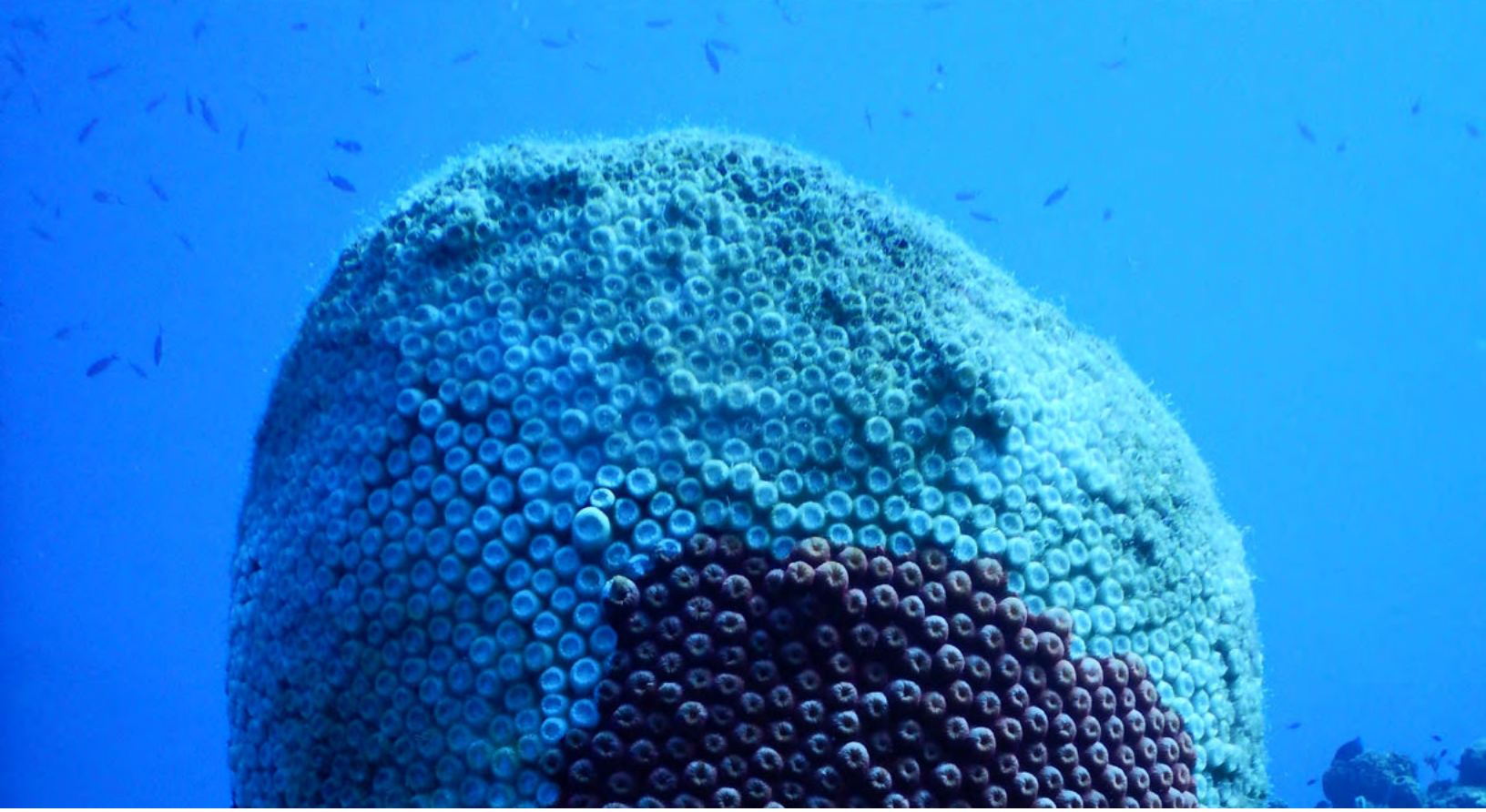

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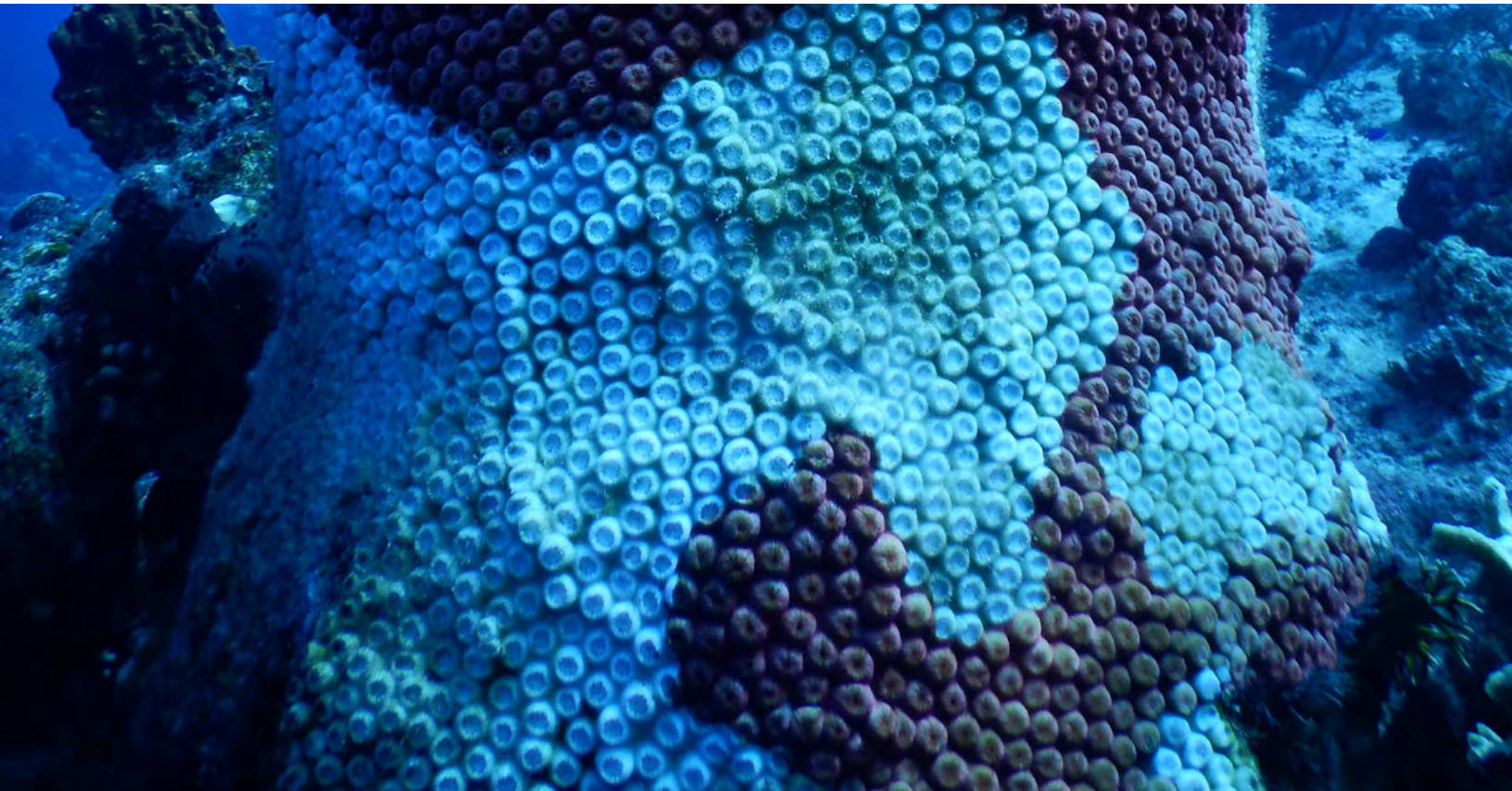
WHITE PAPER ON

Stony Coral Tissue Loss Disease



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Front Page Photo Credit: Alizee Zimmermann – Great star coral (Montastrea cavernosa) affected by Stony Coral Tissue Loss Disease

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The Ministry of the Environment is part of The Government Offices of Sweden. It is responsible for matters related to reduced climate emissions, a non-toxic everyday environment and strengthening biodiversity on land and in water. Sweden supports UNEP and wants to strengthen the UN's role in the environmental area and intergovernmental environmental cooperation.

Government Offices of Sweden
Ministry of the Environment

List of Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment Program
BSAC	British Sub-Aqua Club
CARICOM	Caribbean Community
CCAD	Central American Commission on Environment and Development
CONANP	Mexican National Commission for Natural Protected Areas
CORALIUM	Laboratorio de Investigación Integral para la Conservación de Arrecifes
FAQ	Frequently Asked Question
GCFI	Gulf and Caribbean Fisheries Institute
GCRMN	Global Coral Reef Monitoring Network
HRI	Healthy Reefs for Healthy Peoples Initiative
ICML	Unidad Académica de Sistemas Arrecifales
IMO	International Maritime Organization
INAPESCA	Mexican National Fisheries Institute
INVEMAR	Institute of Marine and Coastal Resources
IUCN	International Union for the Conservation of Nature
LBS Protocol	Protocol Concerning Pollution from Land-Based Sources and Activities
MARFund	Mesoamerican Reef Fund
MPA	Marine Protected Area
NGO	Non-government Organization
NOAA	National Oceanic and Atmospheric Administration
OECS	Organisation of Eastern Caribbean States
PADI	Professional Association of Diving Instructors
RAC	Regional Activity Centre
RAC-REMPEITC-Caribe	Regional Activity Centre – Regional Marine Pollution Emergence, Information and Training Centre - Caribe
RAN	Regional Activity Network
RMP	Roatan Marine Park
SCTLD	Stony Coral Tissue Loss Disease
SPAW Protocol	Protocol Concerning Specially Protected Areas and Wildlife
SusGren	Sustainable Grenadines, Inc.
TCRF	Turks and Caicos Reef Fund
TIDE	Toledo Institute for Development and Environment
UKOT	United Kingdom Overseas Territories
UNAM	Universidad Nacional Autónoma de Mexico
USVI	U.S. Virgin Islands
WCR	Wider Caribbean Region

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Photo: Florida Keys National Marine Sanctuary

Executive Summary

Stony Coral Tissue Loss Disease (SCTLD) was first identified in 2014 off of Virginia Key, Florida. Since then, this unprecedented coral disease has spread to the Caribbean. As of March 2021, the disease has been confirmed in 16 Caribbean countries and territories: Jamaica, Mexico, Sint Maarten, the U.S. Virgin Islands, the Dominican Republic, the Turks and Caicos Islands, Belize, Sint Eustatius, Puerto Rico, The Bahamas, the British Virgin Islands, the Cayman Islands, Guadeloupe, St. Lucia, Honduras, and Martinique.

The impact of the disease is devastating. Lesions spread rapidly across individual coral colonies and coral reefs. Within weeks to months, the disease may cause up to nearly 100% mortality of the most highly susceptible coral species. It affects more than 20 species of the slowest-growing and longest-lived reef-building corals, including the iconic brain, star, and pillar corals. Unlike coral diseases of similar appearance, whose prevalence may decrease over time and remain within localized areas, this disease has shown no signs of abating since it was first identified and continues to spread over large geographic regions. If not addressed, the disease will continue to have devastating impacts on coral reef ecosystems and, in turn, threaten the economies throughout the Wider Caribbean Region that depend on healthy coral reefs.

In 2003, coral reef ecosystems within the Wider Caribbean Region were valued at over US$1.8 billion. This value includes their contributions to tourism, the fishing industry, and shoreline protection, all of which are under threat as the disease moves through the Caribbean. Income generated by tourism and fishing industries will decrease as coral ecosystems deteriorate, and shoreline protection provided by heavily rugose coral reefs will be reduced, making coastlines and infrastructure more susceptible to erosion and damage.

However, there are actions that managers can take. While researchers work to identify the pathogen(s) responsible for the disease, outreach to stakeholders about the disease can help them to detect and report possible signs of the disease. Stakeholders can also be encouraged to take practical action to reduce disease transmission. Communication and collaboration with multiple agencies can help drive support for preventative action, monitoring and response action planning, and interventions such as the implementation of best practice treatment protocols and coral rescue/restoration.

As SCTLD continues to spread through the Wider Caribbean Region, recommended next steps include:

- **Ensure SCTLD is placed on the regional agenda.**

  Addressing this new threat requires coordination and partnerships between sectors and between agencies at multiple levels. Given how quickly the disease is spreading throughout the Caribbean, regional organizations can help with consensus building on disease response and in sharing best practices so as to avoid duplication of effort or wasting limited resources (e.g. on the use of intervention methods that have already proven ineffective in other locations).

- **Encourage countries of the WCR to endorse and participate in the SCTLD Caribbean Cooperation Team**

  Participation in the SCTLD Caribbean Cooperation Team will provide countries of the WCR with opportunities to exchange relevant and up-to-date information on the latest research initiatives, treatment efforts and resource opportunities to help guide and inform their management response to the threat of SCTLD.

- **Develop, support, and enforce the implementation of preventative regional ballast water guidelines to reduce the potential for disease transmission**

  In areas where SCTLD has yet to be observed, coordinate with the shipping and recreational diving communities to prevent the introduction of related pathogens via ballast water, bio films, wastewater, and/or contaminated dive gear.

- **Develop national and/or local SCTLD monitoring and response action plans**

  It is imperative that the appropriate government agencies, non-government organizations, academic institutions, private sector, and local stakeholders work together to develop SCTLD monitoring and response plans. Planning can focus on high priority areas, including where there are significant populations of highly susceptible coral species and reefs that are adjacent to, or downstream from, areas of shipping activity such as ports or anchorage areas.

- **Facilitate a coordinated and structured approach to regional capacity building**

  A coordinated and structured approach to training regional coral reef managers in SCTLD best management practices is needed in order to maximize knowledge sharing from experts and mentors with those who will respond to SCTLD.

- **Identify and contribute funds to regional SCTLD initiatives**

  Funding is needed to facilitate capacity building and information sharing as well as to support research, monitoring, and intervention on the ground.

- **Improve stakeholder awareness**

  Stakeholder awareness will encourage participation in mitigation and intervention measures. These would include implementing ballast water exchange guidelines and decontamination protocols, volunteering to monitor and treat affected corals, assisting in research projects, and complying with other existing regulations and guidelines that serve to enhance coral resilience.

- **Facilitate the speedy implementation of best practice treatment interventions**

  Currently, the only effective treatment method for SCTLD is the topical application of the amoxicillin:Base2B mixture, which will require the importation of at least the Base2B. Government organizations can help facilitate the importation of the necessary materials.

- **Encourage partnerships for coral rescue and restoration**

  Low-cost/low-tech solutions are needed for coral rescue to maintain and eventually restore coral diversity within the region.

- **Facilitate information sharing about research initiatives and intervention approaches**

  Encourage regional academic institutions to assist with monitoring, treatment, and pathogen(s) identification research.

Introduction

The world's coral reefs are under considerable threat despite being some of the planet's more valuable resources. Globally, reefs only encompass 0.09% of the world's oceans, but are incredibly diverse ecosystems that may house up to 3 million species that consist of corals, sponges, plants, dinoflagellates, cnidarians, echinoderms, fish, tunicates, and reptiles (Spalding et al., 2001). That diversity also makes them integral to coastal economies by providing food, shoreline protection, recreational opportunities, and medicine (Spalding et al., 2001). Cesar et al. (2003) estimated that the annual aggregate value of the ecosystem services provided by coral reefs was almost US$30 billion in net benefits to world economies. Within the Wider Caribbean Region (WCR), coral reefs were estimated to contribute over US$1.8 billion to the region despite only comprising 19,000 km^2. Additional natural resource valuation studies undertaken within the WCR have estimated that coral reef-associated tourism contributed between US$101-130 million and US$160-194 million to Tobago and St. Lucia, respectively (Burke et al., 2008); Belize's coral reefs provide an estimated US$120-180 million in avoided damages each year by protecting that country's shorelines (Cooper et al., 2009). A 2018 study showed that coral reefs' contribution to Caribbean economies continues to grow, with reef associated tourism alone estimated to be over US$7.9 billion (Spalding et al., 2018). However, these values are dependent upon healthy reefs. As coral reefs degrade, their ability to provide these goods and services will also decrease.

The threats to coral reefs are both numerous and diverse. Coral reefs are impacted by both anthropogenic and natural events including eutrophication, unsustainable tourism and fishing practices, coastal development, thermal stress, and hurricanes (Spalding et al., 2001). The impacts of all of these factors vary but may lead to coral bleaching, algal overgrowth and smothering of corals, a reduction in growth and reproductive potential, and, ultimately, the destruction of coral colonies (Spalding et al., 2001). The stress placed on coral reefs by environmental factors may make them more susceptible to coral diseases (Muller & van Woesik, 2012); coral disease outbreaks are often seen after stressors such as coral bleaching (e.g. Miller et al., 2009; Ruiz-Moreno et al., 2012). In 2014, a new coral disease was identified near Virginia Key, Florida following a coral bleaching event (Precht et al., 2016). The outbreak also coincided with the dredging of the Port of Miami and the release of sediment into the water column (Miller et al., 2016). The disease, Stony Coral Tissue Loss Disease (SCTLD), has since spread throughout the Florida Reef Tract and the Caribbean and, as of March 2021, has been identified in 17 countries/territories throughout the WCR (Roth et al., 2021) (Figure 1).

