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NOAA Strategy for Stony Coral Tissue Loss Disease Response and Prevention

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A diver applies an antibiotic paste to a diseased colony of great star coral on Molasses Reef in Florida Keys National Marine Sanctuary. Credit: Karen Neely/Nova Southeastern University

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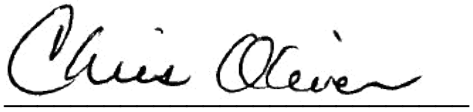

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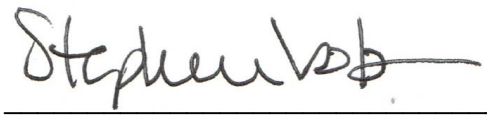

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Summary

From the Florida Keys to the islands of the Indo-Pacific, shallow-water coral reefs are essential to healthy, resilient coastal communities, ecosystems, and economies. Thriving reefs provide critical services, including fisheries, opportunities for tourism and recreation, and powerful shoreline protection from waves, storms, and currents, and are valued at $3.4 billion every year for the U.S. alone ([1-2]). Reefs protect lives, property, and businesses through these services, and provide habitats for 25 percent of all marine species ([3]).The impacts of coral reefs are therefore far-reaching - both inland and seaward. Currently, coral reefs are facing a multitude of global and local stressors such as increasing ocean temperatures, ocean acidification, unsustainable fishing, coastal development, extractive and recreational uses, pollution, nutrient input, storm water runoff, sedimentation, and invasive species. These stressors individually and cumulatively reduce the ability of coral reefs to resist and recover from disturbances, such as mass bleaching, outbreaks of disease, and storm events, which are projected to increase in a warming world ([4]).

Atlantic-Caribbean coral reef ecosystems are in the midst of an unprecedented outbreak of a newly described coral disease, Stony Coral Tissue Loss Disease (SCTLD). This particular disease is characterized by rapid spread, rapid tissue loss, and high mortality rates. While SCTLD was first reported on Florida's Coral Reef in 2014, reports of its spread to the wider Caribbean region began to occur in early 2018. As of August 2020, SCTLD has affected corals along the entirety of Florida's 360 mile-long reef system, with the exception of the Dry Tortugas region, and has been reported in thirteen Caribbean countries/territories, including the U.S. Virgin Islands and Puerto Rico.

There is still much to learn about SCTLD. Since 2016, NOAA, along with our response partner organizations, has been working to document the outbreak, identify potential pathogen(s), understand how environmental factors may be contributing to the outbreak/spread of the disease, develop innovative treatments to slow or halt the spread of the disease, and implement best practices to restore damaged habitats. State and Territorial governments are supporting local response efforts in each of the three affected U.S. jurisdictions. NOAA is supporting both regional and national level coordination to facilitate communication, identify information and resource gaps, and efficiently allocate federal resources to support an effective response to this current threat to U.S. coral reef resources. While we know that SCTLD can be transmitted via direct contact and seawater, we do not know how it is traveling across the broader Caribbean region as its appearance has not followed known oceanographic circulation patterns. NOAA is actively working with federal partners to research potential vectors for SCTLD transmission related to shipping activity, such as the release of ballast water.

As the SCTLD outbreak unfolds in the Caribbean region, questions regarding how it is transmitted and concerns regarding its potential spread to the Indo-Pacific region are rising. Coral reefs are found across the U.S. Pacific Island region, which consists of the Hawaiian Islands (State of Hawaii), the Marianas Islands (Territory of Guam and Commonwealth of the Northern Mariana Islands), the eastern portion of the Samoan Islands (Territory of American Samoa), several islands and atolls in the central Pacific collectively referred to as the Pacific Remote Island Areas, or PRIAs, including Wake Island, Johnston Atoll, Palmyra Atoll, Kingman Reef, Jarvis Island, Baker Island, and Howland Island, as well as partners, such as the Freely Associated States of the Republic of Palau, Federated States of Micronesia, and Marshall Islands. Indo-Pacific reefs are represented by an even greater diversity of stony coral species, including many of the same coral families and genera that are found in the Atlantic-Caribbean region; therefore, the threat potential to the Indo-Pacific is of grave concern.

