et al. 2019).

This apparently new disease has been called "Stony Coral Tissue Loss Disease" (SCTLD). It is waterborne, highly transmissible and highly virulent (rapidly kills coral tissues at a rate of 3-4 cm/day), affecting at least 22 foundational, scleractinian species (generalist), both usually characteristic traits of a novel pathogen (Weil and Rogers 2011). Furthermore, in Florida and St. Thomas, most diseased coral lesions treated with an antibiotic (*amoxicillin*) showed

Table 1. Chronological dispersion of SCTLD in Florida and the northern Caribbean, and appearance of localized disease outbreak in Puerto Rico

2014 - First reported off the coast of Miami-Dade County, Florida
2015 - Expanded to Biscayne National Park and north to Broward County in Florida
2016 - Continued spreading in Florida, south to the Upper Keys and north to Palm Beach County
2017 - Moved south into the Middle Keys and to the northern latitudinal edge of the Florida Reef Tract
2017 - First reports from the north coast of Jamaica in July 2017
2018 - Reached the Lower Keys in Florida, more reports made from Jamaica, new reports from Mexico, Belize and St. Maarten

- Spring 2018: New observations from the northwest coast of Jamaica
- July 2018: First reports from Quintana Roo, Mexico
- October 2018: First report in the eastern Caribbean, St. Maarten

2019 - Moved to the southwest end of the Lower Keys, not into the Dry Tortugas National Park. AGRRA created a map to report and track SCTLD throughout the Caribbean:

- January 2019: First reports at Flat Cay, St. Thomas, U.S. Virgin Islands
- March 2019: Reported at more locations in St. Maarten; First report in northwest coast of the Dominican Republic
- June 2019: First report from Belize
- August 2019: First report from Saint Eustatius

2019 - First reports of a localized disease outbreak off the eastern coast of Puerto Rico

- November 2019: Reports of highly virulent tissue loss disease affecting several corals in Tamarindo Chico reef, Culebra, Puerto Rico. Many colonies with signs similar to those reported for SCTLD.

https://floridakeys.noaa.gov/coral-disease/disease.html; https://www.agrra.org/coral-disease-outbreak/

signs that disease progression had slowed or even stopped (SCTLD, Florida Keys National Marine Sanctuary 2018; M. Brandt pers. comm.). These characteristics indicate that a bacterium or a complex of bacteria might be responsible, although the putative agent(s) have yet to be identified (Meyer et al. 2018; Aeby et al. 2019). Similarities of SCTLD signs with those of white plague disease type II (WPD-II) (Richardson et al. 1998; Weil and Rogers 2011; Woodley et al. 2006; SCTLD-Report-Florida Keys National Marine Sanctuary) has produced uncertainty when attempting to identify the disease in the field. Some differences with WPD include: acute multifocal infections on single colonies, tissue and mucus sloughing, and more rapid tissue mortality. These symptoms may not, however, be observed in all colonies, or in a single survey, but only in repetitive surveys of the same colonies.

Both of the above diseases are "generalists", affecting multiple species, although species susceptibility seems to vary. Of the 22 species reported with SCTLD signs, most of them are important reef-building species in the Caribbean. Six species seem to be highly susceptible in Florida (prevalence > 85%) and other localities: *Meandrina meandrites, Colpophyllia natans, Dichocoenia stokesii, Pseudodiploria strigosa, P. clivosa* and *Dendrogyra cylindrus*. Five species showed prevalence values higher than 45% in Florida (*Eusmilia fastigiata, Diploria labyrinthiformis, Montastraea cavernosa, Stephanocoenia intersepta and Orbicella faveolata*) (Meyer et al. 2018; Aeby et al 2019; SCTLD-Report-Florida Keys National Marine Sanctuary-2018). Four susceptible species (*D. cylindrus, O. faveolata, O. franksi* and *O. annularis*) are listed as threatened under the United States Endangered Species Act. The *Orbicella* spp. complex, *Montastraea cavernosa* and *Siderastrea siderea* are listed under intermediately susceptible to SCTLD, however, species susceptibility could vary geographically and temporally as the disease moves through the Caribbean. Corals, like many other modular cnidarians, do not show many different visible structural/ physiological responses to diseases, specially, within the white band-white plague syndromes. These syndromes produce a white, clean skeletal band after the die-off of the tissue, between the normal-looking tissue and the colonizing turf algae. The band width

is determined by the balance between how fast the tissue is dying (virulence) and how fast algal turf is colonizing. Although similar signs have been observed across sites, we cannot assume that the observed signs represent the same disease produced by the same pathogen (s), as this may not be the case all across the local and/or geographic distribution of the disease (Sunagawa et al. 2009). Once the pathogen(s) of SCTLD has been determined, diseased colonies in all the reported localities will have to be tested to confirm whether all cases represent the same disease.