The cause(s) of SCTLD are currently under investigation by researchers. However, the over 20 species of reef building corals affected, with varying degrees of susceptibility, (FKNMS, 2018; J. Lang, pers. comm) (Table 1) have been shown to respond to antibiotics, which indicates that a bacterial component is associated with the disease (e.g. Aeby et al., 2019; Walker & Pitts, 2019; Neely, 2020a). Researchers have also found that the disease is transmitted through both water and direct contact with infected corals (Aeby et al., 2019; Paul et al., 2019). While initially reported in conjunction with a coral bleaching event associated with elevated water temperatures (Precht et al., 2016), additional studies have found no correlation between higher incidences of SCTLD and thermal events (Aeby et al., 2019; Alvarez-Filip et al., 2019; Meiling et al., 2020a; Sharp et al., 2020; Zimmermann et al., 2020). Instead, a cessation of, or slowing in, the progression of the disease during bleaching events has been reported (Meiling et al., 2020a; Sharp et al., 2020; Zimmermann et al., 2020).

Figure 1. Corresponding dates and map showing the progression of the SCTLD outbreak throughout the Wider Caribbean Region (Roth et al., 2021).

Date identified	Country/territory affected	Corresponding letter
November 2014	United States of America (Florida)	A
February 2018	Jamaica	B
July 2018	Mexico	C
November 2018	Sint Maarten	D
January 2019	U.S. Virgin Islands	E
March 2019	Dominican Republic	F
March 2019	Turks and Caicos Islands	G
June 2019	Belize	H

Date identified	Country/territory affected	Corresponding letter
August 2019	Sint Eustatius	I
December 2019	Puerto Rico	J
December 2019	The Bahamas	K
May 2020	British Virgin Islands	L
June 2020	Cayman Islands	M
June 2020	Guadeloupe	N
August 2020	St. Lucia	O
September 2020	Honduras	P
October 2020	Martinique	Q

Corals affected by the disease show tissue and mucus sloughing off (Weil et al., 2019) along the edge of the coral colony, which spreads upwards leaving exposed white skeleton (FKNMS, 2018). The lesions can also begin as patches or 'blotches' within intact tissue and these can increase in size and ultimately fuse together (Figure 2). Some species may have bleached tissues adjacent to the tissue-loss lesion, while in the case of the Massive starlet coral (*Siderastrea siderea*), one or more areas of dark discoloration may be present in the remaining tissue while tissue loss is occurring (FKNMS, 2018).

Figure 2. Great star coral (*Montastrea cavernosa*) affected by Stony Coral Tissue Loss Disease. Photo credit: Alizee Zimmermann.

What most distinguishes this disease from other coral diseases within the WCR is its high mortality rate. Depending on species susceptibility, 100% mortality of the infected coral colony may occur within weeks to months if left untreated (Neely & Lewis, 2018; Estrada-Saldívar et al., 2020). SCTLD has also proven to be more persistent and virulent when compared to other disease outbreaks (Walton et al., 2018). Taken together, the mortality rate, the number of species affected, and the duration of the outbreak could have devastating effects on the reefs within the region, especially when considering its continued rapid spread throughout the WCR.

This paper, which is a collaborative effort between the Secretariat of the Cartagena Convention, the Protocols Concerning Specially Protected Areas and Wildlife (SPAW) and the Pollution from Land-Based Sources and Activities (LBS), and the Gulf and Caribbean Fisheries Institute (GCFI) examines the potential effects SCTLD may have on the WCR and how SCTLD may be differentiated from other coral diseases. The mitigation and monitoring protocols that may be used to minimize its impact on reefs within the region are outlined and the resources currently available to assist coral reef managers to prevent the spread of the disease will be detailed. Best practices for treating infected corals, containing the spread of the disease, and management case studies are also presented. It is intended to be a reference document for government, non-government and inter-governmental organizations, research, academic and maritime institutions.

Table 1:

Degree of susceptibility for hard coral species in the WCR (Adapted from FKNMS, 2018 and J. Lang, pers. comm.).

High Susceptibility	Intermediate Susceptibility	Presumed Susceptibility	Low/No Susceptibility
Colpophyllia natans (Boulder brain coral)	*Orbicella annularis* (Lobed star coral)	*Madracis arenterna* (Pencil coral)	*Porites astreoides* (Mustard hill coral)
Dendrogyra cylindrus (Pillar Coral)	*Orbicella faveolata* (Mountainous star coral)	*Favia fragum* (Golfball coral)	*Porites porites* (Finger coral)
Dichocoenia stokesii (Elliptical star coral)	*Orbicella franksi* (Boulder star coral)	*Isophyllia sinuosa* (Sinuous cactus coral)	*Porites divaricata* (Thin finger coral)
Diploria labyrinthiformis (Grooved brain coral)	*Montastraea cavernosa* (Great star coral)		*Porites furcata* (Branched finger coral)
Eusmilia fastigiata (Smooth flower coral)	*Solenastrea bournoni* (Smooth star coral)		*Acropora palmata* (Elkhorn coral)
Meandrina meandrites (Maze coral)	*Stephanocoenia intersepta* (Blushing star coral)		*Acropora cervicornis* (Staghorn coral)
Pseudodiploria strigosa (Symmetrical brain coral)	*Madracis decactis* (Ten-ray star coral)		*Oculina* spp. (Bush corals)
Pseudodiploria clivosa (Knobby brain coral)	*Agaricia agaricites* (Lettuce coral)*		*Cladocora arbuscula* (Tube coral)
Meandrina jacksoni (Whitevalley maze coral)	*Agaricia spp.* (Plate/saucer corals)		*Scolymia* spp. (Disc corals)
Siderastrea siderea (Massive starlet coral)*	*Mycetophyllia lamarckiana* (Ridged cactus coral)		*Isophyllia rigida* (Rough star coral)
Agaricia agaricites (Lettuce coral)*	*Mussa angulosa* (Spiny flower coral)		

*=*sometimes high susceptibility*

Regional impacts

The WCR is comprised of 28 countries (Box 1) with the United Kingdom, the United States of America, the Netherlands, and France represented in the WCR by territories. As of March 2021, 11 of those countries (~39%) are currently affected by SCTLD. This includes territories such as St. Maarten, the U.S. Virgin Islands, the Turks and Caicos Islands (TCI), St. Eustatius, Puerto Rico, the British Virgin Islands, the Cayman Islands, Guadeloupe, and Martinique (Roth et al., 2021). Countries affected by the disease cover the Mesoamerican Reef System, The Bahamas-Turks and Caicos Islands Reef System, and the Florida Reef Tract, which are the region's largest coral reef ecosystems.

As SCTLD continues to spread throughout the WCR, this could have devastating effects on the ecosystem services provided by coral reefs as well as the species present within those ecosystems. In addition, there may be impacts to reef-associated economic activities (especially tourism and fishing industries) within affected countries/territories. This is because corals are autogenic ecosystem engineers and they change their environments through the structures they provide (Jones et al., 1994). Those structures provide habitat for species and reduce wave impacts, which in turn contribute to fisheries and tourism-based economies in the Caribbean and provide shoreline protection to local communities. This section will explore SCTLD's possible impacts on coral reef ecosystems and the services they provide.

Antigua and Barbuda	Honduras*
The Bahamas*	Jamaica*
Barbados	Mexico*
Belize*	Netherlands*
Colombia	Nicaragua
Costa Rica	Panama
Cuba	St. Kitts and Nevis
Dominica	St. Lucia*
Dominican Republic*	St. Vincent and the Grenadines
France*	Suriname
Grenada	Trinidad and Tobago
Guatemala	United Kingdom*
Guyana	United States of America*
Haiti	Venezuela

*Countries affected by SCTLD

Box 1. List of countries found in the Wider Caribbean Region* (Adapted from Roth et al., 2021; UNEP-CEP, 2021).

Ecosystem Changes

Corals affected by SCTLD can experience up to 100% mortality within weeks to months (Estrada-Saldívar et al., 2020) (Figure 3), which will reduce coral diversity on reefs and could lead to the functional extinction of some species (Alvarez-Filip et al., 2019; Zimmermann et al., 2020; Neely & Lewis, in press). Along the Florida Reef Tract, Pillar coral (*Dendrogyra cylindrus*) has been declared functionally extinct with a 73% loss of genotypes, 88% loss of colonies, and 91% loss of tissue (Neely & Lewis, in press). The Pillar coral is currently listed as Vulnerable on the International Union for the Conservation of Nature's (IUCN) RedList of Threatened Species, and its extirpation from the Florida Reef Tract could have dire consequences for the species. Species loss has also occurred in other regions throughout the Caribbean; for example, within the Turks and Caicos Islands, highly susceptible species have died along the West Caicos and Grand Turk reefs and Maze coral (*Meandrina meandrites*) has

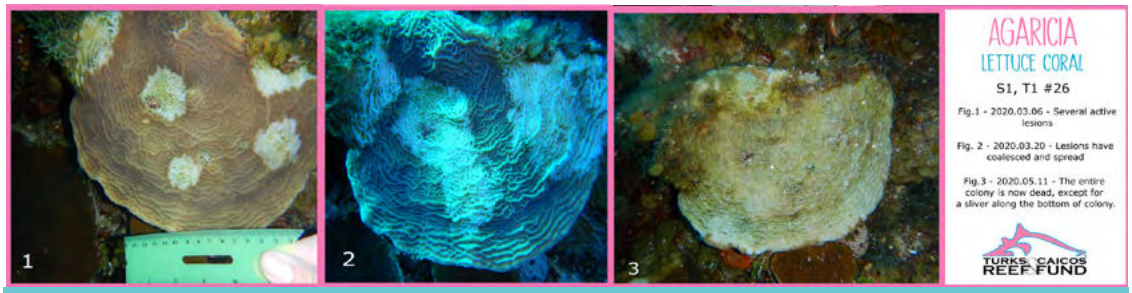


Figure 3.

Progression of SCTLD on a Lettuce Coral (*Agaricia agaricites*) colony. Photo Credit: Turks and Caicos Reef Fund.

been declared functionally extinct on both of those reef systems (Zimmermann et al., 2020). Local extinction events have been predicted for Maze and Pillar corals in Mexico (Alvarez-Filip et al., 2019). The loss of these species throughout the WCR could result in changes in species composition and affect the ecosystem services that reefs provide.

As the major reef-builders are lost to SCTLD, this may provide an opportunity for other species to colonize reefs (Figure 4). Coral species, such as the Mustard hill coral (*Porites astreoides*) and Finger coral (*P. porites*), that have low/no susceptibility to SCTLD (Table 1) may increase in density and dominate the reef (e.g. Miller et al., 2009; Walton et al., 2018). These faster growing, "weedy" coral species create small, short-lived colonies and could replace more architecturally complex species that are susceptible to the disease (Green et al., 2008; Alvarez-Filip et al., 2009; Alvarez-Filip et al., 2019). This is supported by Hayes (2019), who found significant increases in species such as *P. porites* and *P. astreoides* between 2013 and 2018, while noting significant decreases in species susceptible to SCTLD. Architectural complexity on reefs will also be affected by bio-erosion. As corals die, the skeletons left behind become susceptible to grazing, etching and boring organisms making them more vulnerable to storm damage (Hutchings, 1986). While the architectural complexity of reefs in the Caribbean has been declining for decades (Alvarez-Filip et al., 2009), this may be further exacerbated by the high mortality rates associated with SCTLD.

This impact of SCTLD is significant because the architectural complexity provided by reef-building corals is extremely important for fish and invertebrate diversity on reefs as this structural complexity provides settlement areas, refuge, and habitat (e.g. Idjadi & Edmunds, 2006; Alvarez-Filip et al., 2009; Rogers et al., 2014). Rogers et al. (2014) found that small fish benefitted from the refuge provided by reef crevices making them less vulnerable to predation, thus, increasing fish abundance. Prey species will not only benefit from crevice density but also crevice diversity since prey species across a wide range of body sizes will be able to avoid predation. While reef skeletons will continue to provide these functions, their ability to do so will decrease once they begin to erode and habitat loss occurs (e.g. Idjadi & Edmunds, 2006; Rogers et al., 2014).

Figure 4.

Algal growth beginning on a coral colony affected by SCTLD. Photo credit: Alizee Zimmermann.

Changes to Ecosystem Services

The flattening of reefs will further reduce the ecosystem services that reefs provide throughout the region, negatively impacting the fishing and tourism industries that rely on healthy and productive reefs. Losses in structural complexity have been associated with decreases in fisheries productivity of up to 35% and biomass declines by up to 64% (Rogers et al., 2017). Reef-associated tourism may also decline along degraded reefs. Kragt et al. (2009) found that reef degradation along the Great Barrier Reef in Australia could result in an 80% decrease in reef trips by divers and snorkelers. Given that reef-associated tourism in the Caribbean has been valued annually at US$7.9 billion (Spalding et al., 2018), reef degradation could have devastating impacts on Caribbean economies

With over 11 million visitors (Spalding et al., 2018) drawn to the Caribbean by its reefs, tourist visitation could drastically decline as reefs degrade due to SCTLD. This will not only have direct negative impacts on tourism operators such as dive and snorkel tour operators, but will also affect hotels and restaurants as well as other associated services such as transportation and fuel provision. Burke & Maidens (2004) estimated that dive tourists spent between 60-80% more money than other tourists. Since dive tourism is dependent on healthy reefs with high levels of fish and coral diversity and clear water, coral reef degradation is estimated to result in annual losses of between US$100 million-US$300 million to the Caribbean's tourism industry by 2015, affecting all the services dependent on them (Burke & Maidens, 2004).

The fishing industry is comprised not only of fishers but also those involved in processing, marketing, vessel construction, and trap and net building as well as other support services (Burke & Maidens, 2004). Coastal communities may also be heavily dependent on reef fisheries as a cheap source of protein. As reefs degrade and their ability to replenish fish stocks diminishes, their contribution to food security and the fishing industry will decline, affecting Caribbean economies. For example, in 2004, the maximum sustainable fisheries yield in the Caribbean was estimated to be approximately 100,000 metric tons of fish per year, with net fishing revenues valued at approximately US$310 million per year. However, with the continued degradation of reefs, fisheries production was expected to decrease to between 60,000 to 70,000 metric tons, with the net value declining to between US$95-140 million per year by 2015 (Burke & Maidens, 2004).

Reduced Shoreline Protection

Reef structural complexity helps to dissipate wave energy (Sheppard et al., 2005; Harris et al., 2018) and as reef complexity decreases, because of SCTLD, their ability to protect shorelines will also decrease. Given that coral reefs may help to reduce wave energy by 97% (Ferrario et al., 2014), this could have devastating effects on shorelines throughout the WCR. Within the Caribbean, the net benefit associated with shoreline protection was US$720 million per year (Cesar et al., 2003). With reduced shoreline protection coastal areas will be more susceptible to damage, increasing the costs associated with remediation efforts. These SCTLD impacts could affect coastal and urban communities, infrastructure, tourism assets, agricultural production, and government funding needed for remediation.

With the spread of SCTLD to 17 countries/territories around the region, as of March 2021, and given the breadth of potential impacts on communities, private sectors, and public resources across the region, the issue is deserving of policy attention and international cooperation.

Institutional Context for Stony Coral Tissue Loss Disease in the Caribbean

SCTLD is a trans-boundary issue so it is critical to ensure a coordinated management response is developed between countries/territories and with regional initiatives. An effective management response also requires cross-program collaboration in order to bridge marine-ecosystem health and maritime sector links. The regional governance frameworks of the WCR that are relevant for the prevention, management, and mitigation of SCTLD, and could help bring attention and resources to SCTLD are:

- **The Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention)**

The Cartagena Convention is a regional legal agreement for the protection and development of the marine environment of the WCR. SCTLD is the latest in a series of emerging issues (e.g. the lionfish invasion and the pelagic sargassum influx) to affect the WCR's marine environment and which falls under the Cartagena Convention's sphere of cooperation. Valuable support from Contracting Parties, international donors, and allies could be meaningfully invested in on the ground capacity building and small project support to assist countries/territories monitor for SCTLD and treat affected corals, according to best practice guidelines. The Cartagena Convention is supported by three protocols - the Protocol Concerning Co-operation in Combating Oil Spills in the Wider Caribbean Region, the Protocol Concerning Specially Protected Areas and Wildlife in the Wider Caribbean Region, and the Protocol Concerning Pollution from Land-Based Sources and Activities. Contracting Parties are obliged to prevent, reduce and control pollution of the Convention area and ensure sound environmental management through best practicable means in accordance with their capabilities. Parties should also take appropriate measures to protect and preserve rare or fragile ecosystems, as well as the habitat of depleted, threatened, or endangered species, in the Convention area. The Convention also recommends that Contracting Parties cooperate, when appropriate, in scientific research, monitoring, and the exchange of data and other scientific information in relation to the Convention (UNEP, 2012). The potential role of these Protocols in relation to SCTLD is as follows:

- The Protocol Concerning Specially Protected Areas and Wildlife in the Wider Caribbean Region (SPAW Protocol)

The Protocol requires Contracting Parties to take all necessary measures to protect, preserve, and manage in a sustainable way, areas that require protection to safeguard their special value and threatened or endangered species of flora and fauna (UNEP, 2012). SCTLD affects coral reefs, which are a key habitat in the WCR, and help support the sustainable development of local livelihoods and national economies. The SPAW Regional Activity Centre in Guadeloupe (SPAW-RAC), through the Marine Protected Areas Working Group, the Species Working Group, and the Global Coral Reef Monitoring Network (GCRMN) in the Caribbean can assist with monitoring, prevention and treatment initiatives throughout the region. Members of the MPA Working Group have benefited from knowledge sharing about SCTLD and are well-placed to help guide and ensure technical credibility of SCTLD initiatives developed by SPAW-RAC. GCRMN in the Caribbean has a potentially important role to play in assisting with monitoring and documentation of SCTLD, especially in conjunction with data-sharing via the SCTLD platform and regional dashboard maintained by AGRRA. GCFI is a Regional Activity Network (RAN) of the SPAW Protocol and, in line with its mission, has taken a leading role in communications about SCTLD with Caribbean marine natural resource managers and the coordination of the first SCTLD capacity building small grants.