In the Atlantic-Caribbean region, SCTLD is now well established, and coordinated research and response efforts are underway. Through NOAA, the Florida Department of Environmental Protection (Florida DEP), U.S. Environmental Protection Agency (EPA) and other funding sources, important progress has been made to characterize the coral microbiome in several species ([5-7]). Most recently, investigations are underway into the underlying immune status of susceptible and resistant individuals, and the role algal symbionts may play in disease susceptibility. However, fundamental research questions remain regarding the role of these microorganisms, how these change in response to SCTLD, and linkages between the occurrence, severity and impacts of SCTLD and environmental factors. Answers to these questions are needed in order to develop effective surveillance, prevention, control, and intervention strategies. The NOAA SCTLD Strategy prioritizes:

- Clearly defined research questions, aims and objectives and coordination among research teams, response teams and partners;
- Innovation through new partnerships to aid in the integration of emerging technologies to expand capacity for data collection, management, and analysis to effectively and efficiently meet research objectives. Technological integration in SCTLD response efforts will also be critical to implementing and scaling restoration approaches, improving ecosystem assessments and predictions, and monitoring reef health in response to environmental change.

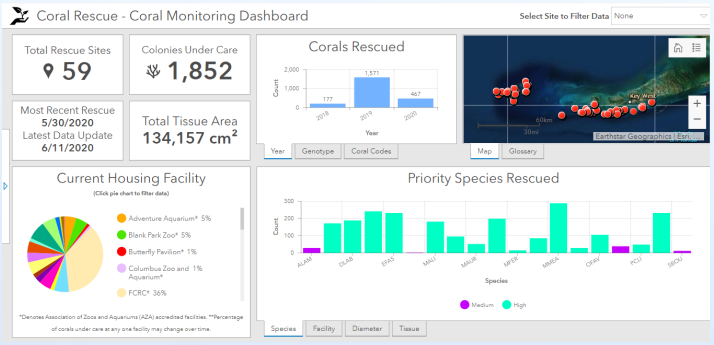
Background

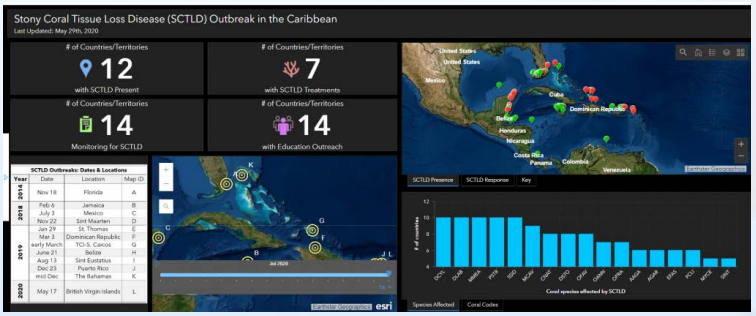
The SCTLD panzootic (wildlife epidemics are officially known as epizootics and panzootics) is unprecedented in scale, duration, and rate of associated coral mortality for susceptible coral species ([8]). Nearly half of the 45 known scleractinian (stony coral) species that comprise Florida's Coral Reef and at least one third of species documented throughout the Caribbean are susceptible to SCTLD, including some of the slowest-growing and longest-lived primary reef-building species of brain, star, and starlet coral, and threatened species such as pillar coral and cactus coral (9). Five of the susceptible species are listed as threatened under the Endangered Species Act (ESA). While the causative agent remains unknown, visible signs of the disease include lesions of rapid tissue loss that advance at rates ranging from ~5 - 40 cm2/day across an individual coral colony ([10]). The success of antibiotics in halting or slowing the spread in field and laboratory studies for some coral species suggests that a bacterium may be involved; however, it remains unclear whether or not the bacterium (or bacterial assemblage) is the primary agent, a secondary infection, or an opportunistic component of the coral microbiome.

