SECOORA
SOUTHEAST
COASTAL OCEAN OBSERVING
REGIONAL ASSOCIATION

Harmful Algal Bloom Plan

This document is an addendum to the Southeast Coastal Ocean Observing Regional Association (SECOORA) Regional Coastal Ocean Observing System Strategic Operational (RCOOS) plan, which establishes priorities for contributing to our improved understanding, management, and stewardship of valued coastal ocean resources. This document will serve as a guide for future investments in regional harmful algal bloom (HAB) observing and monitoring in the SECOORA region.

May 2023

Version Control

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0.10	Initial HAB Plan Draft for staff review	October 22, 2021
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Contents

1. Overview

1.1 Document Description

This Harmful Algal Bloom Plan is an addendum to the Southeast Coastal Ocean Observing Regional Association (SECOORA) [Regional Coastal Ocean Observing System Strategic Operational (RCOOS) plan](), which establishes priorities for contributing to our improved understanding, management, and stewardship of valued coastal ocean resources. This document expands upon the Harmful Algal Bloom (HAB) section of the RCOOS plan to provide sub-regional information for algal species negatively impacting the region and serves as a guide for future investments in regional HAB observing and monitoring. This plan will be reviewed and updated periodically, but no less than every two years, by the SECOORA Science Committee.

The SECOORA Harmful Algal Bloom Plan is intended to inform:

1. SECOORA staff and Board of Directors to establish priorities for funding decisions.
2. SECOORA members to articulate priorities and provide guideposts for future activities.
3. Regional stakeholders and potential members to demonstrate capabilities and describe connections to regional needs and priorities.

1.2 SECOORA Background

The SECOORA footprint spans the four-state region of North Carolina (NC), South Carolina (SC), Georgia (GA), and Florida (FL). Our ocean and coastal waters reach from the eastern side of the Gulf of Mexico to the South Atlantic Bight and are connected by the Loop Current-Florida Current-Gulf Stream continuum.

SECOORA is organized to provide ocean data, tools, and services in the following focus areas, which correspond with U.S. Integrated Ocean Observing System (IOOS®) societal goals and are important to southeast stakeholders: Ecosystems, including Water Quality and Living Marine Resources; Marine Operations; and Coastal Hazards and Climate Variability. As outlined in SECOORA's RCOOS Plan, HABs have been identified as a novel area of investment for SECOORA's resources.

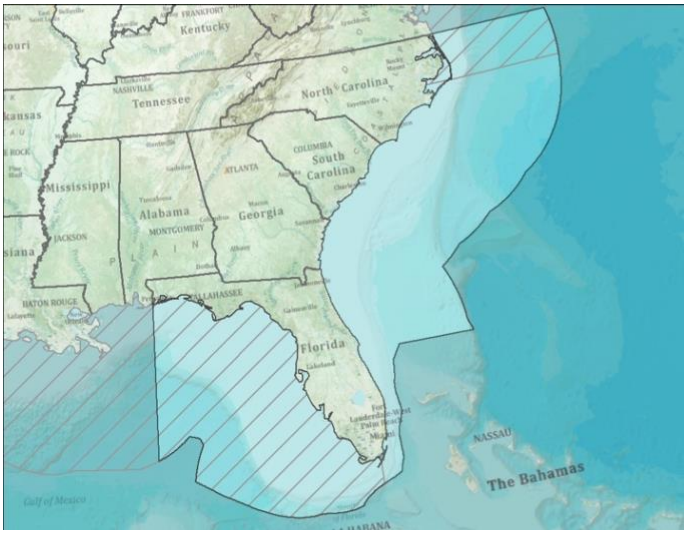

Figure 1 - Map of the SECOORA Region.