- The Protocol Concerning Pollution from Land-Based Sources and Activities (LBS Protocol)

The LBS Protocol encourages Contracting Parties to develop and implement appropriate plans, programs, and measures that will effectively prevent, reduce, or control pollution from land-based sources and activities (UNEP, 2012). The protocol is supported by two RACs, the Centre of Research and Environmental Management of Transport and the Institute of Marine Affairs. While regional scientists work to identify the pathogen(s) responsible for SCTLD, indications are that ports may play a role in disease transmission (Baigent, 2020). This potentially brings it within the mandate of the LBS Protocol through linkages with broader marine affairs and coastal zone management.

- Protocol Concerning Co-operation in Combating Oil Spills in the Wider Caribbean Region (Oil Spills Protocol)

The Oil Spills Protocol encourages Contracting Parties to take necessary measures for the protection of the marine and coastal environment within the WCR from oil spill incidents (UNEP, 2012). The Secretariat is supported by their RAC, the Regional Marine Pollution Emergency, Information and Training Centre – Caribe (RAC-REMPEITC-Caribe), which is of particular importance since it supports countries with the implementation of international conventions created to reduce pollution from ships (RAC-REMPEITC Caribe, 2021). SCTLD is known to be water-borne and may be spread through the release of ballast water (Baigent, 2020; Dahlgren, 2020) and wastewater from ships. These linkages bring SCTLD within the remit of RAC-REMPEITC-Caribe and their related networks of maritime specialists and focal points who can help bridge marine ecology and the maritime sector. An issue of high priority in addressing SCTLD is the review of existing policies and consideration of needs to support best maritime practices in order to prevent the spread of SCTLD.

- **International Maritime Organization (IMO)**

  The International Maritime Organization is responsible for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships (IMO, 2021a). The IMO is responsible for the management of international conventions related to shipping, including the International Convention for the Control and Management of Ships' Ballast Water and Sediment, which aims to prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water. Under the Convention ships are required to manage their ballast water and ensure that aquatic organisms and pathogens are removed or rendered harmless before ballast water is released (IMO, 2021b). Since the pathogen(s) responsible for SCTLD are water-borne and may be transmitted through the release of ballast water (Baigent, 2020; Dahlgren, 2020), it is critical that the IMO be involved in developing and enforcing ballast water regulations for the WCR that will limit the transmission of the disease.

- **Caribbean Community (CARICOM)**

  The Caribbean Community is comprised of 15 Member States (Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St. Lucia, St. Kitts and Nevis, St. Vincent and the Grenadines, Suriname, and Trinidad and Tobago) and 5 Associate Members (Anguilla, Bermuda, British Virgin Islands, Cayman Islands, and the Turks and Caicos Islands) (CARICOM, 2021a) whose objectives include the enhanced coordination of Member States' foreign economic policies and enhanced functional cooperation. CARICOM's mission is to mainstream all aspects of sustainable development, including environment, economic and social initiatives, promoting the optimum sustainable use of natural resources on land and in the marine environment, and protecting and preserving

the health and integrity of the environment (CARICOM, 2021b). As of March 2021, SCTLD has been found in 4 Member States and 3 Associate Members of CARICOM. The impact that the disease may have on local economies through its effects on shoreline protection, tourism, and fisheries should be of concern to CARICOM members.

- **Organisation of Eastern Caribbean States (OECS)**

  The Organisation of Eastern Caribbean States is an inter-governmental organization dedicated to regional integration in the Eastern Caribbean. Its Member States include Antigua and Barbuda, Dominica, Grenada, Montserrat, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines. Associate OECS members include the British Virgin Islands, Anguilla, Martinique, and Guadeloupe (OECS, 2021). Operating under the Revised Treaty of Basseterre Establishing the Organisation of Eastern Caribbean States Economic Union (2010), OECS States will seek to adopt, wherever possible, common positions on international issues and to establish and maintain, arrangements for joint overseas representation and common services. As of March 2021, SCTLD has been found in one Member State and three Associate Members of the OECS. As the disease continues to spread, it may threaten other OECS members.

- **Central American Commission on Environment and Development (CCAD)**

  The Central American Commission on Environment and Development is comprised of eight countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and the Dominican Republic) and was established to create a regional regime for cooperation and environmental integration within its Member States (CCAD, 2021). As of March 2021, SCTLD has been found in three CCAD Member States. It continues to spread and may threaten additional members.

Regional efforts include assistance both within territories, as well institutional support for the WCR. Examples include the establishment of:

- **The SCTLD Caribbean Cooperation Team**

  As a component of Florida's response to SCTLD, the Caribbean Cooperation Team is coordinated by National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program and AGRRA and shares technical knowledge and lessons learned with partners within the Caribbean. These include the Gulf and Caribbean Fisheries Institute (GCFI), MPAConnect, Nova Southeastern University, Healthy Reefs for Healthy Peoples Initiative (HRI) of the Smithsonian Institution, The Nature Conservancy Reef Resilience Network, the Florida Keys National Marine Sanctuary, the Florida Fish and Wildlife Conservation Commission, Florida Sea Grant, the National Park Service, and the United Kingdom's Joint Nature Conservation Committee. Representatives from the affected countries participate in the meetings held by this team and key international partner organizations, donors, and allies associated with the Caribbean are added to the team as appropriate.

  The Team maintains communications with regional networks and initiatives, tracks the spread of SCTLD, shares SCTLD reporting mechanisms, lessons learned from ongoing response efforts, key informational materials, and helps to identify resources to support capacity building, monitoring, and response in the Caribbean region.

- **Virgin Islands Coral Disease Advisory Group**

  The Virgin Islands Coral Reef Advisory Group has established a Coral Disease Advisory Committee. Weekly calls are held with natural resource managers and scientists from Puerto Rico, the British Virgin Islands, and the U.S. Virgin Islands to share updates on the spatial extent/progression of the disease, scientific research, intervention, communication efforts, and data management (Gore, 2019).

- **Joint Nature Conservation Committee Collaborative Working Group**

  This working group is comprised of government and non-government representatives from the United Kingdom Overseas Territories (UKOT) (Anguilla, Bermuda, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks and Caicos Islands) and members of the Joint Nature Conservation Committee. Meetings are held every two weeks and discuss SCTLD identification, stakeholder engagement, current research initiatives, and the long-term management of coral reefs within UKOT.

  Organizations/programs within the region have also begun to prioritize SCTLD outreach and training initiatives to improve capacity building throughout the region. These include:

- **MPAConnect**

  MPAConnect, a partnership between the Gulf and Caribbean Fisheries Institute and NOAA's Coral Reef Conservation Program, addresses MPA management capacity building needs in 32 MPAs from 11 countries and territories in the WCR. Since the SCTLD outbreak, MPAConnect has hosted learning exchanges for countries affected by the disease or susceptible to its introduction, hosted webinars and online training sessions on how to monitor for and identify SCTLD, developed educational materials, and provided funding for site-specific projects. MPAConnect's SCTLD capacity building efforts have included the members of the network as well as managers from other affected and susceptible countries and territories in the region beyond the 11 who regularly participate in the network. In this way, technical capacity building has reached 18 countries and territories. Resources and materials on SCTLD have been disseminated in English, Spanish, and French. MPAConnect through GCFI implemented the first small grants program in support of SCTLD capacity building.

- **Atlantic and Gulf Rapid Reef Assessment Program**

  AGRRA's mission, in part, is the curation and distribution of data, research, and educational materials that support coral reef conservation (AGRRA, 2021). To that end, AGRRA has provided monitoring training and assistance, developed a Caribbean regional database and maps to track SCTLD's progression throughout the WCR, developed basic and detailed survey forms to collect data on suspected cases of SCTLD, and facilitates collaborative research on the causes of the disease. AGRRA, in collaboration with MPAConnect, has also developed a SCTLD Dashboard for the Caribbean that is available in both English and Spanish. The Dashboard provides up-to-date information on countries affected by the disease, management response initiatives, and the coral species affected by SCTLD.

- **Healthy Reefs for Healthy People Initiative**

  HRI is an international, multi-institutional effort that tracks the health of the Mesoamerican Reef and evaluates how socio-economic, cultural, and policy factors influence reef health (HRI, 2021). They have been actively involved in combatting SCTLD throughout the Mesoamerican Reef region (Mexico, Belize, Guatemala, and Honduras) through monitoring programs, assisting with treatment initiatives, and the hosting of webinars.

- **Mesoamerican Reef Fund (MARFund)**

  MARFund is an ecoregional planning and coordinating body that supports capacity building initiatives for the conservation, restoration, and sustainable use of the Mesoamerican Reef. They have provided capacity building support to Mesoamerican reef countries (Mexico, Belize, Guatemala, and Honduras) through the establishment of a Reef Restoration Network to share SCTLD information, best practices, the hosting of a regional workshop to address SCTLD monitoring and data collection, the development of national response plans within countries, and through the provision of funding and technical advice.

- **Ocean Alchemists**

  Ocean Alchemists has been instrumental in the development of methods to treat SCTLD, including the creation of Base2B, one component of what is currently the most effective treatment for SCTLD. They have shared free samples with affected countries, assisted with shipping logistics, and provided technical support on treatment mixing and application.

Identification

SCTLD causes tissue loss that may initially occur along the edge of the colony and then spread inward, or the lesions may occur in multiple locations on the colonies where tissue loss had not previously occurred (Figure 5) (Bruckner, 2020). The disease is characterized by newly exposed, white intact skeleton that can be covered with small turf algae within 3-7 days. In some instances, the tissue bordering areas of chronic tissue loss may show indistinct bands of pallor (1-5 cm), progressing to normal pigmentation away from the denuded skeleton (FKNMS, 2018) (Figure 6). The sloughing off of tissue and mucus may also be seen (Weil et al., 2019). Starlet coral (*Siderastrea siderea*) may have one or more areas of dark discoloration on their remaining tissues (FKNMS, 2018). Over 20 species may be susceptible to the disease, with varying levels of susceptibility (FKNMS, 2018) (Table 1), and the disease may present itself differently in the same coral species (Neely, 2019; Bruckner, 2020). Unlike other coral diseases, SCTLD is not more virulent during the summer, and no correlation has been found between higher incidences of SCTLD and warm thermal events (Aeby et al., 2019; Alvarez-Filip et al., 2019; Meiling et al., 2020a; Sharp et al., 2020; Zimmermann et al., 2020). Instead, some evidence suggests that the disease's progression slows during warmer temperatures (e.g. Meiling et al., 2020a; Sharp et al., 2020; Zimmermann et al., 2020)

Species that are considered highly susceptible are the first species that present with the disease when an outbreak occurs with Maze corals (*Meandrina meandrites*) and Elliptical star corals (*Dichocoenia stokesii*) among the first to become infected. Smaller colonies may experience total mortality within a week; larger colonies may experience complete mortality within 1 to 2 months. Intermediately susceptible species may become infected a month after highly susceptible species, with smaller colonies taking months to die while total mortality may take years to occur in larger colonies (FKNMS, 2018).

Disease progression rates may vary not only between species but also within species. For example, in the Middle Keys in Florida, Sharp & Maxwell (2018) found that disease progression rates in Maze corals, Boulder brain corals (*Colpophyllia natans*), and Symmetrical brain corals (*Pseudodiploria strigosa*) ranged from 20-40 cm2 / day while disease progression was approximately 5 cm2/day in infected Elliptical star corals and 10cm2/ day in the Great star coral (*Montastrea cavernosa*) and *Orbicella* spp. However, disease progression rates in Boulder brain corals and Symmetrical brain corals in the U.S. Virgin Islands were determined to be 16.31 ± 4.27 cm2 / day and 6.56 ± 1.78 cm2 / day, respectively (Meiling et al., 2020a).

Figure 5. Coral affected by SCTLD with multiple small lesions. Photo credit: Alizee Zimmermann.

Figure 6. Paling of tissue on Pillar Corals. Photo credit: Marcio Aronne.

A list of characteristics that may be used to identify SCTLD may be found in Box 2.

1.	Distinct pattern of spread among species
2.	Presence of unusual patterns of bleaching
3.	Lesions occur in multiple locations on colonies
4.	Patterns of tissue loss are highly variable among the same species inhabiting the same reef
5.	Affected corals have prominent areas of recently denuded skeleton
6.	High prevalence of affected corals once disease is established
7.	High rates of colony mortality in early susceptible species
8.	Disease active throughout the year and for multiple years on individual reefs
9.	Disease often highly virulent during winter months with declines during peak temperatures

Box 2. List of characteristics associated with Stony Coral Tissue Loss Disease (Bruckner, 2020).

SCTLD shares some similarities with other coral reef diseases (FKNMS, 2018) and can be superficially similar to damselfish predation and coral bleaching (Bruckner, 2020). Please see Tables 2 & 3 to help distinguish SCTLD from other coral diseases and coral reef events.

Differentiating SCTLD from Disease and Non-Disease Factors

Coral Diseases

Coral diseases such as White Plague, Black-band Disease, Caribbean Ciliate Infection, Dark Spots Disease, and Yellow Blotch Disease may be confused for SCTLD (FKNMS, 2018) (Figures 7 & 8). While SCTLD does share some similarities with these diseases it tends to be more persistent and virulent. For example, while background disease levels on Caribbean coral reefs may be between 2 and 10% (Kramer, 2003; McField & Kramer, 2007), SCTLD prevalence on reefs may be between 66-100% (Precht et al., 2016; Graulty, 2020). In addition, SCTLD may persist for multiple years on individual reefs (Bruckner, 2020). The similarities and differences between SCTLD and these diseases may be found in Table 2.

Figure 7. White band disease.
Photo credit: Andy Bruckner

Figure 8. Yellow blotch disease.
Photo credit: Andy Bruckner

Table 2: Similarities and differences between Stony Coral Tissue Loss Disease and other coral diseases in the Caribbean. (Adapted from Gil-Agudelo & Garzón-Ferreira, 2001; Verde et al, 2016; FKNMS, 2018).

Diseases	Similarities	Differences
White Plague	• Affects many coral species • Variability in the rate of tissue loss within and among affected species • Disease progression starts at the base or margin of the coral and radiates out in a distinct band • Coral colonies exhibit rapid tissue loss • No microbial biomass is observed at the tissue loss margin • An area of bleached tissue up to 3 mm wide at the edge of the lesion may be present • Most corals of the same species are susceptible	• SCTLD lesions may begin in areas other than the margin or base of the coral colony • SCTLD outbreaks last much longer (years) • White plague occurs in restricted areas and often appear on multiple reefs at the same or different times • White plague tends to subside in winter months when temperatures cool. SCTLD has no seasonal patterns • SCTLD affects species in a specific order
Black-band Disease	Affects at least 22 species of corals	• Black-band disease has a black or dark reddish-brown linear, diffuse, or annular band of acute or sub-acute tissue loss with a 1 mm to 5 cm wide margin. The band is composed of black-red filamentous organisms mixed with white filaments that separates healthy tissue from white, bare skeleton
Caribbean Ciliate Infection	Affects several of the same species including *Diploria labyrinthiformis*, *D. strigosa*, *C. natans*, *Orbicella faveloata*, *O. annularis*, and *O. franksi*	• Caribbean ciliate infection has a diffuse black or grey band several mm to 2 cm thick that separates healthy tissue from bare skeleton • Caribbean ciliate infection also infects acroporids, which are not susceptible to SCTLD
Dark Spots Disease	Affects some of the same species including *S. siderea*, *O. annularis*, *O. faveolata*, *O. franksi*, and *Stephanoceonia intersepta*	• Dark spots disease has focal to multifocal patches of discolored tissue or tissue-loss lesions with annular to irregular margins that are purple to brown in color and 1 cm to more than 45 cm in diameter • Higher prevalence during summer months • Affected tissue may be associated with a depression of the coral surface • Underlying skeleton may retain dark pigmentation when tissue is gone
Yellow Blotch Disease	Similar species, such as *Orbicella* spp., are susceptible to both	Yellow blotch disease has focal or multifocal, diffuse lesions with annular to linear margins of pale-yellow tissue. The margin of the remaining tissue is always pale yellow, lemon colored or colorless, whereas previously affected tissue gradually darkens prior to full tissue loss

Non-Disease Factors

Other events, such as coral bleaching and predation, may also have similar characteristics to SCTLD (Figures 9 & 10). Characteristics of these factors that will help differentiate them from SCTLD may be found in Table 3.

Figure 9.
Coral bleaching. Photo credit: Andy Bruckner.

Figure 10.
Parrotfish focal biting. Photo credit: Andy Bruckner.

Table 3: Distinguishing Characteristics of Non-Disease Events on Coral Reefs (Adapted from Bruckner, 2020).