Initially observed in 2014 in Miami, Florida, off of Virginia Key in close proximity to an ongoing Port of Miami dredging project, SCTLD has since spread across coral reef ecosystems in Florida and the Caribbean at a rate of ~ 7-10 km/month from 2015 - 2017, and 2.5 km/month since 2018, transmitting between coral colonies within a week to a month ([11]). While coral disease is a natural occurrence in reef environments, with a normal background disease rate of 2 - 3% of the corals on the reef, the occurrence of SCTLD may result in 66 - 100% prevalence, especially for highly susceptible species of elliptical star coral (Dichocoenia stokesii) and maze coral (Meandrina meandrites). According to the Florida Fish and Wildlife Commission (FWC), Florida's Upper Keys have seen greater than 40% loss in coral cover between 2013 and 2018 ([12]).

Over the past four years, NOAA, the Florida DEP, FWC, and the National Park Service (NPS) have been leading an unprecedented multisector response, including over 60 federal, state and local government agencies, private industry, academic and research institutions, conservation organizations, and concerned citizens ([13-14]). As SCTLD continues to spread along Florida's Coral Reef and throughout the greater Caribbean region, NOAA has participated in collaborative response efforts to monitor the progression of the outbreak, identify causative agents and vectors, develop treatments and intervention strategies, build capacity for effective response coordination, and conduct coral rescue missions to protect and preserve genetic diversity for reef restoration ([15]). NOAA leads or participates in:

- Co-leading organized SCTLD response efforts in Florida and the U.S. Virgin Islands working through coordinated teams in priority areas from research to intervention ([15]).
- Funding SCTLD response coordinators in Florida, the U.S. Virgin Islands. and Puerto Rico, who provide critical capacity for efficient and effective local response efforts.
- Executing the Florida Coral Rescue Plan via a multi-agency team ([15]) co-led by NOAA Fisheries and the State of Florida. The goals of the plan are to preserve genetic diversity and provide broodstock for future restoration efforts by collecting healthy coral ahead of the disease front and caring for them in land-based aquariums across the U.S. that are accredited by the Association of Zoos and Aquariums (AZA).([16-17])
- Pioneering direct application of antibiotic treatments to fragments of the ESA listed pillar coral (Dendrogyra cylindrus) at NOAA's National Centers for Coastal Ocean Science (NCCOS), and preserving some of the last remaining genotypes from Florida's Coral Reef ([13]). This species, already effectively reproductively extinct in the Florida Keys, is highly susceptible to SCTLD and wild populations have been devastated by the disease outbreak.





Advancing tools to monitor coral rescue, SCTLD presence, and response. NOAA Fisheries co-leads the Coral Rescue Team- *a multi-agency effort to rescue healthy coral ahead of the disease front and house them in land-based aquaria, in partnership with the AZA Florida Reef Tract Rescue Project, to preserve genetic diversity through gene-banking and propagate those corals to provide offspring for future restoration activities. Rescued coral are prioritized based on their susceptibility to the disease, gene-banked, and held for future propagation and introduction into the wild. As of 08/07/2020, 1,850 colonies are under care. Left: Coral rescue - Coral Monitoring Dashboard. Right: The Caribbean SCTLD Dashboard designed for Caribbean coral reef managers to monitor the status and spread of SCTLD, developed by the Atlantic and Gulf Rapid Reef Assessment (AGRRA), in collaboration with MPAConnect, the Gulf and Caribbean Fisheries Institute (GCFI) and NOAAs Coral Reef Conservation Program (CRCP).*

The Coral Rescue Team works to collect and maintain coral from Florida's coral reef in housing facilities on land. *Left: Assessing rescued coral. Credit: Jennifer Moore/NOAA. Right: Rescued coral underwater in a holding tank. Credit: FWC.*