2. Harmful Algal Blooms (HABs)

2.1 Harmful Algal Bloom Background

Harmful Algal Blooms (HABs) occur when algae — photosynthetic eukaryotic organisms or prokaryotic organisms and macroalgae that live in marine and freshwater environments — experience increased growth while producing toxic or harmful effects on people, fish, shellfish, marine mammals, birds, and submerged habitats. HABs can be caused by a multitude of organisms including phytoplankton, macroalgae, and benthic microalgae (NOAA, 2021). The HABs in fresh and marine waters are usually very different, but they can overlap in low-salinity estuaries (NOAA, 2019b).

Overall, HABs can have deleterious effects on the economics, environmental health, and human health of coastal communities. Exposure to HAB-related toxins can lead to a multitude of illnesses including respiratory illness, liver illness, neurological damage, and in severe exposure cases can lead to death (Paerl et al. 2016). HABs are continually becoming a more persistent and widespread issue throughout the Southeast. There are multiple challenges associated with monitoring HABs, as tracking HABs requires assets, multi-agency coordination, and investment in the development and implementation of hands-on and autonomous data collection methods. The fundamental challenge with HABs is that the pace and severity of outbreaks is not matched by science, monitoring, and support for communities to identify and implement solutions (Elko et al., 2022). Overall, prevention, control, and mitigation of HABs is critical for management and requires multi-institutional efforts and coordinated investment in research to develop viable strategies and technologies as well as cooperation among agencies for implementation.

2.2 Harmful Algal Blooms in the Southeast

This plan will address coastal HABs as defined within the National Harmful Algal Bloom Observing Network (NHABON) Framework. The geographic extent of HABs addressed in SECOORA's plan will be constrained to coastal regions of NC, SC, GA, and FL. These coastal regions will include the area from the head of tide to the edge of the U.S. Exclusive Economic Zone. This plan does not include an exhaustive list of all HABs within the Southeast, rather it highlights the species of concern and areas to improve observing and monitoring. Each HAB is formed from a different algal species and presents unique challenges in terms of monitoring and evaluating environmental impacts.

2.2.1 Blue-Green Algae or Cyanobacteria (CyanoHABs)

Studies have shown that some harmful blue-green algae or cyanobacteria (CyanoHABs) can be salt-tolerant and able to live in estuarine environments. Eutrophication of fresh and brackish waters, largely due to nutrient run-off from anthropogenic sources (e.g., development, agriculture), has increased the number of CyanoHAB events in coastal areas of the Southeast U.S. (Paerl and Huisman 2009). Studies have found that freshwater HAB events can turn into coastal or estuarine HAB events, as HABs are transported to the coast via water management actions (Heil and Muni Morgan, 2021; Oehrle et al., 2017; Metcalf et al., 2021; Tatters et al., 2021).

CyanoHABs can contain harmful toxins known as cyanotoxins. The most common in the US include microcystins, cylindrospermopsin, anatoxins, and saxitoxins (EPA, 2022). Cyanotoxin exposure in humans can lead to gastrointestinal illness, respiratory illness, muscle weakness, dermatitis, and death. Saxitoxins, produced by eukaryotes and prokaryotes, are responsible elsewhere for paralytic shellfish poisoning, which occurs when shellfish in marine or brackish systems consume toxic algae, concentrating the toxins and posing a threat to human consumption (EPA, 2022).

2.2.2 *Karenia brevis* (Red Tide)

One of the most well-known HABs in the Southeastern region is the red tide alga *Karenia brevis,* a species of dinoflagellate that produces potent neurotoxins. Blooms of *Karenia brevis* have been documented to have deleterious impacts on marine ecosystems including mass fish die-offs and marine mammal deaths. Toxins can accumulate in shellfish and when eaten can cause Neurotoxic Shellfish Poisoning in humans (WHOI 2019). Additionally, toxins from *Karenia brevis* can become aerosolized and cause human respiratory illness. Red tide is currently the most prolific HAB in the state of Florida and has the farthest-reaching impacts affecting the most people and biota (Heil and Morgan, 2021; Heil and Steidinger, 2009; Steidinger, 2009).