In Florida in 2015-2017 SCTLD spread quickly (at a rate of 7–10 km/month) along the Florida Reef Tract both south and north of "ground zero". Since then it has expanded to several northern Caribbean localities (Table 1 - https://www.agrra.org/coral-disease-outbreak/; https://floridakeys.noaa.gov/coral-disease/disease.html) producing significant mortalities in populations of the susceptible species in all localities where it has been observed, raising concerns about the overall impact it could have on the already declining coral reef communities across the region (Lunz et al. 2017; Florida Keys National Marine Sanctuary 2018; Meyer et al. 2019; Aeby et al. 2019). The dispersion pattern of SCTLD does not seem to follow directly the direction of local and regional currents from "ground zero", since it has shown up in localities in directions against the normal current, and/or at sites thousands of km apart. Since the disease is waterborne and highly infectious, it would be expected to follow the direction and speed of ocean currents, however it was reported from Jamaica in July 2017 with no reports from Cuba or the Cayman Islands. It was reported in Quintana Roo, Mexico in July 2018 and in Belize in June 2019.

The disease was first observed in St. Thomas, USVI, in January 2019, before it was observed in the Dominican Republic and then in the Turks and Caicos Islands. It quickly spread along the southwest coast of St. Thomas, producing highly localized mortality of the susceptible species, and has been documented as spreading northeastward as well. There are no reports of outbreaks of SCTLD from the Bahamas, Cuba or other localities intermediate to the southernmost areas where it has been reported, leading some researchers to postulate that cruise/cargo ships or "contaminated" dive equipment might be involved in SCTLD dispersion. There might be other biological/oceanographic explanations for this discontinuous dispersion pattern. For example, the pathogen (s) might be part of the normal microbiome of the holobiont, as mutualistic components, or the sediment and substrate, and become virulent given certain changes in environmental conditions, host susceptibility or both.

Oceanographic current models projected that as a waterborne pathogen SCTLD would reach Puerto Rican waters, close to Vieques or Culebra, by May-June 2019. It was not however until October 2019 that a few, isolated colonies of some of the susceptible species were observed with the described SCTLD signs in Culebra. Between March and August 2019 several colonies of *S. siderea* were observed with signs of what looked like acute WPD or SCTLD on many reefs in the east (Ceiba, Humacao, Culebra and Vieques) and west (Cabo Rojo, Guanica and Mona) of Puerto Rico. Some colonies showed mucus and tissue sloughing, and fast, multifocal, acute rapid loss of live tissue, similar to SCTLD signs. In what seems a systemic immune response, several colonies became dark purple or just dark (Fig. 2). However, there were no other diseased species and no signs of an outbreak, which could indicate that this is a different disease affecting only *S. siderea*, possibly induced by the thermal anomaly hitting the area this year (Miller et al. 2009; Weil and Rogers 2011). By November 2019, a minor, localized outbreak of what looked like SCTLD also affected many colonies of several species at Punta Tamarindo Chico reef (18°18.578'N - 65°19.040'W) on Culebra Island, off the eastern coast of Puerto Rico (Fig. 1.). Curiously, colonies with typical multifocal signs of SCTLD were not observed in November 2019 at any of the 29 random sites surveyed in Culebra for NOAA's National Coral Reef Monitoring Program (NCRMP). So far, Tamarindo Chico reef is the only locality reported to have characteristic signs of SCTLD in Puerto Rico.