- Fostering Coral Disease Research, surveillance, communication, and outreach by leading the Coral Disease and Health Consortium (CDHC), a working group of the U.S.Coral Reef Task Force with over 150 partners from federal agencies, non-profits, industry, and academia ([18-19]).
- Incorporating cutting-edge technologies and informatics of 'omics (a suite of advanced methods used to analyze material such as DNA, RNA, proteins, or metabolites) at NOAA's Atlantic Oceanic and Meteorological Laboratory (AOML) and NCCOS to study the complex interactions of biological molecules that govern SCTLD pathology, and resistance traits to disease or other stressors to inform coral disease etiology, intervention, diagnostic development, mitigation, and restoration ([20-21]).
- Partnering with the U.S. EPA, U.S. Coast Guard, and U.S. Naval Research Laboratory to examine potential links between ballast water discharge, the spread of SCTLD, and the efficacy of ballast treatment practices.
- Integrating the surveillance of SCTLD into the National Coral Reef Monitoring Program, implemented by the Southeast Fisheries Science Center in Florida.
- Working to permit SCTLD intervention, research, and restoration activities, and to integrate recommendations to reduce the spread and/or likelihood of SCTLD contamination in coastal construction projects via Florida's Regulatory Review Team, led by the NOAA Fisheries Southeast Regional Office, NOAA's Office of National Marine Sanctuaries, and FWC.
- Ensuring that restoration efforts in Florida Keys National Marine Sanctuary are coordinated with the Florida disease response effort so that current and future impacts of SCTLD on the ecosystem are considered ([15]).
- Develop community engagement through partnerships such as Force Blue, a nonprofit group empowering former military combat divers to use their specialized training to augment coral restoration activities, monitor SCTLD spread, and administer treatments to diseased coral ([22-23]).
- Collaborating with Florida Sea Grant to support a national SCTLD coordinator position that will work across U.S. coral reef jurisdictions to foster information exchange, coordination of effort, and capacity building.
- Co-leading the Caribbean Cooperation Team that works with regional-level organizations and initiatives, including The Nature Conservancy, the Reef Resilience Network, the Atlantic and Gulf Rapid Reef Assessment (AGRRA), the Gulf and Caribbean Fisheries Institute, and the Smithsonian's Healthy Reefs Initiative, to provide targeted training on SCTLD detection and response for affected Caribbean jurisdictions. This team has developed and shared best practices for diver gear decontamination, considered ballast water as a possible vector, developed and distributed identification cards for disease identification, provided instructional webinars, conducted surveillance methodology trainings, distributed reporting resources, and developed disease intervention action plans ([15, 24]).
- Supporting MPAConnect, a partnership between the Gulf and Caribbean Fisheries Institute (GCFI) and NOAA's Coral Reef Conservation Program, to build regional marine protected area (MPA) management capacity for SCTLD response and prevention by developing and sharing materials for managers to assist with SCTLD identification, action planning and communications, supporting network development, and small grants for projects designed during a regional peer-to-peer learning exchange ([25-27]).
- Participating on the Virgin Islands Coral Disease Advisory Committee (VI-CDAC) and Florida and supporting strike teams in addressing SCTLD in Florida and the U.S. Caribbean ([28]).
- Leading, funding, and implementing restoration projects throughout the Caribbean and the Pacific, including efforts to grow coral in both in situ and ex situ nurseries for future restoration activities ([29]).

The Florida Aquarium successfully enabled ex-situ coral reproduction *of ridged cactus coral (Mycetophyllia lamarckiana). The Florida Aquarium is one of many AZA-accredited facilities across the U.S. working to store and conserve coral that are native to Florida and the Caribbean and susceptible to SCTLD. These corals will be used as brood-stock for future restoration efforts (45). Credit: The Florida Aquarium.*