Event	Distinguishing Characteristics
Coral bleaching	• Tissue is still present in bleached areas • Abnormal coloration: - Colonies are colorless, mottled in color, or only some areas are colorless
Predation	**General Characteristics** • Skeletal damage or loss of the underlying skeleton may occur • Predators include fireworms (*Hermodice* spp.), snails (e.g. *Coralliophila galea*), damselfish (*Stegastes planifrons* & *Microspathodon chrysurus*), and parrotfish (*Scarus* spp. and *Sparisoma* spp.)
	Fireworms • Suck the tissues off branch tips, projections or knobs • Tissue adjacent to exposed skeleton is normal • Attracted to diseased corals • Most of the normal feeding occurs at night so fireworms may not be seen
	Snails • Suck tissues off the coral colonies • Can form clusters of up to 50 snails • Irregular, scallop-shaped margin to lesion (size of the shell)
	Damselfish • Threespot damselfish (*Stegastes planifrons*) and the Yellowtail damselfish (*Microspathodon chrysurus*) will bite the corals • May create spots where individual corallites have been bitten • "Ridge mortality" by feeding on the elevated ridges of brain corals • Algae then settle in the tissue -denuded areas; acroporids will grow around the algae, creating "chimneys"
	Parrotfish • Spot biting - Individual lesions that match the size of the jaw - Tissue will start to re-colonize in a matter of weeks • Focused biting occurs in Stoplight Parrotfish (*Sparisoma viride*) - Fish returns to the same coral and all the initial phase parrotfish will feed on the same area - Scrape marks from jaws are visible - Tissue remains in the crevices of the coral colony

Potential Causes of Stony Coral Tissue Loss Disease and its Spread Throughout the Wider Caribbean

The occurrence and severity of coral diseases have been associated with environmental conditions such as high-water temperatures, increased nutrient loads (Kuta & Richardson, 2020), and turbidity (Pollock et al., 2014). SCTLD was first observed following a bleaching event (Precht et al., 2016), and its appearance also coincided with the dredging of the Port of Miami and the resulting sediment plumes that occurred (Barnes et al., 2015). Although neither incident has been directly linked to causing SCTLD, they could have contributed to the emergence of the disease by further degrading coral health (Aeby et al., 2019) or by releasing a novel pathogen when sediment was disturbed (e.g. Hodgson, 1990). While the cause of SCTLD has yet to be identified (e.g. Paul et al., 2019; Rosales, 2020; Ushijima et al., 2020), it has been determined to be water-borne and transmitted through direct contact (Aeby et al., 2019; Paul et al., 2019). It is also believed to have a bacterial component since the only effective treatment known to date is the topical application of the antibiotic amoxicillin (e.g. Aeby et al., 2019; Walker & Pitts, 2019; Neely, 2020a).

Researchers have found a number of bacteria associated with SCTLD lesions; although, the bacteria have not been consistent across all lesions and infected corals suggesting that the identified bacteria are not the primary cause of the disease (Meyer et al., 2019; Rosales et al., 2020; Ushijima et al., 2020). In some cases, the bacteria associated with SCTLD lesions were linked not only with other coral diseases but also with healthy coral tissue; however, the bacteria were more abundant in SCTLD lesions as opposed to healthy tissue (Meyer et al., 2019). While none of the bacteria found were identified as the cause of SCTLD, several theories have been proposed to account for their contribution to the disease including that the bacteria may be:

- Normally resident on healthy corals but multiply in response to changes in the host during disease progression (Meyer et al., 2019);

- Saprophytic colonizers (Meyer et al., 2019; Rosales et al., 2020);

- Assisting in lesion progression (Aeby et al., 2019; Rosales et al., 2020; Ushijima et al., 2020);

- Contributing to coinfections (Ushijima et al., 2020); **or**

- Opportunistic pathogens contributing to secondary infections (Aeby et al., 2019; Rosales et al., 2020; Ushijima et al., 2020).

The spread of SCTLD along the Florida Reef Tract is presumed to have followed currents with the northerly spread occurring more quickly than the spread to the south in coastal countercurrents (Precht et al., 2016; Dobbelaere et al., 2020; Muller et al., 2020; Sharp et al., 2020) (Figure 11). SCTLD's causative agent may be transported within neutrally buoyant particles such as coral mucus, diseased coral tissue, sediment, zooplankton, phytoplankton, or marine snow in the water column (Dobbelaere et al., 2020). The disease's association with sediment is supported by Rosales et al. (2020) who found that the bacterial orders Rhodobacterales and Rhizobiales, which were found in higher abundances in SCTLD lesions, were also found in accompanying sediment and water samples.

Unlike its transmission in Florida, SCTLD's large-scale spread throughout the Caribbean does not appear to be associated with the region's prevailing currents (Weil et al., 2019; Baigent, 2020) (Figure 12). The first reported outbreak of the disease in the Caribbean

was in Jamaica in February 2018, followed by outbreaks in Mexico (July 2018) and then Sint Maarten (November 2018) (Figure 1) (Roth et al., 2021). The chronology and spatial arrangement of these SCTLD cases does not match the direction of the currents in the WCR. Instead, a correlation between the spread of the disease and shipping routes was found with over half of the initial reported occurrences of SCTLD found close to major ports (Baigent, 2020). It is hypothesized that the transmission of the disease via shipping activities may be facilitated by the release of ballast water from infected sites to uninfected sites (Baigent, 2020; Dahlgren, 2020). Other potential sources of transmission may be through the release of sediment and biofilm within ballast water tanks (e.g. Drake et al., 2007). Once established in a new location, the pathogen(s) associated with the disease may disperse with the prevailing currents and countercurrents, along coastlines, around islands, as well as to neighboring countries and territories (Baigent, 2020; Dahlgren, 2020).

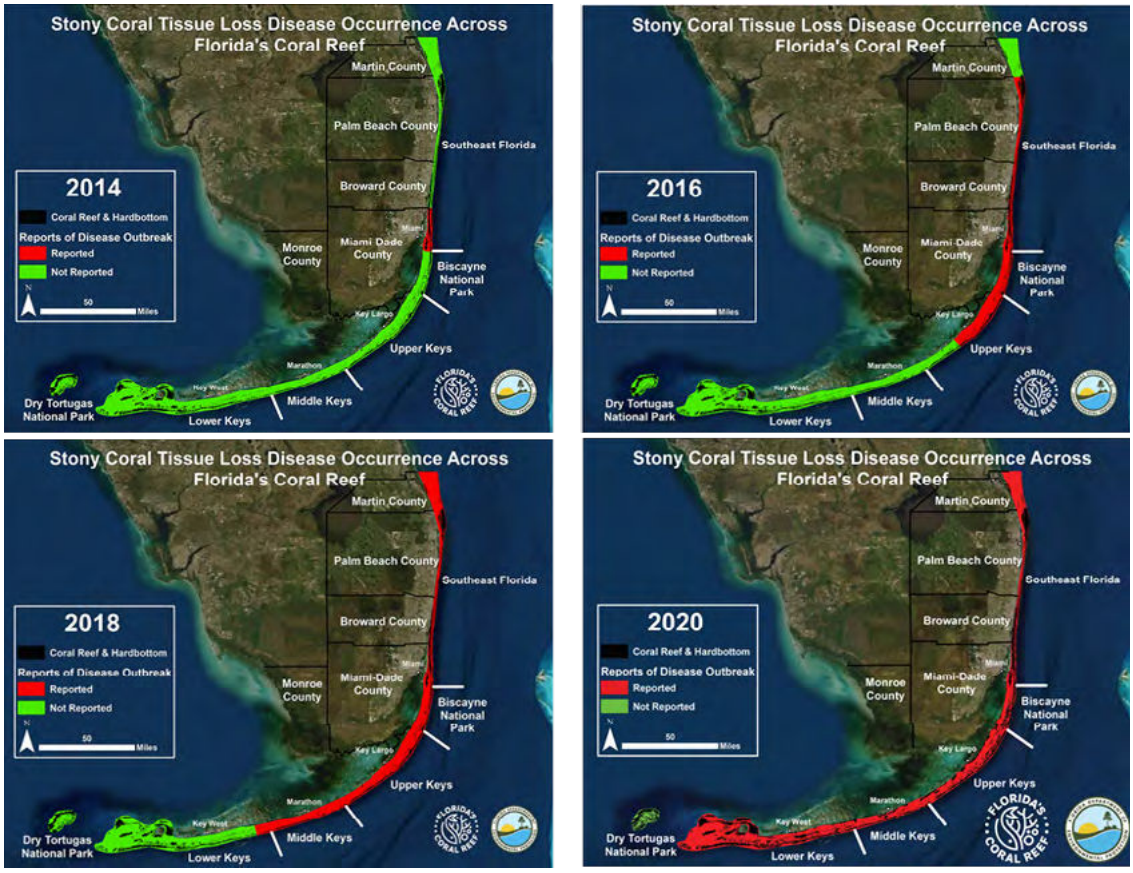


Figure 11. Progress of SCTLD from 2014-2020 (FKNMS, 2021).

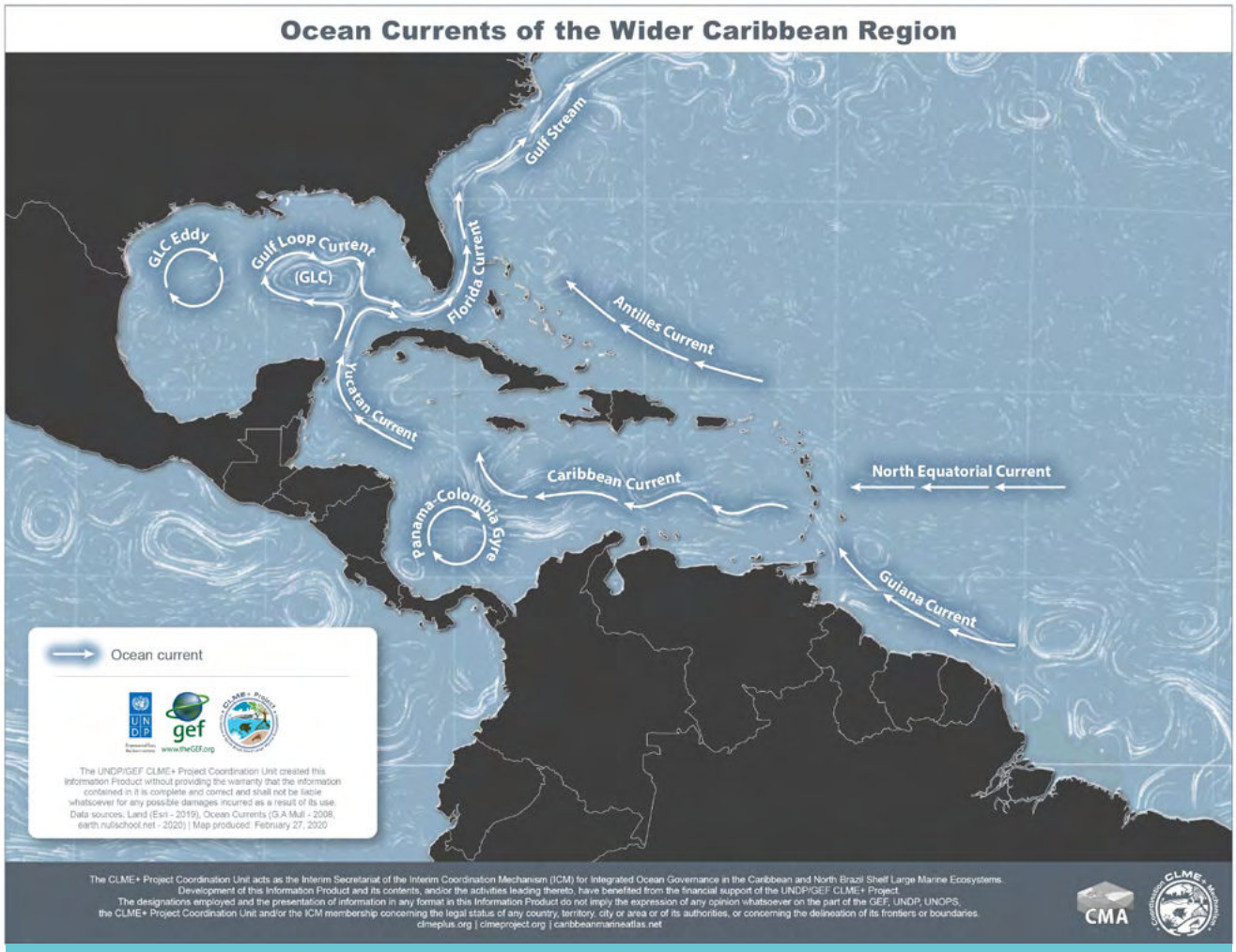


Figure 12. Currents within the Wider Caribbean Region (Acosta et al., 2020).

Monitoring

A wide variety of methods have been used to monitor SCTLD depending on the research question and management need (e.g. Precht et al., 2016; Sharp & Maxwell, 2018; Aeby et al., 2019; Alvarez-Filip et al., 2019; Weil et al., 2019; Meiling et al., 2020a; Muller et al., 2020). To provide guidance to Caribbean natural resource managers, MPAConnect developed a guide on monitoring objectives and monitoring methods (Doyle & O'Sullivan, 2020a) and has hosted two educational webinars on Identifying SCTLD and How to Monitor Reefs for SCTLD. Links to additional educational webinars are provided in the Resources Section. The following monitoring recommendations have been adapted from MPAConnect's monitoring guide (Doyle & O'Sullivan, 2020a), the Florida Coral Disease Intervention Plan (Neely, 2018a), and The Coral Disease Outbreak Response Plan for the United States Virgin Islands (Meiling et al., 2020b).

Selecting a monitoring method depends, in part, on the management objective (Figure 13), and the 'stage' of SCTLD present in an area (Table 4). Four stages of SCTLD disease outbreak have been described based on whether, and how long, a reef has been affected by SCTLD (Table 4) (Neely, 2018a; Lang, 2020). The design of a monitoring program for SCTLD is also influenced by the availability of human resources and the team's technical capacity for monitoring, the availability of logistical support for in-water field work, and the level of funding or in-kind local support available. Partnerships with the private sector and the involvement of local community researcher programs and/or volunteers can contribute to the implementation of SCTLD monitoring.

Table 4: Stages of Stony Coral Tissue Loss Disease progression (Adapted from Neely, 2018a).

Condition	Duration of Exposure	Disease Prevalence	Coral Community
Pre-invasion	None	**None**	Normal, pre-disease coral communities
Invasion	1 - 7 Months, usually <3 months	**Low** Acute lesions visible only on early susceptible species	Still has full suite of species, though early susceptible ones will be experiencing mortality
Outbreak	3 months - 1 year	**High** Lesions acute as well as chronic	Rapidly transitioning between pre-diseased community and one with lower abundances / absence of susceptible species
Endemic	1 - 4 years	May be low since susceptible species are rare. May be chronic on remaining susceptible species.	Few to no remaining susceptible species. Diminished coral cover and higher proportion of non-susceptible species.

Monitoring - what is your objective?

Management need	Recommended monitoring approach
Detect new occurrence of disease	Stakeholder reporting Awareness during other monitoring
Approximate prevalence of SCTLD	Roving diver surveys
Track progression of SCTLD	Marked colonies, establish sentinel reef sites, photo series
Assess SCTLD interventions	AGRRA-type surveys (or standard national protocol)
Determine impacts on coral reef ecosystems, including fish	6-monthly repeat of AGRRA-type surveys at long-term monitoring sites affected and unaffected by SCTLD

Figure 13. SCTLD management objectives (Adapted from Doyle & O'Sullivan, 2020a).

Monitoring Approaches Based on Disease Stage

The following monitoring approaches are suggested based on the stage of SCTLD at a reef and based on the proposed management objectives (Figure 13). Developing standardized monitoring protocols is extremely important to ensure consistency with respect to data monitoring and analyses across different monitoring sites.

- **Pre-Invasion Stage**

Objective:
Detect new occurrence of SCTLD

Given the current widespread extent of SCTLD, reefs in the Caribbean should be regularly monitored for SCTLD, even if the disease has not yet been reported, through regular monitoring programs and by initiating SCTLD outreach and awareness efforts with various stakeholders (Figure 13). Stakeholders who regularly visit the same sites, such as dive operators and fishers, can provide information on the first observable changes in reef health that occur with SCTLD. During the pre-invasion stage, if funding and human resources allow for monitoring, surveyors should monitor the status of the species that are most susceptible to SCTLD (Table 1), especially early indicator species (those that tend to get infected first) like Maze coral (*Meandrina meandrites*) (Neely, 2018b). This can be achieved by checking the health of these species during other scheduled monitoring surveys or by dedicated surveys using manta tows. Manta tows involve a snorkeler being towed at a constant speed behind a boat and allow rapid surveying of large areas of reef (e.g. Miller et al., 2003) while observing and noting any suspicious signs of SCTLD. The Atlantic and Gulf Rapid Reef Assessment Program (AGRRA) has compiled a map detailing the location of coral species susceptible to SCTLD (Kramer et al., 2021a). This may be used to help determine areas most susceptible to infection in order to prioritize monitoring needs.

One of the most important characteristics of SCTLD that distinguishes it from other coral diseases is how quickly it spreads on coral colonies with the disease spreading between 5-40 cm2/day on individual coral colonies (Sharp & Maxwell, 2018). It is therefore important to take photographs of any suspicious looking lesions or possible signs of SCTLD. Repeatedly photographing the same corals over the course of a month, at different angles and using a centimeter scale in the photo for reference, will allow you to document the progression of the disease (Box 3).