Water temperatures have been above average this year for the northeastern Caribbean, reaching seven Degree Heating Weeks (DHW) (local measurements and NOAA) by November 2019. In September 2019, this thermal anomaly induced yet another extensive bleaching event that expanded all over Puerto Rico's shallow and upper-mesophotic coral communities by November. Bleached corals make it difficult to distinguish the signs of SCTLD or WPD. Bleaching prevalence measured around Culebra during the NCRMP surveys in November 2019 varied between 50-62% (partially to totally bleached), with the most susceptible species in this area being *O. annularis, O. faveolata, P. strigosa, D. labyrinthiformis* and *S. siderea*. During this period hard corals in Culebra were possibly more susceptible to disease

due to thermal stress. Per anecdotal evidence, SCTLD lesion progression rates appeared to slow down or even stop during periods of higher water temperatures and/or coral bleaching in Florida and the USVI; however the relationship between these factors is still uncertain (Aeby et al. 2019).

Consecutive surveys in Tamarindo Chico reef showed a significant increase in disease prevalence in SCTLD susceptible species, from 4% in October, to 50% in November, and 74% in December (Hernández-Delgado and Suleimán-Ramos, unpublished data). Similar to the initial stages of SCTLD in St. Thomas, acute impacts have remained highly localized across a single reef site, affecting mostly meandroid species. Disease prevalence varied across species: >50% in *D. cylindrus*, 80% in *P. strigosa, P. clivosa,* and *D. labyrinthiformis*, and >90% in *M. meandrites* and *S. siderea*, which, as mentioned above, have shown signs of disease well before this localized outbreak. The disease indiscriminately affected wild and nursery-restored colonies of *D. cylindrus, Pseudodiploria* spp., *D. labyrinthiformis, C. natans, M. meandrites* and *S. siderea*. It has also affected colonies of *D. cylindrus* and *E. fastigiata* on adjacent coral farms, but with a significantly lower prevalence (<5%). With the collaboration of Nova Southeastern University, the NGO Sociedad Ambiente Marino and a provisional permit provided by the Puerto Rico Department of Natural and Environmental Resources (DNER), preliminary testing with an experimental treatment of amoxicillin antibiotic in CoreRX Base2B yielded promising results, halting disease progression in 90% of treated colonies of *Pseudodiploria spp.*, *D. labyrinthiformis, Colpophyllia natans, D. cylindrus, M. cavernosa* and *S. siderea* (N = 50 colonies).