Vision

NOAA has recognized the significant impacts that the ongoing SCTLD panzootic event is having on U.S. coral reef resources and has called for the development of this strategy to apply NOAA expertise to this challenging problem in the Atlantic-Caribbean, and to prevent the spread of the disease to Indo-Pacific coral reefs. NOAA will continue to work collaboratively with coral reef states and territories across multisector response efforts in each of the affected U.S. coral jurisdictions, and to determine actions that fall within NOAA capabilities and support both the NOAA mission and goals outlined in the SCTLD Strategy. The strategy will guide an agency-wide response to SCTLD that provides a framework for NOAA engagement in regional response efforts as the disease spreads across reefs in Florida and the Caribbean and NOAA support for preventative action to limit the spread of the disease. NOAA will continue to work collaboratively across public and private sectors in affected areas, and provide support for agreed-upon priorities. By establishing SCTLD as a NOAA priority, leveraging existing NOAA strategies for emerging technologies, and applying them to priority response actions, this strategy will accelerate ongoing efforts in coral disease research, detection, prevention and intervention in response to the SCTLD outbreak. By investing in research, innovative partnerships, capacity-building, and the timely exchange of relevant data between regions, NOAA and partners will work to slow the continued spread of SCTLD across the Atlantic-Caribbean and make every effort to prevent and prepare for its potential spread into the Indo-Pacific region in support of resilient coastal ecosystems, communities and economies.

Purpose

The NOAA SCTLD Strategy aims to

- Expand our capacity to respond to the disease outbreak in the Atlantic-Caribbean region;
- Support timely, efficient, and effective action to slow the outbreak by unifying regional efforts under a NOAA response framework that is national in scope; and
- Prevent and prepare for the potential spread of SCTLD to the Indo-Pacific region.

As ongoing coral research, restoration, and rescue operations in Florida and the Caribbean provide new insights into potential management actions and treatments, this Strategy will highlight areas in need of investment, and support timely, efficient, and effective action to slow the panzootic by unifying regional efforts under a NOAA response framework that is national in scope.

Strategy Goals

1. Expand capacity for research and data collection on SCTLD

a. Refine the case definition as new information becomes available on morphological and physiological characteristics that are unique to SCTLD and can be used to specifically differentiate the disease from others

b. Identify data gaps and sampling needs. For example, evaluate mechanisms of resistance in endemic-zone corals resistant to or surviving SCTLD; define steps in the disease progression; compare SCTLD with other similar coral diseases (i.e. white plague) to understand if it is variant or novel from other regions/islands/jurisdictions; conduct simultaneous functional analyses of subsampled tissues to characterize healthy and diseased coral microbiome, understand factors in disease resistance, and assess effectiveness of antibiotic/probiotic treatments and their effects on the surrounding marine environment

c. Explore alternative treatment options, such as probiotics and other colony and reef-level treatments

d. Promote partnership collaborations in trans-disciplinary projects addressing the role of environmental factors in disease development, persistence, transmission, and/or spread

e. Promote multi-sector projects and partnerships to study potential vectors, such as ballast water, biofilms, and waste water with regard to transmission over small and great distances

f. Foster international partnerships to expand research goals to include: 1) additional sampling locations to explore regional differences or disease evolution in occurrence, spread, and treatment effectiveness, 2) reef-building coral species that are now scarce on the Florida reef tract, and 3) mesophotic reef ecosystems and unaffected reefs

g. Expand applications of 'omics, artificial intelligence (AI), and uncrewed systems for surveillance (e.g., water quality, coral health across reef zones, including mesophotic reefs) and/or research (e.g., understanding coral resilience, SCTLD etiology/pathology)

h. Conduct laboratory transmission experiments with Pacific corals to identify susceptibility of Pacific coral species to SCTLD, and incorporate results into restoration plans

i. Build the capacity of the Coral Disease and Health Consortium (CDHC) to enable effective NOAA leadership of and engagement in coral disease response efforts