- **Invasion Stage**

Objective:
Quantify the prevalence of SCTLD

During the invasion stage at a site, a few corals of the most susceptible species will initially show signs of disease. Since SCTLD can resemble other coral diseases, especially white plague and yellow band disease, if signs of these diseases are noted then they cannot be considered diagnostic of SCTLD. If SCTLD is present, then more corals will start dying, especially any meandroid (maze, pillar, elliptical star, and smooth flower corals), brain, and possibly the massive starlet and lettuce corals (Lang, 2020). To confirm if SCTLD is present, it is necessary to quantify the prevalence of the disease among any coral species affected. Whenever possible, repeat visits to the site at weekly-biweekly intervals are encouraged in order to monitor for SCTLD. The recommended monitoring protocol for this is to do roving diver surveys which provide a method of quickly observing coral condition and can inform whether additional monitoring is

needed (Neely, 2018a). This survey method requires familiarity with the common or scientific names of SCTLD-susceptible species. A reef census swim is conducted (Figure 14), focused on SCTLD-susceptible species. This involves making counts of healthy corals, counting corals with signs associated with SCTLD, bleaching or other diseases, and counting recently dead corals (Figure 15) (Lang, 2021). These are defined as follows:

1. Healthy Corals - Normal healthy tissue color, no active disease, bleaching, or unusual signs of stress

2. Colonies with SCTLD - based on the Florida Case Definition (FKNMS, 2018)

3. Bleached Corals including:
- **Pale:** discoloration of coral tissue, polyps are just starting to bleach or are in recovery
- **Partly Bleached:** some polyps are fully bleached and others are either unbleached or pale
- **Bleached:** all (>90%) polyps are fully bleached, no zooxanthellae visible

4. Other Diseases -
(e.g. yellow-band, black band)

5. Recently Fully Dead - coral tissue has recently died, but the underlying corallite skeletal structure is visible and identifiable to species or corallite structures has been covered with a thin layer of algae, sediment, or bacteria (having died in previous days to weeks)

The compilation of specific coral condition metrics gathers important information on prevalence of SCTLD, species susceptibility, amount of coral mortality, and other signs of coral stress such as bleaching and hot spot locations. AGRRA advises trying to survey a total of 100-200 corals where possible at each site. The bar-drop survey method used by the Healthy Reefs Healthy Peoples Initiative similarly assesses 100-200 colonies along swum transects (McField, 1999). More detailed coral belt transects, such as the AGRRA coral protocol, can also be conducted to quantify the extent of any SCTLD disease in spatially-defined transects (e.g. Alvarez-Filip et al., 2019). Photographic documentation is also important in confirming SCTLD (Box 3). Photos (with scale bars) should be taken at a reefscape view of the affected site and of several SCTLD-affected corals (see Zimmerman, 2021 for guidance on taking photographs). Findings can be entered into the Caribbean SCTLD Online Data Tool and Tracking Map.

- **Invasion/Outbreak Stage**

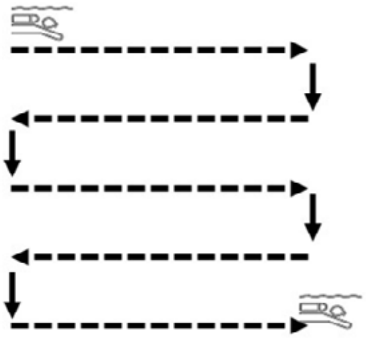
As a reef transitions from an invasion stage to an outbreak stage of SCTLD, few meandroid and brain corals will be unaffected; star and great star corals will start to die, as will some of the other less susceptible corals. The objective during this stage is to track the progression of SCTLD.

Objective:
Track progression of SCTLD

Once SCTLD has been confirmed, it is important to quickly determine the spatial extent of the disease boundary (Neely, 2018b; Lang, 2020). Starting at the discovery site or areas of concern, spot checks can be conducted by moving away from the affected reef (i.e. moving east-west along a linear reef trending in that direction). The further progression of SCTLD can be tracked by identifying priority coral reef sites and currently unaffected sentinel corals to monitor for disease spread. Table 5 outlines possible criteria for identifying priority reef sites and sentinel corals which can be adapted to provide locally relevant guiding principles for SCTLD monitoring (Neely, 2018a; Doyle &O'Sullivan, 2020a).

Roving Diver Overview

- Record site information (e.g. lat/long, reef type etc.)
- Swim site to cover ~ 50-100m area
- Survey key coral health metrics (see below)
- Survey 100-200 SCTLD-susceptible corals, unless susceptible species are rare, to gain a representative sample of the habitat
- Avoid counting the same corals twice; keep ~2 m apart from other divers
- Start before SCTLD invades or, when in outbreak stage, also survey non-affected sites in advance of the outbreak (boundary).
- Repeat surveys at the same site allow disease incidence estimates (number of new cases or probability of developing the disease).
- Enter data in Caribbean SCTLD Online Data Tool https://www.agrra.org/coral-disease-outbreak



Count corals that are:

- Healthy
- SCTLD
- SCTLD + Bleaching (As BL, PB, P)*
- Bleaching (As BL, PB, P)*
- Other Diseases
- Recently Fully Dead

*BL-Fully Bleached, PB-partly Bleached, P-Pale)

Figure 14. Rover diver method for surveying SCTLD (Adapted from Lang, 2021).

AGRRA SCTLD-Bleaching Survey Datasheet

Surveyor Name:	Date: Time:	Latitude: Longitude: (or Location):	Reef Name *(if known)*:
Detailed Surveys: AGRRA Site Code if any:	*Detailed Surveys:* MPA Status: Yes? No? Unsure?	*Detailed Surveys:* If a Restoration Site: Outplant? Nursery?	Reef Type: Backreef? Reef Crest? Patch Reef? Fore Reef? Other *(Describe)*:
Average Depth: m? or ft?	Bottom Temp.: °C or °F?	Site Comments *(e.g.*, major organisms):	

Tally all corals (including clumps) of species known to be susceptible to SCTLD.

Species	# Healthy Corals	# SCTLD Corals	# Corals with SCTLD &/or Fully Bleached (BL), Partially Bleached (PB), or Pale (P)			# Corals Fully Bleached (BL), Partially Bleached (PB), or Pale (P)			# Corals with other Diseases(s)	# Recently Fully Dead Corals	Notes; any Photos?
			BL	PB	P	BL	PB	P			
OFTEN SEEN *Colpophyllia natans:* CNAT (Boulder Brain)***											
Dendrogyra cylindrus: DCYL (Pillar)***											
Dichocoenia stokesii: DSTO (Elliptical Star)***											
Diploria labyrinthiformis: DLAB (Grooved Brain)***											
Eusmilia fastigiata: EFAS (Smooth Flower)***											
Meandrina jacksoni: MJAC (White-valley Maze)***											
Meandrina meandrites: MMEA (Maze)***											
Montastraea cavernosa: MCAV (Great Star)**											
Orbicella annularis: OANN (Lobed Star)**											
Orbicella faveolata: OFAV (Mountainous Star)**											
Orbicella franksi: OFRA (Boulder Star)**											
Pseudodiploria clivosa: PCLI (Knobby Brain)***											
Pseudodiploria strigosa: PSTR (Symmetrical Brain)***											
Siderastrea siderea: SSID (Massive Starlet)**											
Stephanocoenia intersepta: SINT (Blushing Star)**											
SEEN LESS OFTEN *Agaricia agaricites*: AAGA (Lettuce)*											
Agaricia lamarcki: ALAM (Whitestar Sheet)											
Agaricia tenuifolia: ATEN (Thin Leaf Lettuce)											
Space for other species, e.g., *Porites astreoides?:* PAST (Mustard Hill)?											

Describe the survey protocol used:	*Detailed Surveys:* What % of all corals at the site have each kind of partial mortality? New? Trans? Old?	*Detailed Surveys:* How were the data collected? Qualitatively? Quantitatively?	Other Comments

* numbers represent **usual** order of contracting SCTLD, from first (***) to last (*), if known.

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Figure 15. AGRRA SCTLD/Bleaching Survey Datasheet.

Table 5: Proposed guiding principles to determine which coral reef sites and species should be prioritized for monitoring (Adapted from Neely, 2018a and Doyle & O'Sullivan, 2020a).

Criteria	Guiding Principles	Justification
Ecological (Sentinel Reef Sites)	Presence of SCTLD susceptible corals	Does the reef contain species susceptible to SCTLD? Information on the distribution of susceptible corals within Caribbean countries/territories may be found on AGRRA's map on the distribution of susceptible species (Kramer et al., 2021a).
	Reef types affected by SCTLD	Aim for representatives of each type as constituent corals are locally adapted to different environments with respect to wave exposure, sediment stressors, and ambient illumination.
	Coral diversity	A diverse community may provide more opportunity to protect an intact ecosystem and preserve reproductive capacity of many species with less effort (the loss of particular species is less likely to disrupt the ability of the entire ecosystem to function).
	Coral density	A high density of corals may provide greater habitat complexity, more ecosystem services to other organisms, and experience higher reproductive potential. However, crowded sites may also be more susceptible to infectious diseases especially if many corals are clonemates and equally susceptible to the particular pathogen involved.
	Coral composition	Sites that contain a large number of colonies of susceptible corals may be prioritized.
	Coral demographic structure	Sites with large, reproductively active, framework structure-producing corals contribute proportionately more to habitat and propagation. These sites are often high-relief spur-and-groove reefs or large patch reefs.
	Isolation	Sites isolated by sand or hard bottoms lacking many live corals may be less susceptible to ongoing or high infection rates from water-borne pathogens. Discrete sites are easier to scout/search and may be able to be treated more effectively.
Ecological (Sentinel Corals)	Structure builder	Some susceptible species contribute substantially to reef-building and associated ecosystem services especially *Orbicella* spp., *Montastraea cavernosa*, and *Colpophyllia natans*. These species may be prioritized over others that are not primary framework builders.
	Size	Larger colonies are likely to have greater reproductive capacity and provide more habitat. Corals of species that grow larger than 2 meters may be prioritized for these features.
	Relative size	Colonies that are large for their species are likely to be older and thus more resilient to long-term environmental conditions. They are also likely to substantially contribute more to reproduction than their smaller conspecifics. Corals in the top 5% of size for their species may be prioritized.
	Localized reproductive capacity	A coral surrounded (in the same general reef area) by other live colonies of the same species probably has greater reproductive potential than a more isolated coral because its fertilization rates are likely to be greater.
Regulatory (Sentinel Reef and Coral Species)	Iconic corals	Corals identified by stakeholders as important for historical, educational, or economic reasons. These could include frequently-visited colonies at popular SCUBA diving sites.
	Within a marine protected area	Corals within zones of extra protection may be living under better environmental conditions and should be prioritized.
	Within a recreational area	Corals near mooring balls are likely to receive greater visitation. This could provide greater visibility for monitoring and treatment efforts and potentially create greater citizen engagement. Alternatively, if recreational diving is large-scale and unsupervised, they are more likely to perish than corals in other areas.

Box 3. Used to Document SCTLD Progression through Photographs

Time-Series Photos:

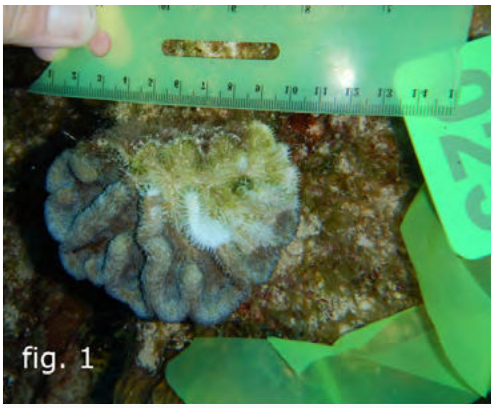
To assess the effects of SCTLD on individual corals, particularly susceptible corals, time-series photos (2D) can be taken to track their mortality and/or survivorship. Corals can be tagged using a variety of methods and several views of affected corals should be taken such as the coral colony from top and side, close-up of coral disease margin, and the affected coral shown with surrounding corals (see Zimmerman, 2021).

Photomosaics:

A photomosaic is a large-scale, detailed picture created by combining many smaller photographs. They are beneficial in documenting the effects of SCTLD or other disturbances on a larger scale and tracking changes over time. Benefits of photomosaics include a higher power to detect change, the ability to use historical data, allowing for rapid surveys of the entire benthic reef community, and providing a historic digital record (Gleason et al., 2007; Gintert et al., 2018; Green, 2020; Lang, 2021).

3D Photogrammetry

New technology is available that allows for the construction of 3D photo-models to track the condition of corals. Since corals are semi-spherical, three-dimensional animals, these new models allow the calculation of metrics at a high resolution such as tissue loss due to SCTLD, mortality, or amount of bleaching (Meiling et al., 2020a).



Time Series Photographs.
Photo Credit: Turks and Caicos Reef Fund.

- **Outbreak/Endemic Zone**

  Continued monitoring can be done to track the effects of SCTLD outbreaks on reef ecosystems and ecosystem services and to assess the effectiveness of SCTLD intervention methods.

  Objective: Assess the effects of SCTLD on the surrounding reef community

  The loss of numerous corals due to SCTLD is likely to affect the surrounding benthic composition and may affect fish communities. AGRRA-like surveys, or national monitoring protocols that assess overall reef condition, should be done to evaluate reef community structure and function (Alvarez-Filip, 2019; Estrada-Saldívar et al., 2020). This includes coral belt transects such as non-fixed AGRRA-coral transects to quantify the extent of the disease in spatially-defined transects (e.g. Alvarez-Filip et al., 2019). These can be undertaken at usual intervals, or as possible, for different locations between annually and every 5 years.

  Objective: Assess the efficacy of SCTLD intervention treatments

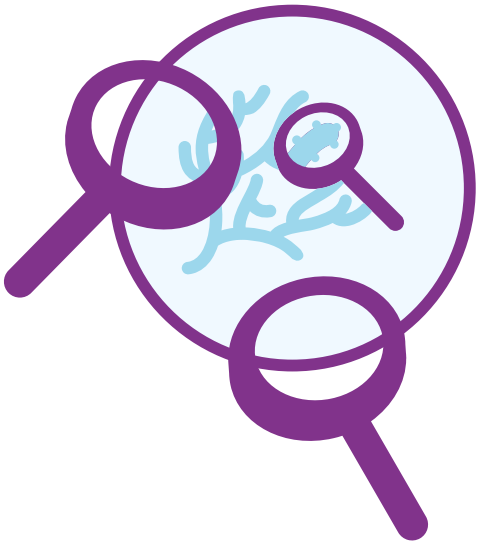
  If individual corals have been treated according to best practice intervention treatments, then long-term monitoring should be done to determine the effectiveness of these treatments. Fate tracking of individual corals can be done through 2D photos or 3D photogrammetry (Neely, 2018a; Zimmermann, 2020; Meiling et al., 2020a). Corals are sometimes individually identified with numbered tags to allow for tracking. The extent of disease lesions or the margins of treatments are sometimes marked with nails to assist with tracking.

  Objective: Assess socio-economic effects

  It is recommended to broaden SCTLD monitoring from tracking not only the biophysical impacts of the disease on coral reefs but to also consider socio-economic effects. Several guides on incorporating socio-economic metrics are available including SocMon (e.g. Pena et al., 2012).

Long-term SCTLD Monitoring Program

The evolution of SCTLD monitoring in Florida over the course of several years is potentially instructive for other locations to guide the design of a long-term SCTLD monitoring program. Long-term monitoring objectives include continued tracking of the disease boundary, observing transmission and linking spread with hydrology, hotspots and ports/marinas, estimating disease prevalence/longevity/severity, estimating overall coral mortality and changes in community structure, investigating coral resilience, and determining sites for restoration. Monitoring of intervention success, reproduction, and restoration are also long-term monitoring considerations (Schopmeyer, 2021).



Proposed Citizen Science Protocol

Citizen science for coral disease monitoring can take several forms and contribute to several management information needs. When detecting a new SCTLD occurrence it is important to engage stakeholders, such as fishers and divers, in monitoring since they may be the first to notice signs of SCTLD in local waters. This requires tailored outreach and education in order to inform stakeholders about the new threat of SCTLD, to explain what it looks like, and to encourage reporting of disease suspicions to coral reef managers. By engaging stakeholders in monitoring, they become eyes and ears on the reef, providing spot checks over a potentially larger area than coral reef managers alone could feasibly monitor.

For the objectives of confirming SCTLD and tracking SCTLD progression, there is potential to engage local community researchers and volunteer divers in monitoring as citizen scientists. Some Caribbean countries and territories have existing, local community researcher programs based on the involvement of local community members in marine protected areas and other environmental monitoring such as the program founded by the Toledo Institute for Development and Environment (TIDE) in Belize and subsequently adopted by the Grenadines Network of Marine Protected Areas (MPAs) and championed by Sustainable Grenadines, Inc. (SusGren). Other Caribbean countries and territories have dive volunteers who either live locally or are dive tourists who seek to contribute locally during their visit.

The roving diver survey methodology, in particular, lends itself to implementation by citizen scientists especially when using a simplified data gathering protocol. Implementing roving diver surveys with citizen scientists requires the recruitment and training of volunteers, logistical coordination and supervision of fieldwork, consideration of stipends for local community researchers, the development of partnerships for in-kind support, technical assistance with data analyses and review of findings, and sharing of results with stakeholders. Underwater photography, either alone or in conjunction with roving diver surveys, also provides an opportunity for dive volunteers to contribute to citizen science monitoring of SCTLD.

Experience from the U.S. Virgin Islands (USVI), Mexico, Honduras, the Turks & Caicos Islands, and the Grenadines indicates that the establishment of a citizen science program for SCTLD monitoring should be considered. Engaging potential volunteers through community outreach, social media posts, traditional media outlets, etc. will attract as many people as possible in order to ensure a large group of volunteers. The establishment of a citizen science program should include:

- Hiring a dedicated Program Coordinator
A Program Coordinator who is solely responsible for the development of training materials, organizing monitoring trips, and overseeing volunteers is necessary to ensure the successful implementation of the program.

- Developing/Using easy-to-understand training and monitoring materials
Volunteers will have different educational backgrounds so the use of simple, easy-to-understand materials is necessary to maximize comprehension. For example, many may not be comfortable with the use of scientific names so common names should be used instead. AGRRA has developed a simplified version of their data sheet that can be used (Figure 16).

- Pairing weaker volunteers with stronger ones
This will allow the weaker volunteers to learn and improve their monitoring skills and the stronger volunteers to provide mentorship.

- Identifying dedicated photographers for each monitoring trip
As part of the monitoring program. make sure that there is a dedicated photographer that can document any potential signs of SCTLD as well as take reef-wide photographs to assess coral health.