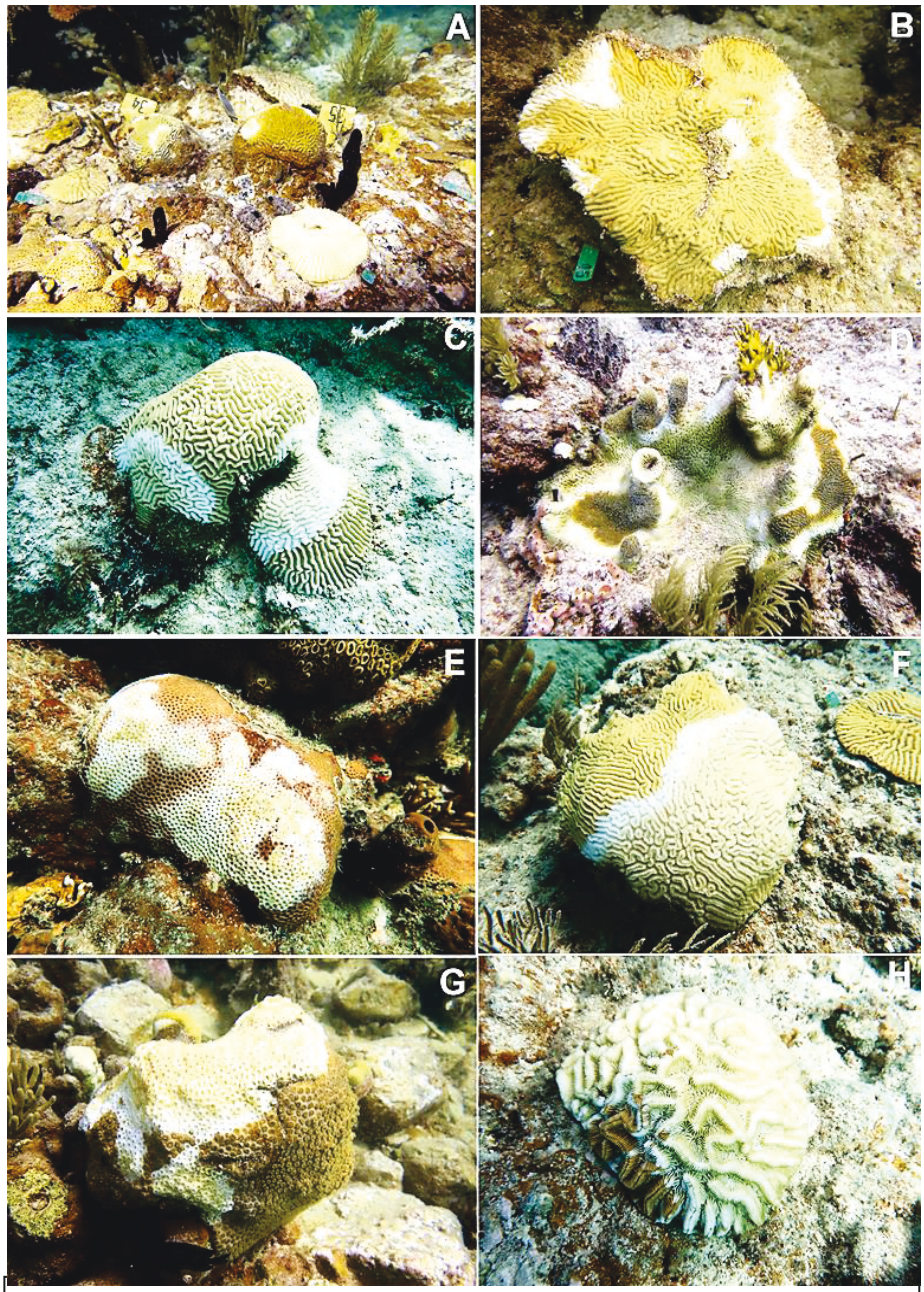

Figure 1. Photographs of diseased colonies of species susceptible to SCTLD in Tamarindo Chico, Culebra. Several small colonies of *P. strigosa* with multi-focal infected areas (A). Colony of *P. clivosa* with fast advancing, multi-focal infections (B). Medium sized *P. strigosa* with two rapidly advancing diseased areas (C). Almost 100% mortality in small *D. cylindrus* (D). Mucus and tissue sloughing in *S. siderea* (E). Rapidly advancing white band area in *D. labyrinthiformis* (F) and *M. cavernosa* (G). Small colony of *C. natans* that is almost 100% dead in a short time (H).

One of the most effective responses documented thus far, from Florida and St. Thomas, has been the use of amoxicillin; but given the characteristics of SCTLD, there is a pressing need to increase significantly the number of colonies treated per locality (and to text other antibiotics) in order to minimize the risk of infection spreading to other