2. Build capacity for coral disease detection, prevention and intervention

a. Coordinate exchange of information, personnel, and best practices between Atlantic and Indo-Pacific MPAs and other local jurisdictions

b. Support workshops and training sessions to increase capacity for communication, detection of and monitoring for SCTLD

c. Support the development and/or updating of jurisdiction-specific response plans

d. Promote dive gear decontamination protocols as a preventative measure for disease spread
e. Institute surveillance protocols to provide early warning and track disease progression
f. Scale NOAA capacity to respond to and treat affected coral in U.S. coral jurisdictions
g. Support citizen science-based reporting systems to increase spatial awareness of SCTLD

3. Support coral rescue, propagation and restoration operations, research and partnerships across the U.S. to preserve the genetic diversity of corals necessary for future restoration efforts and support reef health

a. Work with partners to identify resources, personnel, and long-term storage infrastructure needed to rescue and house corals and propagated coral offspring
b. Invest in sexual propagation efforts in collaboration with research partners and coral nursery practitioners to create more genetically diverse offspring to be used for restoration
c. Develop best management practices for restoration in endemic zones, particularly related to SCTLD-susceptible species
d. Work with partners to ensure that SCTLD is considered in coral restoration efforts
e. Establish a U.S. Caribbean coral rescue effort

4. Promote awareness of SCTLD science, status, and indicators

a. Partner with regional networks, initiatives, reef managers, and community leaders to develop and distribute resources to increase awareness and understanding of SCTLD
b. Work with other federal agencies on the U.S.Coral Reef Task Force to ensure SCTLD awareness and to facilitate its consideration in federal decision-making

5. Collaborate with the coral reef management community to reduce stressors to coral reefs and build ecosystem resilience

a. Explore multi-sector partnerships to reduce the impact of systemic threats and improve water quality, promote sustainable fisheries, and increase resilience to climate change
b. Promote sustainable tourism and recreation in U.S. coral jurisdictions
c. Improve coral reef habitat quality and restore ecosystem function

6. Use the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act and Section 7 Endangered Species Act consultations to ensure SCTLD is evaluated as part of the baseline environmental conditions, in addition to environmental consequences and cumulative impacts that may result from federal actions

a. When available and where appropriate, use and share data generated from environmental commitments in consultations to better understand the linkages between human-induced environmental changes and SCTLD prevalence
b. Ensure that mitigation activities that result from consultations reflect SCTLD intervention and restoration best practices

7. Strengthen and expand international partnerships for SCTLD surveillance and sharing of data, best practices, and resources

a. Prepare unaffected jurisdictions for surveillance and intervention response
b. Increase capacity for and coordination of surveillance, data collection, rescue, communications, and response planning
c. Coordinate standardization of data collection and data management
d. Foster efficient communication of research findings

8. Work with relevant partners to prevent the spread of SCTLD to the four U.S. coral reef jurisdictions and Freely Associated States in the Indo-Pacific region

a. Continue to promote best management practices for ballast water treatment with the maritime industry domestically and internationally, and continue support for research on the connection between ballast water treatment, the presence of biofilms located on a ship's hull, waste water or other ship-related discharges
b. Work with the EPA, U.S. Coast Guard and jurisdictional environmental enforcement authorities to promote active enforcement of existing regulations as they pertain to ballast water discharge ([30]) under the Vessel Incident Discharge Act

The National Marine Sanctuary of American Samoa (NMSAS) *designed and implemented dive-gear decontamination protocol using resources developed in the Caribbean to prevent the spread of coral diseases. Photo: Diver in the NMSAS, Fagatele Bay. Credit: Kip Evans*

Are Indo-Pacific corals susceptible to SCTLD?
Nearly half of the known stony coral species of Florida's Coral Reef and at least one third of species documented throughout the Caribbean are susceptible to SCTLD. While coral assemblages differ between Atlantic and Pacifc reefs, some Pacifc coral species bear genetic similarities to those that are highly susceptible to SCTLD in Florida and the Caribbean, warranting study of possibility for transmission and precautionary monitoring. Coral with SCTLD (Caribbean/Florida). (Credit: Lisa Morse, Ben Edmonds/NOAA).