As a marine species, *Karenia brevis* is hypothesized to initiate offshore in deeper water and be transported and concentrated onshore by coastal ocean currents on the West Florida Shelf (Steidinger, 1975; Tester and Steidinger, 1997; Walsh et al., 2006). The coastal ocean circulation was found to be largely responsible for the initiation and termination of the major West Florida Shelf red tide event in 2018 (Weisberg et al., 2019; Weisberg and Liu, 2022). Field and lab studies indicate that *Karenia brevis* can utilize a diversity of nutrient sources to fuel growth, including those resulting from fish kills. Whether or not the offshore nutrient state is conducive for *Karenia brevis* outcompeting other HAB species may depend on the ocean circulation (Weisberg et al., 2014, 2016; Weisberg and Liu, 2022).

2.2.3 *Sargassum* (Macroalgae)

Sargassum, a type of brown macroalgae, grows in the Atlantic Ocean and feeds off natural nutrient sources. Data has shown that increased nitrogen from anthropogenic sources is supporting the excess growth of *Sargassum* leading to blooms that have harmful impacts (Lapointe et al. 2021). Unlike other species of HABs, the algae itself is not toxic; however, once large blooms of *Sargassum* wash onshore, they can negatively impact critical coastal habitats and ecosystems as well as have economic and human health impacts. Decomposing *Sargassum* on beaches releases hydrogen sulfide gas. The inhalation of hydrogen sulfide gas can cause respiratory issues for humans (Miami-Dade County, 2023). In 2019, Miami-Dade County officials estimated it would cost $45 million to remove *Sargassum* from a 15-mile stretch of beach (FIU News, 2021). Beyond the economic cost of clean-up, *Sargassum* blooms can also result in a reduction in tourism and recreation at impacted beaches. Within ecosystems, *Sargassum* can also have deleterious effects; blooms can impact seagrasses, coral reefs, and many other marine animals including sea turtles (Lapointe et al. 2021).

Figure 2 - Image of Sargassum in Palm Beach County, Florida. Image Credit: Brian Lapointe, FAU

2.2.4 Aureombra lagunensis (Brown Tide)

Brown tide, *Aureoumbra lagunensis,* blooms have been observed in the Indian River Lagoon (IRL) (Lopez et al. 2021). There are multiple sources and factors of anthropogenic nutrients that influence brown tide growth in the IRL. Large amounts of anthropogenic nutrients discharging from Lake Okeechobee and the St. Lucie Basin have contributed to outbreaks (Florida Audubon Society, 2013). Additional factors contributing to brown tide growth include nutrient input from septic systems, nutrient laden-stormwater runoff, an organic muck layer, and limited water flow within the IRL (St. Johns River Management District, 2022; Marine Resources Council, 2018). Similar to *Sargassum*, the algae itself is non-toxic but can cause damage to ecosystems, fisheries resources, and recreational facilities, often due to the sheer biomass of the accumulated algae, which blocks sunlight from reaching submerged vegetation. When this biomass decays as the bloom terminates, oxygen is consumed, leading to widespread mortalities of plants and animals in the affected area due to low levels of dissolved oxygen (Anderson 2009; Gobler et al. 2013; Hall et al. 2018).

Figure 3 - Image of Texas Brown Tide in the Indian River Lagoon, Florida. Image Credit: Florian Koch, NOAA NCCOS

3. HABs in the SECOORA Region by State

The following sections provide an overview of the HABS species of concern by state within the SECOORA region. This includes the associated environmental and human health concerns that can result from HABs, HAB monitoring and sampling within the state, and state specific HAB hotspots. These regional hotspots include areas where HABs are an emerging or ongoing (i.e., established) concern and are potentially causing significant harm. This is not an exhaustive list of HABs, but rather an identification of potential high-priority species and regions to focus on for potential future investment in monitoring and observing. SECOORA recognizes that states within the region have limited information surrounding coastal HABs. This document highlights the need to fill in HAB monitoring and sampling gaps within these geographic areas.