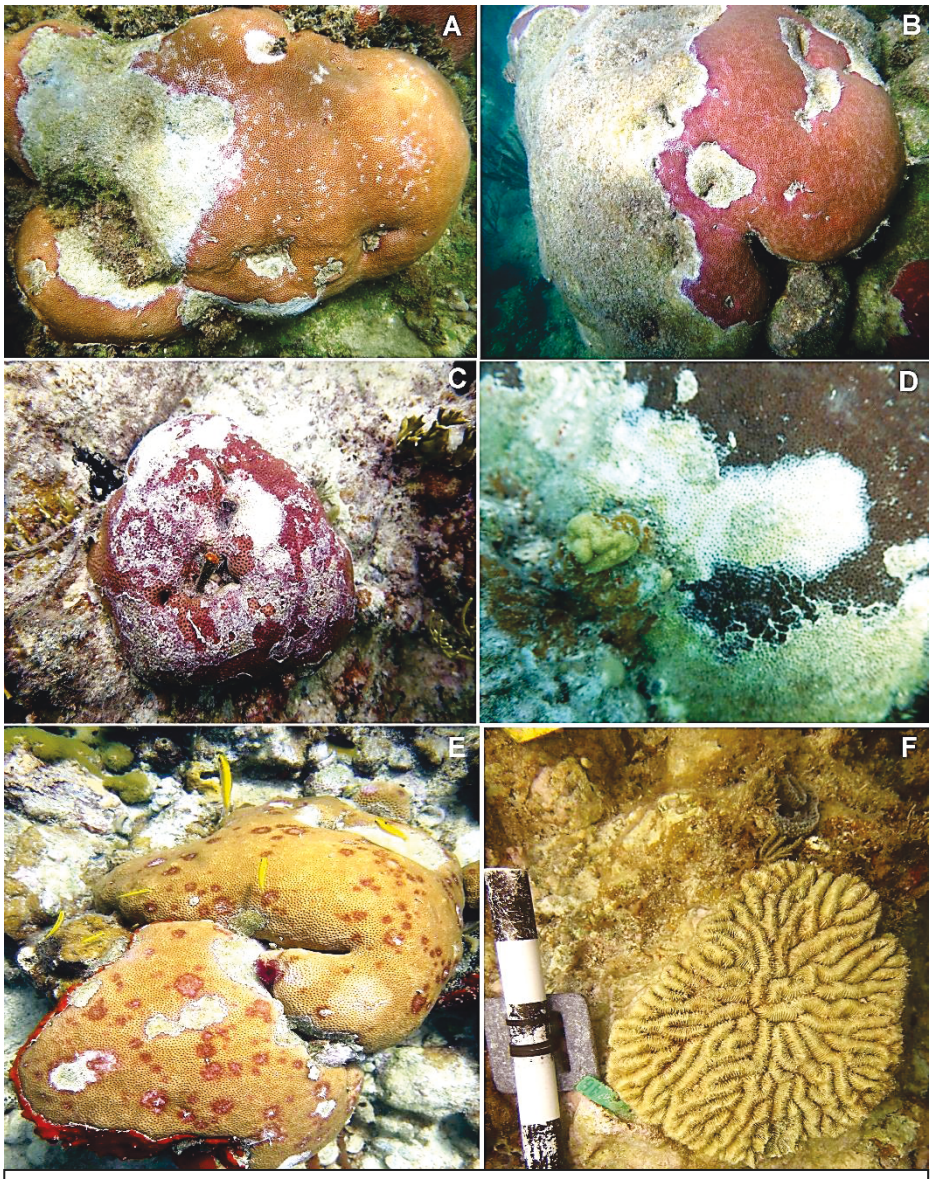

Figure 2. Diseased colonies *of S. siderea* around Puerto Rico, some before the outbreak of the possible SCTLD outbreak was reported in Tamarindo Chico, Culebra. Two large diseased colonies with multifocal infected areas and evidence of fast mortality in Guaniquilla, west coast of Puerto Rico (A, B). Mucus and tissue sloughing in diseased *S. siderea* (C, D). Colony of *S. siderea* with multiple signs of dark spots disease and multi-focal infections of a white-plague type that could be SCTLD (E). A recently fast killed colony of *M. meandrites,* with skeletal structure covered by sediment and signs of some turf colonization (F).

reefs. There is also a need to reduce, if possible, the numbers of recreational visits (i.e., SCUBA diving, snorkeling, kayaking) to the affected sites and to implement strict equipment disinfection protocols and also initiate outreach activities to inform and educate the stakeholders and any visitors. The DNER has been participating in the USVI-SCTLD status monthly calls even before suspicious colonies were identified in Puerto Rico. With the support of the DNER, SCTLD education and outreach materials generated by other jurisdictions have been translated into Spanish and shared with relevant audiences to increase awareness and promote SCTLD prevention. In addition, theoretical and practical training on SCTLD was held by Sea Grant FL, Sea Grant PR and the DNER for coral reef experts, dive shops, fishermen and other stakeholders. Direct communication was also established with tourist operators in Vieques, where SCTLD was expected to show-up first, following UVI projections.

Several other Federal and local government agencies, Institutions and NGOs [the National Oceanic and Atmospheric Administration (NOAA), the University of Puerto Rico in San Juan, Sociedad Ambiente Marino (SAM), HJR Reefscaping, Coastal Survey Solutions, and the Department of Marine Sciences (DMS) of University of Puerto Rico, Mayaguez] have also collaborated to educate, prevent, prepare, and respond to the threat of SCTLD on Puerto Rico's coral reefs. By staying in contact with key stakeholders in both Florida and the USVI, these institutions have had the benefit of learning from other jurisdictions' experiences to develop response plans, protocols and "rapid response teams" (RRT) for Puerto Rico. The RRT are trained on how to identify the disease and differentiate it from other coral diseases and bleaching, how to treat diseased colonies, and how to decontaminate diving equipment after dives in disease-impacted areas, among other response activities. Such training and preparedness is crucial given the threat of SCTLD to coral reefs in Puerto Rico. Researchers are exploring other ways to control the disease.

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