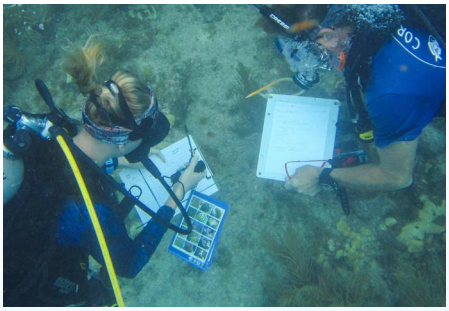
NOAA's SCTLD Strategy aligns with:

- NOAA's Coral Reef Conservation Program Strategic Plan (2018)([31])
- NOAA's Coral Disease and Health Consortium response framework for investigating coral disease outbreaks (2008)([32])
- NOAA's Proposed Action Plan on Coral Interventions (2019)([33])
- National Academies of Sciences, Engineering and Medicine's 'A Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs' (2019)([34])
- Gulf and Caribbean Fisheries Institute Stony Coral Tissue Loss Disease Template Monitoring and Response Action Plan for Caribbean Marine Natural Resource Managers (2019)([35])
- Florida Department of Environmental Protection Coral Disease Intervention Action Plan (2018)([36])
- U.S. Virgin Islands SCTLD Response Plan (2020) ([37])
- Puerto Rico Department of Natural and Environmental Resources (DNER) Draft SCTLD Response Plan (2020)
- U.S. DOD, Department of the Navy, Regional Biosecurity Plan (RBP) for Micronesia and Hawaii (Vol. III) (2014), titled 'Marine Invasive Species Risk Assessment for the Commonwealth of the Northern Mariana Islands, Guam, Hawaii, Palau, the Federated States of Micronesia, and the Republic of the Marshall Islands([38])
- Crowdsourcing and Citizen Science Act (15 USC 3724) (2016)([39])
- NOAA Artificial Intelligence, 'Omics, and Unmanned Systems Strategies (2020)([40-42])
- Joint Statement from the President of the United States and the Presidents of the Freely Associated States (2019). ([43])
- Great American Outdoors Act, Preserving and Protecting our National Parks (2020) ([44])

A U.S.VI-FL SCTLD learning exchange to build capacity for SCTLD response. (Credit: Karen Neely/NSU).

Conclusions

Bold action is required to maintain U.S. coral reef ecosystems, preserve genetic diversity for future restoration, and prevent further spread of SCTLD. Restoration of priority coral species and mitigation of stress from environmental changes and human impacts will be critical to supporting healthy reefs around the world. NOAA is developing an Implementation Plan that outlines a detailed course of action for SCTLD response and prevention and integrates new technologies. By matching agency capacity with SCTLD response needs, and complimenting efforts of our partners, NOAA will expand upon Strategy goals and agency priorities that support ocean health as well as resilient coastal ecosystems, communities and economies.



Diverse use disease identification cards to monitor SCTLD spread. (Credit: Scot Frew/NOAA).

Acknowledgements

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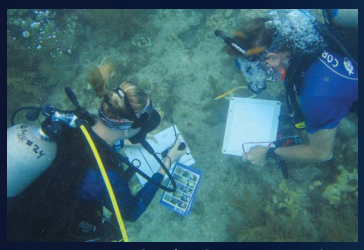
APPENDIX 1.1: Goals: NOAA Strategy for SCTLD response and prevention

RESEARCH

Credit: NOAA AOML

- Expand Research

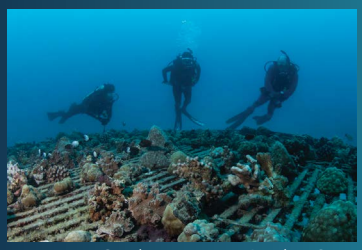
RESPOND



Credit: Scot Frew NOAA

- Build Response Capacity
- Support Coral Rescue

ENGAGE



Credit: LT Laura Rock NOAA

- Promote Awareness
- Collaborate with Coral Reef Managers
- Engage Regional Fisheries Managers
- Advance International Partnerships
- Prevent Spread to the Pacific