3.1 North Carolina

3.1.1 Species of HABs in North Carolina

- CyanoHABs: *Dolichospermum, Microcystis,* and *Cylindrospermopsis*, Anatoxins and Saxitoxins (EPA, 2022).
    - Blooms can result in hypoxic conditions leading to fish and submerged aquatic vegetation die-offs.
    - Blooms can produce toxins including microcystins, cylindrospermopsin, anaxtoxins and saxitons. Ingesting or recreating in contaminated water can kill pets, livestock, and other animals.
    - Exposure to humans can lead to gastrointestinal illness, respiratory illness, muscle weakness, dermatitis, and more.
- *Prymnesium parvum* (Golden Algae)
    - Tolerant of a wide range of salinities and temperatures.
    - Blooms most know for causing fish kills (Harmful Algae, 2019a)
- *Pseudo-nitzschia* spp.
    - Produces Domoic acid, a neurotoxin, that can build up in shellfish (Fire and VanDolah, 2012).
    - When humans ingest shellfish infected by domoic acid, it can cause Amnesic Shelling poisoning. This can lead to mild to severe gastrointestinal and neurological disorders (Harmful Algae, 2019b).
- *Karenia brevis* (Red Tide)
    - Presence can cause Neurotoxic Shellfish poisoning. A major event occurred in 1987, when a large bloom was transported from the West Florida Shelf, around the Florida Keys and up the coast in the Gulf Stream, to the North Carolina coast (Tester et al., 1988).
    - Blooms can result in wildlife deaths (i.e., fish kills)
- *Karlodinium veneficum*
    - Bloom can result in wildlife deaths (i.e., fish kills)
- *Pfiesteria* sp.
    - Blooms can result in wildlife deaths (i.e., fish kills)
- Raphidophytes
    - Several genera including *Heterosigma*, *Chattonella*, and *Fibrocapsa*
    - Linked to fish kills and harm to shellfish

3.1.2 HAB Hotspots in North Carolina

Figure 4 – Image of a CyanoHAB bloom often makes the water look green in the Chowan River, NC. Image credit: NOAA

The NC coastal region is comprised of a series of sounds with the most well-known being the Pamlico Albemarle Sound System (PASS). The PASS is described as a shallow water, lagoonal sound with low-to mid-range salinity due to limited sea water exchange through narrow coastal inlets. Water residence time within PASS is about one year (Giese et al. 1979). Conversely, Bogue Sound has higher salinity and a water residence time only of 2 days due to greater water exchange with the coastal ocean (Anderson et al 2023). The habitat variety in coastal NC sounds and estuaries provide important nursery grounds for many commercially and recreationally important finfish and shellfish species. Additionally, NC has promoted marine aquaculture (mariculture), specifically shellfish mariculture, within these protected sounds. Based on the NC Coastal Habitat Protection Plan 2021 Amendment, mariculture landings have surpassed wild harvest landings since 2017.

CyanoHAB blooms are an issue for the low salinity areas within PASS including Albemarle and Currituck Sounds and the upstream areas of Pamlico River. Since 2015, the Albemarle Sound region (NCDEQ 2021a), and particularly the Chowan River (NCDEQ, 2021b) has experienced an increased frequency of potentially toxic cyanoHABs that threaten its ecological health and recreational value. Measurements of microcystin toxins during one of these blooms had concentrations more than 60 times higher than the U.S. Environmental Protection Agency (EPA) guidelines for recreational use (NCDEQ, 2021b). Sporadic summertime cyanoHAB blooms have also occurred in the Pamlico River and its tributaries, especially in Chocowinity Bay and Bath Creek. As of 2022, efforts to understand the genetic diversity, growth limiting factors, and toxin production by cyanobacteria species causing CyanoHABs in NC water bodies have largely focused on field surveys that can provide correlative rather than causative information (e.g., Anderson et al. 2023, Calandrino and Paerl 2011, Dyble et al. 2002, Isaacs et al. 2014, Polera 2016, Wiltise et al. 2018). A major hindrance to gaining a better understanding of the environmental factors that drive cyanobacterial growth and toxin production in freshwater and estuarine systems has been limited access to local strains for controlled experiments.