Coral SCTLD Datasheet by Species Common Names

Diver Name:		Date:	Lineups from shore if no GPS:		
Site Name:		Latitude:	Depth Range:	Survey Time (in mins):	
Site Protected? Y (Yes) or N (No)		Longitude:	Habitat:	Comments:	
Group or Species		Tally Number			Photos? Y (Yes) or N (No)
Code	Name	Live	Diseased	Recently Dead	
DCYL	Pillar Coral				
MAZE	Any Maze Coral				
BRAIN	Any Brain Coral, or				
CNAT	Boulder Brain Coral				
DLAB	Grooved Brain Coral				
PCLI	Knobby Brain Coral				
PSTR	Symmetrical Brain Coral				
STAR	Any Star Coral, or				
DSTO	Elliptical Star Coral				
MCAV	Great Star Coral				
OANN	Lobed Star Coral				
OFAV	Montainous Star Coral				
OFRA	Boulder Star Coral				
SSID	Massive Starlet Coral				
LETTUCE	Any Lettuce Coral				
OTHERS (describe)					

Figure 16. Simplified monitoring data sheet.

Case studies

Below are three examples of monitoring efforts in the Caribbean. The first is an example of a new initiative designed to increase stakeholder awareness and determine the presence of SCTLD in their waters. The second showcases an example of a larger, longer-term effort to implement a SCTLD Response Action Plan. The third highlights the need to increase stakeholder awareness and prioritize planning to allow for rapid response to an identified SCTLD outbreak.

Case Study 1

Monitoring Objective:
Engage multiple stakeholders and local community researchers to conduct proactive SCTLD monitoring (i.e. pre-invasion surveys, outreach/communication).

Location:
St. Vincent and the Grenadines and Grenada

Challenge:
SCTLD had been confirmed in St. Lucia, the island directly north of the Grenadines; however, no formal SCTLD monitoring had occurred in St. Vincent and the Grenadines or Grenada, and it was not known if SCTLD was present in either of the two countries.

Actions Taken:
In Fall 2020, SusGren led an outreach, training, and field survey effort to increase stakeholder awareness of SCTLD and conduct surveys to proactively look for SCTLD (Figure 17). Sessions included four in-person, four in-water, and three Zoom trainings which resulted in 20 stakeholders learning about SCTLD monitoring and how to identify the common SCTLD-susceptible species. Field work included 30 surveys on six islands within St. Vincent and the Grenadines and Grenada. Priority sites were based on:

- Concern about the disease being associated with ports and cruise terminals, so an MPA site close to Kingstown port was selected.
- Permanent monitoring sites including two in each of six MPAs in the Grenadines.
- Highly susceptible sites selected from AGRRA's Coral Cover of Species Susceptible to SCTLD.
- Sites considered important by dive operators and MPA rangers.

SusGren collaborated with dive operators in St. Vincent, Grenada and Union Island, the Tobago Cays Marine Park rangers, The Fisheries Divisions in St. Vincent and Grenada, Mustique's Chief Environmental Officer, and local community members.

Figure 17. Community researcher engagement in the Grenadines. Photo Credit: Sustainable Grenadines, Inc.

Lessons Learned:
- The success of the outreach and monitoring project was due to multiagency collaboration among non-government organizations (NGOs) and government agencies as well as multi-sector support including dive operators, fishers, MPA rangers, and community researchers.
- A dedicated program coordinator was necessary to ensure the success of the initiative.
- Local dive operators and NGOs were essential in organizing and supporting field logistics and implementing volunteer-driven surveys.
- It was necessary to allocate clear roles to volunteers.
- Information on the data sheets completed by volunteers should be checked at the end of each survey.
- One specific dive member should be responsible for coral photography.
- Additional AGRRA and SCTLD training is needed and the effort should expand to reach new stakeholders.
- No SCTLD was seen.

Contact: Adara Jaggernauth, Monitoring Coordinator, Sustainable Grenadines, Inc. abjaggernauth@gmail.com

Case Study 2

Monitoring Objective:
Implement a comprehensive SCTLD response plan which incorporates widescale SCTLD monitoring, citizen engagement, collaboration with dive shops, and SCTLD treatment trials.

Location:
Turks and Caicos Islands

Challenge:
Following a SCTLD learning exchange with Florida scientists in 2019, the Turks and Caicos Reef Fund (TCRF) developed a SCTLD Action Plan and began the commitment and challenge of implementing the plan.

Actions Taken:
TCRF led a multi-purpose effort to increase citizen awareness, build partnerships with the dive industry, monitor the extent and effects of SCTLD, and begin trial antibiotic treatments of infected corals. TCRF trained more than 70 people in basic coral identification, species condition metrics, and SCTLD monitoring protocols. More than 200 SCTLD surveys were conducted at 30+ dive sites which entailed 750+ hours of in-water volunteer time (Figure 18). Survey data was entered into the AGRRA online data tool. Partnerships with local dive shops were established and 750+ tanks were filled for free by dive shops. SCTLD treatment trials included 200 corals being treated with Amoxicillin in Base2B at three dive sites with subsequent monitoring to track the efficacy of the treatments.

Lessons Learned:
An important key to the success of the project, so far, has been the expanded engagement with and support of the local community and dive shops which has made the monitoring and dive logistics possible. For monitoring the extent of SCTLD, key lessons learned included:

- Baseline AGRRA data contributed to understanding changes over time.
- Numerous broad and targeted surveys helped identify areas with no SCTLD, areas with suspected SCTLD, and areas with confirmed SCTLD (more samples = better data).
- Taking many photographs, including time-series photos, is important for both scientific understanding and communicating with and engaging the public, government, and other stakeholders.
- Pre-SCTLD landscape-view photographs should be taken.
- The level of volunteer dive capacity was enhanced through numerous educational trainings.

Future efforts include continued monitoring to increase the number of corals treated, with a focus on large-sized corals, experimenting with alternative treatments, and incorporating coral restoration into SCTLD response activities. TCRF is also creating a marketable itinerary for dive guests aboard the Aggressor Dive boats.

Contact: Alizee Zimmermann, Executive Director, Turks & Caicos Reef Fund, alizee@tcreef.org

Figure 18. Community researcher engagement in the Grenadines. Photo Credit: Sustainable Grenadines, Inc.

Case Study 3

Monitoring Objective:
Engaging stakeholders and increasing community involvement and awareness.

Location:
Honduras

Challenge:
Following a 2019 SCTLD learning exchange in Florida, Roatán Marine Park (RMP) embarked on a campaign to increase community awareness within Roatán, Honduras on SCTLD.

Actions Taken:
RMP led a multi-strategy campaign to increase community involvement for the early detection of SCTLD in Roátan (Figure 19). In 2020, nine workshops were given to the wider public, local stakeholders, and dive operators on coral species identification. Additional outreach activities between 2019 and 2020 included the hosting of three community meetings, the creation of an educational video, visits to over 40 dive shops, and the distribution of SCTLD identification and detection posters. Social media platforms were also used to disseminate additional information. Bi-monthly monitoring exercises were also conducted to ensure the early detection of SCTLD. 8,810 corals were monitored across 22 sites around the island with 327 corals treated and tagged at eight sites (RMP, 2021).

Figure 19. Community engagement in Roátan. Honduras. Photo Credit: Roatan Marine Park.

Lessons Learned:
The early detection of and response to SCTLD in Roatan's waters highlights the need for active stakeholder engagement and early monitoring. Preparing for the likely occurrence of SCTLD in Honduran waters meant that SCTLD was detected early and treatment interventions could begin almost immediately. This was also aided by community outreach and education efforts which raised awareness amongst stakeholders.

Contact: Francis Lean, Executive Director, Roatán Marine Park, francis.lean@roatan-marinepark.org

Reporting SCTLD in the Caribbean

As SCTLD presence/absence reports have increased in the Caribbean, scientists, managers, and practitioners have begun to expand monitoring to include data on coral condition (e.g. Alvarez-Filip et al., 2019). To help monitor and track the spread of SCTLD in the Caribbean, AGRRA developed an open-access, online Caribbean Coral Health Watch Data Entry Tool and interactive SCTLD Tracking Map to show where SCTLD and Coral Bleaching have been reported in the Caribbean (Figure 20) (Kramer et al., 2021b). The Caribbean Coral Health Watch Data Entry Tool allows surveyors to enter quantitative data, if available, on key coral condition metrics.

Sightings are submitted through the online Coral Health Watch Data Entry Tool (either basic or detailed survey forms) which then appear on the map as purple markers while the information is thoroughly reviewed by a team of scientists. Once a report is reviewed, the markers are turned green if SCTLD is not present, yellow if SCTLD may be present but more information is needed, or red if the presence of SCTLD is confirmed. Over 800 reports (either SCTLD present or absent) have been submitted in the past two years from 23 different countries/territories in the Caribbean. As of March 2021, SCTLD has been confirmed in 17 countries/territories.

The Caribbean SCTLD Tracking Map also automatically incorporates data provided by Florida Fish & Wildlife Conservation Commission's Fish & Wildlife Research Institute and the U.S Virgin Islands Coral Disease Advisory Committee. Some additional SCTLD data, not presented in the Tracking Map, is also available from national datasets (e.g. Bahamas, Cayman Islands).

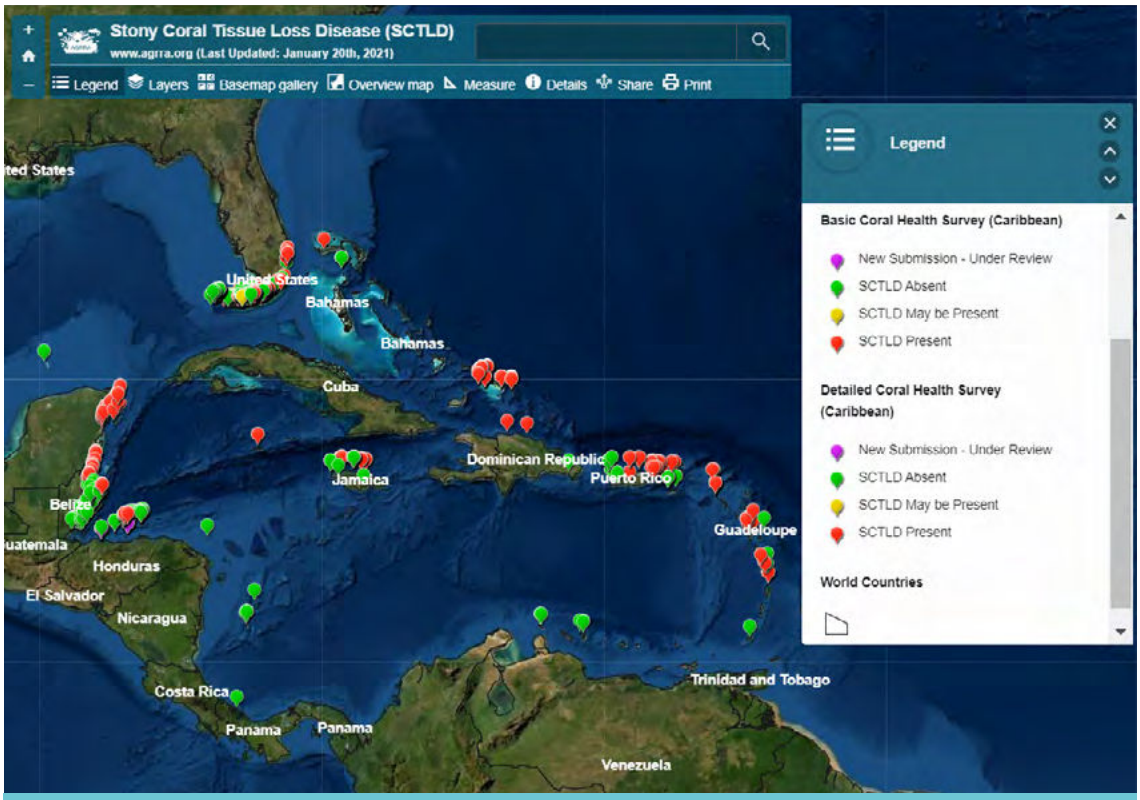


Figure 20. Caribbean Stony Coral Tissue Loss Disease Map. Legend shows data from basic and detailed surveys with location markers representing presence, absence, or not confirmed status (Kramer et al., 2021b).

Management

The growing SCTLD outbreak in the WCR, and the resulting devastating impacts on coral reefs, have placed new demands on marine natural resource managers. As an emerging issue, SCTLD has implications for many aspects of management, and with limited resources throughout the region, it is critical that researchers and managers work together to share resources and experiences in order to maximize the use of those resources.

Possible management actions in response to SCTLD include:

- Communications
- Partnerships and coordination
- Response action planning
- Prevention
- Reduction of environmental stressors
- Monitoring (including with stakeholder participation) and data management
- Field intervention/treatments
- Coral rescue/restoration
- Research
- Capacity building

Communications

Agencies involved in the management of SCTLD are advised to adopt unified messaging about SCTLD in their communications so that the information shared is consistent across all parties. They are further advised to make a careful choice of appropriate language for communicating effectively with stakeholders and decision makers about the latest scientific knowledge and best practices in relation to SCTLD. Managers have to strike a balance between communicating the severity of the disease to underpin quick action whilst not creating an unnecessary sense of panic among the public that could have detrimental impacts on local communities (Figure 21).

The SCTLD outbreak throughout the WCR has highlighted the need for effective marine resource management and the need for rapid responses when addressing threats. In order to support this new interest in marine management, general, audience-appropriate information should be relayed to stakeholders. This may include images, videos, and news updates. For example, one of the major communications tools of the Florida Keys National Marine Sanctuary is a public website that provides up-to-date information on the spread of the disease and their management response efforts (FKNMS, 2021). MPAConnect, the Healthy Reefs for Healthy People Initiative, and other partners have developed many outreach materials for use by Caribbean marine natural resource managers in communicating with their stakeholders about SCTLD. These include educational videos, posters, and fact sheets. Marine natural resource managers in locations affected by SCTLD have now implemented effective communications campaigns to reach a variety of stakeholders. A wide range of media has been employed including press releases, interviews with local or international journalists, local radio or television newscasts, social media posts, videos, and webinars. Please see the resources section of this document for examples and links to sample communications materials.

MPA connect

A partnership between:

GCFI Gulf and Caribbean Fisheries Institute

NOAA Coral Reef Conservation Program

Stony Coral Tissue Loss Disease

terminology for clear science communications

MISLEADING LANGUAGE	MORE ACCURATE TO SAY
White disease	Tissue loss disease
SCTLD acronym	Coral disease affecting hard corals
Mysterious	Emerging, newly occurring disease
Unidentified	Named by scientists as stony coral tissue loss disease
Confused with other diseases	Shares similarities with some other coral diseases
Contagious	Spreads rapidly among stony corals but does not affect humans
Unknown disease	Scientists are working to document the outbreak and develop advanced treatments
Cause unknown	Partners regionally are researching the disease; Scientists are working to identify pathogen(s) responsible
Unmanageable	Targeted, strategic efforts
Closure of reef	Quarantine
Culling	Strategic removal or rescue
Use antibiotics	Strategic, small-scale application of Antibiotics
Uncertain about plans	Range of approaches needed

Highly susceptible species

Meandrina meandrites, *Eusmilia fastigiata*, *Dendrogyra cylindrus*, *Dichocoenia stokesii*

Pseudodiploria clivosa, *Diploria labyrinthiformis*, *Colpophyllia natans*, *Pseudodiploria strigosa*

Orbicella species, *Siderastrea siderea*, *Montastrea cavernosa*

What's at stake?

Our highly diverse and economically valuable coral reef ecosystems.

What can we do?

While the situation is urgent, it is not too late to save these incredibly important ecosystems. Corals are resilient if given the chance and the enabling conditions for their growth and survival.

The key is reducing local and global stressors to support reproduction, growth, and survival.

Figure 21. Suggested language to use when describing SCTLD (Doyle & O'Sullivan, 2020a).

Partnerships and coordination

In order to effectively manage the spread of SCTLD, a coordinated regional response is needed to minimize the impacts on reefs within the WCR. This requires the involvement of governmental and inter-governmental bodies, policy makers, researchers, natural resources managers, fishers, dive operators, and non-governmental organizations in both affected and unaffected countries/territories in order to ensure ongoing monitoring and rapid responses to stem the spread of SCTLD. These partnerships are essential in the management of SCTLD since they bring together the capabilities and strengths of government, NGOs, academia, citizens, the private sector, and policy makers. At a national, state, or island level, inter-agency and trans-disciplinary partnerships might be formalized via a SCTLD advisory committee that can lead efforts on SCTLD response action planning and resourcing.

SCTLD management response may also require partnerships amongst marine natural resource managers, agencies, and stakeholders within and far from the affected sites. The approach to SCTLD response in Florida is potentially instructive for other countries and territories in the Caribbean (Box 4). While the four lead agencies coordinating Florida's response are the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, the National Oceanic and Atmospheric Administration, and the National Park Service; agencies such as the U.S. Environmental Protection Agency, the Smithsonian Institution, the U.S. Geological Survey's National Wildlife Health Center, and all five counties within Southeast Florida provide additional support. The disease response is also assisted by academic and research institutions, NGOs, non-profits, and aquaria (Wusinich-Mendez et al., 2019).

Box 4. Florida's response efforts to Stony Coral Tissue Loss Disease.

Florida's Response to SCTLD

Florida's response effort is coordinated by NOAA, the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, and the National Park Service in conjunction with over 60 collaborative partners. The Florida SCTLD Strategy includes nine key areas:

- Research and Epidemiology
- Reconnaissance & Intervention Team
- Coral Rescue
- Coral Propagation
- Restoration Trials
- Data Management
- Regulatory
- Communications and Outreach
- Caribbean Cooperation

Collaborative response efforts among these groups have included:

- Extensive monitoring of the SCTLD outbreak and progression
- Research on the outbreak, potential causative agents, and vectors
- Development and testing of treat -ments and intervention strategies
- Strengthening the coordination and capacity for effective response actions
- Conducting large-scale coral rescue missions to preserve genetic diversity for future reef restoration

Since 2015, the State of Florida and the U.S Government has funded over US$16 million worth of SCTLD related projects (FDEP, 2021; NOAA, 2020).

Within the WCR it is recommended that managers, where relevant, liaise and coordinate initiatives with the following organizations/ working groups:

- The Secretariat for the Cartagena Convention
- SPAW-RAC
- GCRMN
- RAC-REMPEITC
- IMO
- CARICOM
- OECS
- CCAD
- The SCTLD Caribbean Cooperation Team
- The Virgin Islands Coral Disease Advisory Group
- The Joint Nature Conservation Committee Collaborative Working Group
- AGRRA
- GCFI
- HRI

Response action planning

Managers are encouraged to proactively address potential/realized SCTLD outbreaks within their region. The development of a monitoring and intervention action plan will ensure consistency amongst data collection and analysis methods, the implementation of SCTLD prevention techniques, and the identification/creation of designated communications materials. Doyle and O'Sullivan (2020a) have developed a monitoring and response action plan template that can be tailored for the needs of specific sites.

Prevention

Local managers play an important role in disseminating best practices that can prevent the spread of SCTLD to local stakeholders, such as diving healthy reefs before diving infected reefs, local rental of dive and snorkel gear, and decontamination of gear. Effective communication and partnerships with the dive and fishing industry are important elements of this management action.

The spread of SCTLD by water also raises possible associations with the shipping industry including tankers and cruise ships. The exchange of ballast and other water away from coral reefs is likely to help prevent the spread of SCTLD. There is an opportunity for mandated agencies to further collaborate with the shipping industry and with the smaller commercial vessel sector to develop and promote best management practices.

Reduction of environmental stressors

Communication with marine natural resource users about SCTLD can help to emphasize the importance of coral reef resilience in general. As an emerging issue, SCTLD can also serve to reinforce the importance to users of complying with existing regulations designed to manage those threats to coral reefs that are already well-known and well-understood.

Closure of areas affected by SCTLD was not practical in Florida given the widespread occurrence of the disease. In Mexico, however, zoning changes and closures have been implemented by the Mexican National Commission for Natural Protected Areas (CONANP) in response to the SCTLD outbreak. Roatan Marine Park and the MPA co-managers also closed affected dive sites in Sandy Bay/West End Special Marine Protection Zone. Effective communication and coordination with affected stakeholders are essential for the success of this management action.

Monitoring and data management

Monitoring of SCTLD in the Caribbean has been facilitated due to the willingness amongst countries to share lessons learned, educational webinars and materials to build knowledge and capacity (see Resource section), and the Regional SCTLD Database and Tracking Map Platform. All 17 of the countries/territories with confirmed SCTLD presence have had some level of monitoring. A wide variety of monitoring is needed including the engagement of citizen scientists and trained surveyors and the development of strategic monitoring objectives.

Recommendations for, and examples of, SCTLD monitoring approaches in the Caribbean are provided in the monitoring section. The biggest needs for expanding monitoring and our understanding of SCTLD are increased funding, additional capacity, targeted research, and support from government entities.

Field intervention/treatments

While the cause of SCTLD has not yet been identified, numerous researchers have been investigating a variety of treatment and intervention efforts. These have included creating 'fire breaks' along a disease margin on a coral to stop the disease progression, culling (i.e. removing) infected corals from reefs, applying topical lesion treatments (natural and manmade), developing probiotics to build coral colony immunity, and rescuing healthy corals for genetic banking (e.g. Walker & Pitts, 2019; Meyer, 2020; Neely, 2020a; Neely, 2020b). None of the non-antibiotic products or placebos so far tested in the region have halted disease progression on coral colonies (e.g. Neely, 2020a; Neely, 2020b). Potential treatment methods continue to be studied, including the identification of effective probiotics (e.g. Meyer, 2020; Paul et al., 2020).

Currently, the only effective treatment to reduce the progression of lesions is the strategic application of amoxicillin mixed with Base2B (created by Ocean Alchemists) (e.g. Aeby et al., 2019; Walker & Pitts, 2019; Neely, 2020a) in a 1:8 ratio (Amoxicillin:Base2B). The mixture is applied in a 1-cm strip along an active lesion edge with half of the mixture covering the exposed skeleton and the other half covering the live tissue around the entire disease margin (Figure 22). Neely (2020a) found that average lesion treatment success was 91% in the Florida Keys. Similar results were found in the Turks and Caicos Islands with an 80-90% efficacy rate observed in 150 treated corals (Zimmermann, 2021). Base2B costs US$50 per 400g jar while amoxicillin costs US$122 per 100g. One 400g jar of Base2B and 50g of amoxicillin can treat between 6 to 18 corals depending on their size and the number of lesions. It is recommended that treated corals be visited monthly to determine whether or not the coral needs to be re-treated.

Some of the challenges with using the Base2B/amoxicillin mixture are that it is time-intensive and requires training, manpower, and approval from local government agencies.

Since it is difficult to treat all of the infected corals on a reef, it is necessary to prioritize coral treatment based on prioritization criteria such as (Doyle & O'Sullivan, 2020a):

- Species Type
Some species, such as the brain, star, and starlet corals contribute substantially to reef rugosity and should therefore be prioritized.

- Relative Size of the Coral Colony
Coral colonies that are large for their species may be older and more likely to contribute substantially to reproduction.

- Localized Reproductive Capacity
Corals surrounded by live colonies of the same species may also have greater reproductive potential.

- Species Status
Species that are classified as Vulnerable, Endangered, or Critically Endangered on the IUCN RedList of Species should be prioritized since they are already threatened with extinction.

- Percentage of Colony Affected
Corals should be treated if at least 50-75% of the coral colony is still alive since it will ensure that most of the coral colony will survive.

- Lesion Abundance
Treatment efforts are most efficient if corals with easily treated lesions (i.e. a small number of lesions or small lesion sizes) are prioritized.

- Iconic Corals
Treatment should be prioritized if the coral is important for historical, educational, or economic reasons.

Guidelines for treatment are available (Neely, 2018a). Concerns exist about possible unintended consequences of releasing amoxicillin in the marine environment, and the MPAConnect factsheet on antibiotics and SCTLD provides more details to guide permitting agencies regarding these concerns. Research to develop other treatments is ongoing.

Figure 22. Applying the Base2B/amoxicillin mixture to an affected coral. Photo Credit: Emma Doyle.

Coral rescue/restoration

Coral restoration efforts in the Caribbean have advanced significantly including an increase in population enhancement projects, new micro-fragmentation and larval propagation techniques, and an expanding number of outplanted coral species (e.g. Forsman et al., 2015; Bayraktarov et al., 2020). However, with the SCTLD outbreak in the Caribbean and the longevity of the disease in endemic areas, coral restoration practitioners need to consider the implications of SCTLD for restoration projects. Priority species for restoration, during the outbreak, should be those species that are not susceptible to the disease, such as acroporids. Once the disease has abated, then additional species can be outplanted.

In the context of SCTLD, a change in restoration objectives can be noted with a move away from coral restoration based on fragments of opportunity towards the purposeful growing of more resistant genotypes. Previously, the objective was to grow coral in order to increase live coral cover. In the face of the new

and devastating threat posed by SCTLD, a new objective is to maintain or increase genetic diversity of the affected stony corals. Bio-banking of corals is being employed in Florida to save genetic material. This is being referred to as 'coral rescue' and involves collecting colonies of susceptible species from the reef in advance of the disease margin (identified through monitoring efforts), and keeping them in land-based facilities to prevent them from becoming infected, to preserve their genetic diversity, and to have them serve as propagation source stock for future restoration activities (FCRT, 2018) with the idea of returning them to the marine environment once the disease has passed.

The feasibility of bio-banking in the Caribbean is limited by the lack of suitable in-country storage facilities in which to house corals, the costs to establish, operate, and maintain such facilities, and by the survival rates for corals kept in such facilities. New coral rescue and restoration efforts, with the potential to scale-up, are developing and proving effective with a small number of species to date. Partnerships with aquaria, research institutions, and relevant experts, mentorship from any low-tech/low-cost coral rescue programs being implemented in the region, and new funding sources are needed to enable the uptake of coral rescue initiatives in the Caribbean.

Research

The NOAA Strategy for Stony Coral Tissue Loss Disease Response and Prevention (Skrivanek & Wusinich-Mendez, 2020) identifies goals for research related to SCTLD including work to refine the case definition as new information becomes available on SCTLD characteristics. Skrivanek & Wusinich-Mendez (2020) also recommends ongoing sharing with regional networks and initiatives which allow Caribbean managers to keep abreast of the latest directions and findings in SCTLD research especially since only a small number of local Caribbean research institutions [e.g. University of the Virgin Islands in St. Thomas, the Universidad Nacional Autónoma de México (UNAM, Puerto Morelos), Ross University in St. Kitts] are involved in SCTLD research. Research initiatives include work on the identification of the pathogen(s) causing SCTLD, effective treatment methods, and causes of transmission. Since much is known about the efficacy of different treatment methods, marine natural resource managers are able to forego experimentation with ineffective treatments. This will reduce the amount of time, manpower, and funding wasted while prioritizing monitoring and treatment efforts.

Capacity Building

When SCTLD was first reported in the Caribbean, one of the highest priorities was the establishment of communication pathways to facilitate information sharing amongst managers on SCTLD detection, spread, impacts, monitoring, disease prevention, and potential treatment/response methods. Since 2018, there have been numerous efforts to increase the sharing of SCTLD knowledge and lessons learned between the wider Caribbean and the Florida/USVI groups including learning exchanges, technical sessions at conferences, webinars, online training sessions, and the sharing of educational materials. To date, SCTLD capacity building efforts have been very well-received by participants and have served to improve technical and management capacity throughout the region.

There is a need for ongoing capacity building in the Caribbean for the management of SCTLD. As an emerging issue, there is a need to continually share new advances in science, the latest research findings, and the evolution of best management practices. SCTLD experts and mentors have proven willing to share their experiences with others facing the disease. Funding for face-to-face learning exchanges can be productively applied for theoretical and practical sharing among networks of coral reef managers.

Case Study

Coral rescue in Florida

In response to the considerable loss of corals due to SCTLD, Florida developed a large-scale coral rescue plan to collect and gene-bank high priority healthy corals ahead of the SCTLD disease boundary and maintain these corals in land-based aquaria. The purpose is to prevent rescued corals from becoming affected by SCTLD, preserve their genetic diversity, and propagate them for future restoration efforts. Priority species included 15 high priority species and four medium priority species (FCRT, 2021). Since 2018, 1,989 corals have been rescued from 70 reef sites along Florida's Coral Reef and are being held in 18 facilities throughout the United States. Of the 19 different coral species that have been rescued, the largest numbers collected are Maze coral (*Meandrina meandrites*), Symmetrical brain coral (*Pseudodiploria strigosa*), and the Elliptical star coral (*Dichocoenia stokesii*). To date, 907 of these corals have been genotyped. Boulder brain corals (*Colpophyllia natans*) that were spawned and reared from coral "rescue" parents were recently outplanted and returned to Florida's Reef. Florida's future Coral Restoration Strategy will take SCTLD into consideration.

For more information on Florida's coral rescue initiatives please go to Florida's Coral Rescue – Coral Monitoring Dashboard (FCRT, 2021).

Case Study

Coral rescue, larval propagation, and cryopreservation in Mexico

There are numerous well-established coral restoration efforts in the Mexican Caribbean including coral nurseries, population enhancement, larval propagation, and, more recently, sperm cryopreservation. Cryopreservation of coral sperm is the process of preserving sperm cells through 'freezing' for later use. If properly stored, the sperm may remain viable indefinitely and could be used in future restoration efforts. Cryopreservation can help mitigate the loss of genetic and species diversity (Hagedorn et al., 2017; Daly et al., 2018) and is increasingly important given the significant loss of corals due to SCTLD. The storage of genetic material also provides an opportunity to investigate new restoration efforts such as assisted gene flow, selective breeding, and hybridization (Van Oppen et al., 2015).

A new collaborative pilot project in Mexico is working to rescue and cryopreserve gametes from SCTLD susceptible corals. The collaborators include Laboratorio de Investigación Integral para la Conservación de Arrecifes (CORALIUM)/Unidad Académica de Sistemas Arrecifales (ICML-UNAM), the Regional Center for Fisheries Aquaculture Research of the Mexican National Fisheries Institute (INAPESCA), and the Healthy Reefs for Healthy People Initiative. Colonies of Symmetrical brain coral, Mountainous star coral (*Orbicella faveolata*), Lobed star coral (*O. annularis*), and Grooved brain coral (*D. labyrinthiformis*) were collected and housed in small land-based aquaria. Sperm from all four coral species were cryopreserved. In addition, coral gametes were collected during coral spawning events.

This combination of coral rescue, larval propagation, and cryopreservation provides a unique and promising approach to respond to SCTLD. In addition, existing restoration and larval propagation training courses are already established which provides hope to replicate this approach and scale-up similar efforts in other parts of the Caribbean.

For more information on coral rescue, please see the webinar on coral rescue held by the Healthy Reefs for Healthy People Initiative.

Case Study

Combined coral rescue and restoration in Belize

In Belize, a new combined rescue and restoration pilot project by Fragments of Hope, the Belize Fisheries Department, and Hol Chan Marine Reserve aims to help SCTLD corals and proactively restore SCTLD affected reefs. SCTLD was first observed in Belize's northern barrier reef near Bacalar Chico in June 2019 and has since spread. In-situ coral tables were set up to house fragments of rescued Pillar corals (*Dendrogyra cylindrus*). In Bacalar Chico Marine Reserve, 37 Pillar coral fragments were collected from two parent colonies. Because of the widespread extent of SCTLD in the area, no healthy Pillar coral parent colonies were available, thus, healthy fragments were taken from SCTLD-affected parent colonies. Only one fragment showed signs of SCTLD four months after collection, and it was removed from the table and treated. In Hol Chan Marine Reserve, 76 fragments were collected from four Pillar coral parent colonies (two SCTLD affected colonies, two healthy colonies). Any fragments showing signs of SCTLD were immediately removed. Some of the lessons learned included:

Do not collect fragments from reefs showing signs of SCTLD.

Fragments should only be collected from healthy parent colonies, not SCTLD affected parent colonies.

Fragments located in in-situ rescue nurseries should be monitored frequently (e.g. every two weeks) to check for possible disease infection.

Recommended Next Steps to Respond to Stony Coral Tissue Loss Disease

SCTLD could have devastating impacts on economies and coral reef ecosystems throughout the WCR. Therefore, it is imperative that the countries/territories throughout the region implement initiatives designed to minimize its spread, manage affected coral reefs, and preserve the genetic diversity of affected stony coral species. This requires action at the regional, national, local, stakeholder, and international levels. This section offers suggested next steps that actors at the regional, national, local, stakeholder, and international levels can take to reduce the impacts of SCTLD.

Regional Recommendations

Regional collaborations are necessary to ensure that countries/territories work together to reduce and respond to the threat that SCTLD poses to the WCR. Recommendations include:

- **Prioritize the discussion of SCTLD initiatives at regional meetings**

  The degree of SCTLD interventions vary between countries/territories. However, given how quickly SCTLD is spreading throughout the Caribbean, there needs to be a consensus amongst countries/territories about how it should be addressed. Therefore, SCTLD should be added to the agendas of regional meetings of organizations such as the Caribbean Community (CARICOM), the Organisation of Eastern Caribbean States (OECS), the International Maritime Organization, and the Cartagena Convention (e.g. RAC-REMPEITC-Caribe) in order to develop regional initiatives to combat the problem.

- **Encourage countries of the WCR to endorse and participate in the SCTLD Caribbean Cooperation Team**

  The Caribbean Cooperation Team, which is coordinated by NOAA's Coral Reef Conservation Program and AGRRA, maintains communications with regional networks and initiatives, tracks the spread of SCTLD, shares SCTLD reporting mechanisms, lessons learned from ongoing response efforts, key informational materials, and helps to identify resources to support capacity building, monitoring, and response in the Caribbean region. Countries of the WCR are, therefore, encouraged to participate in the Caribbean Cooperation Team meetings to exchange up-to-date and relevant information on the latest research initiatives, treatment efforts, and resource opportunities that can help guide and inform their management response to the threat of SCTLD.

- **Develop, support, and enforce the implementation of preventative regional ballast water guidelines to reduce the potential for disease transmission**

  While countries/territories in the WCR have implemented their own ballast water guidelines in an effort to reduce the introduction of SCTLD into their waters (e.g. USCG, 2019), further support and enforcement at the regional level would enhance these efforts. Strong and meaningful collaboration between the countries/territories of the WCR and the International Maritime Organization is needed to develop, approve, and enforce guidelines to reduce potential contamination from ballast water, sediment, and biofilm release from commercial shipping activities.

- **Facilitate a coordinated and structured approach to regional capacity building**

  There are a number of organizations/programs (e.g. AGRRA, MPAConnect, Smithsonian Institution's Healthy Reefs for Healthy Peoples Initiative, MARFund) that are already working within the region to increase awareness about SCTLD and its impacts on the Caribbean and to build capacity to monitor and respond to SCTLD. A coordinated and structured approach to training coral reef managers in SCTLD best management practices is needed to maximize the sharing of knowledge from experts and mentors to those responding to SCTLD. Supporting capacity-building needs will allow for proactive response planning and preparedness. Regional organizations, their allies, and donors should partner in the implementation of training programs. Providing support for these initiatives will increase management capacity within the region, translate to more effective response to SCTLD, and enhance the conservation of Caribbean coral reefs.

  The Secretariat of the Cartagena Convention could facilitate multi-lingual capacity building through the simultaneous translation of online SCTLD webinars and the translation of existing and new resource materials on SCTLD in order to ensure accessibility throughout the region.

- **Identify and contribute funds to regional SCTLD initiatives on the ground**

  Funding is needed to facilitate capacity building and sharing by experts and mentors, research, development, and site-level implementation of ongoing monitoring, treatment and intervention efforts, and for outreach activities and materials to support the implementation of guidelines to prevent the spread of SCTLD.

- **Encourage partnerships for coral rescue and coral restoration**

  There are only a few facilities within the WCR capable of housing coral fragments. Given how critical coral restoration projects will be to the rehabilitation of coral reef ecosystems, countries/territories throughout the region should work together to share low-cost/low-tech solutions and support the establishment, operation, and maintenance of coral rescue projects so that coral diversity within the region can be restored.

- **Facilitate information sharing about research initiatives and intervention approaches**

  Regional academic institutions should be encouraged to assist with monitoring, treatment, and pathogen(s) identification research. This could include collaborating with overseas academic/research institutions or developing their own research agendas. Encouraging the sharing of research findings between countries/territories, efficacy of intervention approaches, and lessons learned on low-cost/low-tech coral rescue approaches will help build capacity throughout the region and strengthen the region's ability to combat the disease.

National and Local Recommendations

Within countries/territories, there are a number of national and local actions that can be supported by marine natural resource managers and their partners, allies, and donors. Recommendations include:

- **Prioritize preventative measures**

  Enforce ballast regulations, promote best practices for the treatment of ballast water, and promote dive gear decontamination protocols (FKNMS, 2019) that have been developed to prevent the spread of SCTLD. In areas where SCTLD has yet to be observed, coordinate with the shipping and recreational diving communities to prevent the introduction of related pathogens via ballast water, biofilms, wastewater, and contaminated dive gear. Areas with cases of SCTLD should ensure that any ballast water collected within their territorial waters is treated before release.

- **Adopt unified messaging**

  Agencies involved in the management of SCTLD are advised to adopt unified messaging about SCTLD in their communications and to ensure unified sharing of clear and credible information about the disease.

- **Develop national and/or local SCTLD monitoring and response action plans**

  In order to tackle SCTLD, it is imperative that relevant government agencies, non-government organizations, academic institutions, the private sector, and local stakeholders work together to develop monitoring and response plans to address specific needs identified at different reef sites. In the case of limited resources and capacity for monitoring, efforts should be focused on priority areas including locations where there are significant populations of highly susceptible species and reefs that are adjacent to, or downstream from, areas of shipping activity such as ports or anchorage areas. Collaboration amongst all actors is essential for an effective response to SCTLD, and proactive action planning serves to bring together the capabilities, strengths, and resources of multiple actors for targeted action. There are existing action plans and a SCTLD monitoring response action plan template to help with this step.

- **Facilitate the speedy implementation of best practice treatment interventions**

  Currently, the only effective treatment method for SCTLD is the topical application of the amoxicillin:Base2B mixture in a 1:8 ratio. This requires the importation of Base2B and, in some cases, the importation of amoxicillin, both of which may require permits and customs duty. Given how quickly the disease spreads on individual corals, as well as across affected reef sites, it is recommended that government agencies help facilitate the importation of these materials to ensure that affected corals are treated as soon as possible. To guide permitting processes and enable the timely application of best practice treatment protocols, refer to existing studies of treatment efficacy and factsheets about antibiotics and SCTLD.

- **Coordinate with regional organizations to avoid duplication of unsuccessful treatment trials**

  Given the limited capacity and available resources within the region, it is recommended that information on the testing of alternative treatment methods be shared. This will avoid the duplication of treatment experiments that have already proven to be unsuccessful.

- **Develop citizen scientist programs to support SCTLD response**

  In a number of countries/territories (e.g. the Turks and Caicos Islands, Honduras, the Grenadines), citizen scientists have been instrumental in monitoring and treating SCTLD. Given that monitoring and treatment initiatives are time- and labor-intensive, citizen science programs can help provide the volunteers needed to address the problem. Training for both local and international volunteers in

the identification of coral species, underwater photography, and treatment application methods and dedicated staff and funding for local oversight of these programs are needed. These programs could also include collaborations with international dive organizations such as the Professional Association of Diving Instructors (PADI) and the British Sub-Aqua Club (BSAC).

- **Implement local education programs**

  Education programs are critical to increase stakeholder awareness of SCTLD, reduce the spread of the disease, and underpin enhanced compliance with existing regulations that seek to ensure coral reef resilience. Knowledge of SCTLD will enable regular users of the marine environment to act as stewards and identify changes to the reef, decontaminate their dive and fishing gear to reduce the likelihood of disease spread, and lend local support to existing regulations.

Stakeholder Recommendations

Marine natural resource users (e.g. fishers, divers, dive operators, sailors, cruisers, boat captains) can help reduce the spread of the disease by participating in citizen science programs. Recommendations include:

- **Stakeholders** are encouraged to participate in national or local SCTLD response planning efforts.

- **Marine natural resource managers** should seek to engage with stakeholders and their representative bodies such as fisher cooperatives, fisher associations, dive associations, and sailing bodies.

  At the individual stakeholder level, it is recommended that:

- **Fishers**

  - Fish on unaffected reefs first before fishing on infected sites.
  Fishing on reefs unaffected by SCTLD will reduce the likelihood of transmitting the disease to new sites.

  - Dry fishing gear in the sun.
  Drying gear in the sun will kill any pathogens that might be present.

Divers

- Rent gear locally.
Renting gear locally, instead of carrying gear to different sites, may help minimize the spread of the disease since the disease will not be unknowingly transported through infected gear.

- Decontaminate gear after every dive by:

1. Soaking non-sensitive equipment for 10 minutes in a 1% bleach solution before rinsing and air drying.
2. Rinsing regulators, computers, gauges, and underwater cameras in fresh water and anti-bacterial dish soap. This will help kill any pathogens that may be on the gear.

- Never touch reefs
SCTLD may be spread through direct contact so the pathogen(s) may be unintentionally transported from an infected coral to an uninfected coral.

- Dive at uninfected reef sites before diving at infected sites.
Diving on reefs unaffected by the disease first will reduce the likelihood of transmitting the disease from one site to the next.

International Recommendations

There is a risk of international spread of SCTLD to reefs outside the Wider Caribbean Region. Accordingly, management action at an international level, between regional seas, is recommended. Recommendations include:

- **Develop, implement, and enforce strict ballast water exchange restrictions to reduce the reduce the risk of SCTLD transmission to regional seas**

  Since the pathogen(s) causing SCTLD is water-borne and can also be transmitted through direct contact (Aeby et al., 2019; Paul et al., 2019), it is theorized that the disease may be spread through the release of ballast water (e.g. Baigent, 2020), sediment, or biofilm from commercial shipping activities. Ballast water uptake within the WCR, if released in other areas, could potentially transmit the pathogen(s) outside of the region. For example, one purpose of the NOAA Strategy for Stony Coral Tissue Loss Disease Response and Prevention (Skrivanek & Wusinich-Mendez, 2020) is to prevent and prepare for the potential spread of SCTLD to the Indo-Pacific Region. Engaging with inter-governmental institutions such as the International Maritime Organization to develop, approve, and enforce regulations under the International Convention for the Control and Management of Ships' Ballast Water and Sediments that are designed to reduce the transmission of pathogens throughout and within ocean basins could reduce the likelihood of the disease's transmission.

- **Collaborate with international research institutions**

  While research on the identification, spread, and treatment of SCTLD is ongoing, additional collaborations could be helpful. For example, ongoing collaborations between Oceans Alchemists and organizations within the WCR have helped determine the efficacy of new treatments for SCTLD. The involvement of international academic and research institutions may help further the research projects currently underway.

- **Develop education and awareness programs with international dive organizations**

  It is possible that divers may unknowingly transmit SCTLD to uninfected sites when diving. Collaborating with international dive organizations such as PADI and BSAC to develop education and outreach programs could increase awareness about the disease and the measures that need to be taken to reduce its transmission. Initiatives could also be developed that would train divers on how to monitor and treat SCTLD and allow them to volunteer with citizen science initiatives when travelling to the region.

Resources

There are many informational and training resources available to natural resource managers to help them understand, increase awareness, and guide action in responding to SCTLD. This includes materials on how to monitor for and correctly identify SCTLD, communicate about the disease, plan a coordinated response to SCTLD, and develop best practices for treating corals affected by SCTLD.

The approach to SCTLD response in Florida is potentially instructive for other countries and territories in the Caribbean. Many government agencies and non-governmental organizations are collaborating in the response to SCTLD in Florida and the WCR. In Florida, the lead agencies are the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, the National Oceanic and Atmospheric Administration, and the National Park Service. Additional support has been provided by the U.S. Environmental Protection Agency, the Smithsonian Institution, the U.S. Geological Survey's National Wildlife Health Center, academic and research institutions, as well as non-government and non-profit organizations and aquaria.

As part of Florida's disease response, the SCTLD Caribbean Cooperation Team was formed to share technical knowledge, informational materials, and lessons learned with the Caribbean. To date, the SCTLD Caribbean Cooperation Team, which is coordinated by NOAA's Coral Reef Conservation Program and AGRRA, includes representatives from GCFI's MPAConnect, Nova Southeastern University, the Smithsonian Institution's Healthy Reefs for Healthy People Initiative, The Nature Conservancy's Reef Resilience Network, the Florida Keys National Marine Sanctuary, Florida Fish and Wildlife Conservation Commission, Florida Sea Grant, the National Park Service, and the United Kingdom's Joint Nature Conservation Commission (Wusinich-Mendez et al, 2019).

Additionally, TCRF and RMP have been instrumental in peer-to-peer sharing about SCTLD through activities within the MPAConnect network. Available materials include reporting and monitoring documents, factsheets, videos, posters, webinar recordings, and workshop reports.

Documents

- ### NOAA Strategy for Stony Coral Tissue Loss Disease Response and Prevention

  This document describes NOAA's strategy to combat SCTLD and prevent its spread throughout the WCR and the Indo-Pacific region. It details NOAA's objectives, in regard to SCTLD, as well as the projects currently being implemented under NOAA's auspices (Skrivanek & Wusinich Mendez, 2020).

- ### Template Monitoring and Response Action Plan

  This document outlines the intervention measures available to natural resource managers to monitor, treat and prevent the spread of SCTLD, and provides a template that can be used by resource practitioners to develop site-specific monitoring and response action plans (Doyle & O'Sullivan, 2020a). The report is available in English, French, and Spanish on GCFI's SCTLD webpage.

- ### Reporting Template for Stony Coral Tissue Loss Disease

  To promote consistency across monitoring reports, MPAConnect has developed a reporting template that may be used by natural resource practitioners when reporting on SCTLD monitoring and outreach efforts (Doyle & O'Sullivan, 2020b).

- ### Data Sheets

  AGRRA has designed two data sheets that can be used to collect survey information on SCTLD. One data sheet has been simplified for use by beginners while the second data sheet may be used by scientists. The data sheets may be accessed by contacting AGRRA at info@agrra.org.

- ### Identification guides

  The Florida Keys National Marine Sanctuary, in collaboration with NOAA, the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, and the U.S. National Parks Service has created a set of guides showing healthy and infected corals in order to allow stakeholders to recognize possible infection (Bruckner, 2019). These guides may be printed and laminated for use in the field.

  Nova Southeastern University has created a PowerPoint presentation that shows what SCTLD looks like on susceptible species. This will help stakeholders accurately identify SCTLD on their reefs (Neely, 2019).

- ### Factsheets

  MPAConnect, in collaboration with NOAA, Nova Southeastern University, AGRRA, and the Florida Keys National Marine Sanctuary, has developed a series of factsheets with answers to Frequently Asked Questions (FAQs) about SCTLD. The FAQs include information on monitoring, funding, communications, available resources, and treatment methods, including the use of antibiotics.

SCTLD Dashboard

AGRRA, in collaboration with MPAConnect, designed a SCTLD Dashboard for the WCR in both English and Spanish. The Dashboard provides summary information on the status of the SCTLD outbreak in the Caribbean and the regional efforts being implemented to respond to the disease. The Dashboard includes information on the countries/territories affected by SCTLD, SCTLD outreach and treatment response (Roth et al., 2021) (Figure 23).

Figure 22. The Caribbean SCTLD Dashboard (Roth et al., 2021).

Figure 24. Poster providing divers with information on how to identify SCTLD and where to report its presence.

Posters

- **Detection**

  This poster was designed to help natural resource managers correctly identify SCTLD. Copies of the poster may be found in English, French, and Spanish.

- **Diver Awareness**

  This poster was designed to promote awareness amongst recreational SCUBA divers so they can recognize SCTLD. Since divers might visit sites more regularly than researchers, they may be the first to identify SCTLD on reefs. This poster provides them with the information needed to report any signs of SCTLD (Figure 24). Copies of the poster may be found in English, French, and Spanish.

- **Reducing SCTLD Transmission**

  Since SCTLD can be transmitted through contact, this poster provides divers with information on what they can do to reduce disease transmission. Copies of the poster may be found in English, French, and Spanish.

  In addition, RMP has created a set of infographics to guide users on how to mix the Base2B – amoxicillin mixture, pack the mixture into syringes, and apply the treatment to affected reefs (Figure 25).

In addition, RMP has created a set of infographics to guide users on how to mix the Base2B – amoxicillin mixture, pack the mixture into syringes, and apply the treatment to affected reefs (Figure 25).

Figure 25. Part of RMP's infographic on mixing the treatment for SCTLD.

Videos

A number of videos have been, or are being, developed by MPAConnect, TCRF, and RMP to inform stakeholders about issues surrounding SCTLD. Videos created by MPAConnect, in collaboration with TCRF, provide practical information on how to identify, treat, and mitigate against SCTLD. Topics addressed include:

- **How to monitor for SCTLD**

How to mix the treatment for SCTLD

How to prepare the treatment for application

How to treat corals affected by SCTLD (GCFI, 2021a)

How to document SCTLD (GCFI, 2021b)

How divers can help to prevent SCTLD (GCFI, 2021c)

How fishers can help to prevent SCTLD (GCFI, 2021d)

Links to the videos are posted to GCFI's webpage on SCTLD.

RMP has created an educational video for stakeholders on how to identify SCTLD, treatment measures, and how to report the disease in Roatán. The video is in English with Spanish subtitles (RMP, 2020).

Webinars

Several organizations such as GCFI, The Nature Conservancy's Reef Resilience Network, and the Perry Institute for Marine Science have hosted webinars on SCTLD. Topics include monitoring, identification, treatment, and lessons learned. AGRRA acts as a repository for recorded webinars and the videos may be found on their website.

Florida Sea Grant has created an observer training program to teach volunteers how to identify the corals susceptible to SCTLD, distinguish SCTLD from other diseases, collect data, and decontaminate gear (Krueger, 2019). TCRF has also created a set of training webinars (Zimmermann, 2020a – d) designed to teach volunteers how to identify, monitor, and treat SCTLD. Those webinars have been uploaded to YouTube:

Introduction (Zimmermann, 2020a)

Identification of susceptible species (Zimmermann, 2020b)

How to differentiate SCTLD from other coral diseases (Zimmermann, 2020c)

In- water monitoring protocol (Zimmermann, 2020d)

Funding Opportunities

There are a number of organizations that might be able to provide funding. These include GCFI, which has a small grants program, the PADI Foundation, and MARFund. Some organizations have also been able to access funds through local embassies and government institutions. Dive shops may also be able to provide in-kind support by donating boat time and tank refills.

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MPA connect

A partnership between:

GCFI

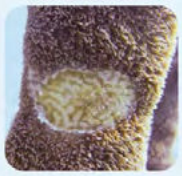
NOAA CORAL REEF

MPAConnect guide to detect

Stony Coral Tissue Loss Disease on Caribbean coral reefs

Total loss of affected tissue

Bare skeleton with no tissue



Sloughing away of tissue

Be Alert!

A new coral disease is causing high mortality of stony corals

Cause is unknown but it is water-borne and may spread via direct contact

Take care not to confuse with other coral diseases, bleaching or fish bites

Correct field diagnosis depends on multiple factors

Highly susceptible species

1

Meandrina meandrites

Eusmilia fastigiata

Dendrogyra cylindrus

Dichocoenia stokesii

2

Pseudodiploria clivosa

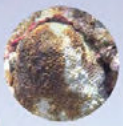
Diploria labyrinthiformis

Colpophyllia natans

Pseudodiploria strigosa

3

Orbicella species



Montastrea cavernosa

Siderastrea siderea

Typical order of infection

Rapid spread

Within one week to two months

High prevalence and mortality

Among susceptible species

~2-3% Normal background disease prevalence

66-100% Species-specific Stony Coral Tissue Loss Disease prevalence

On coral colonies
Multiple lesions

Rapid mortality

On dive sites
Rapid spread among corals

What can managers do?

1. Monitor highly susceptible species via roving diver surveys
2. Monitor sentinel sites weekly – old, large, healthy, spawning colonies
3. Monitor suspected cases every three days to weekly, take photos, note date and location
4. Inform your agency about new threat, seek contingency support, investigate supplies for treatment
5. Inform relevant stakeholders, encourage reporting
6. Prevent spread – wash dive gear in lots of fresh water and sun dry, disinfect survey tools, dive on clean sites before infected sites
7. Promote ballast water management, exchange ballast offshore and not on coral reefs
8. Seek training in protocols for treatment of priority corals

February 2019

Coral photography:
K. Neely, Nova Southeastern University.

Contact MPAConnect for advice and training mpaconnect@gcfi.org
For more information, see https://floridakeys.noaa.gov/coral-disease/ and https://www.gcfi.org/emerging-issues-florida-coral-disease-outbreak/

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Stony Coral Tissue Loss Disease