In addition to CyanoHAB blooms, NC coastal areas, specifically the PASS, have experienced dinoflagellate blooms. Dinoflagellates are marine plankton species that can produce toxins harmful to humans, marine mammals, and fish. *Pfiesteria* and *Karlodinium veneficum* blooms have resulted in several large-scale fish kills in the lower Neuse River which feeds into the Pamlico Sound (Burkholder et al. 2001, Hall et al. 2008).

3.1.3 Monitoring and Sampling in North Carolina

- NC Department of Environmental Quality (DEQ) has a Fish Kill & Algal Bloom Report Dashboard.
- The University of North Carolina at Chapel Hill Institute of Marine Sciences (UNC IMS) conducts HAB research and monitoring, including examining the respiratory threats of specific HAB species.
    - Two long-term water quality monitoring programs: ModMon and FerryMon.
        - The Neuse River Estuary Modeling and Monitoring Project (ModMon) is a collaborative effort between the UNC IMS and the NC DEQ to monitor conditions in the southern Pamlico Sound.
        - ModMon data are available on the SECOORA portal.
        - FerryMon uses NC Department of Transportation ferries to collect water quality data in rivers and the Pamlico Sound.

    - In 2020, researchers published [Quantitative Evaluation of Changing Nutrient Sources to the Albemarle Sound System] as a final report for the Albemarle Commission. This report outlined cyanobacteria blooms in the Chowan River and Albemarle Sound, their nutrient sources and trends in blooms, and informed management strategies to restore water quality.
    - In 2021, the project Determining Nutrient Controls on Phytoplankton Production and the Proliferation of Harmful Algal Blooms in Albemarle Sound was initiated. This study is using experimental nutrient additions to determine the limiting nutrient for HAB growth in Albemarle Sound and is making direct measurements of nitrogen inputs via biological nitrogen fixation.
- The NC State University Plankton Ecology Lab conducts toxin monitoring studies in several water bodies in coastal NC.
    - In situ HAB tracking is ongoing in the Chowan River, the Tar River, Lake Mattamuskeet and Bogue Sound (Wiltise et al. 2018, Anderson et al. 2023). Overall, studies indicate the presence of multiple toxins (mainly microcystin, cylindrospermopsin, and anatoxin) at low levels year-round in each of these water bodies. This raises concerns about potential chronic long-term exposures and human health risks.
    - A study conducted in collaboration with the NC Division of Marine Fisheries found both microcystin and cylindrospermopsin accumulation in several commonly caught fishes and blue crab in the western Albemarle Sound. These algal species were found in varying parts of the animals (gut, viscera, and muscle).
    - The NC State University Center for Marine Sciences and Technology team is monitoring the accumulation of microcystin and domoic acid in several marine sounds in the wider Albemarle-Pamlico Sound region. Preliminary results indicate that there is a measurable amount of microcystin transported to these coastal sounds from upstream freshwater sources and both toxins are present in oysters within the Sounds.
- The UNCW Center for Marine Science (CMS) HAB Research Group conducts studies on HAB toxins and CyanoHABs in the PASS and in Southeastern North Carolina.
    - Ocean and Land Color Imagers (OLCI) on Sentinel-3 (from the Algal Bloom Monitoring System (ABMS) prepared by [NOAA NCCOS]) have been used to assess HABs occurrence and intensity in the PASS. Preliminary results show that HABs in the Sound usually have strong seasonal variability, with two HAB peaks each year, one in Spring (March) and a second one in Fall (July to October). Strong daily variations in the surface CyanoHAB area also were observed, potentially caused by physical processes (e.g., turbulent mixing and horizontal advection).
    - UNCW physical oceanographers are building a short-term HAB forecast system for the Albemarle Sound, which is based on a particle tracking model initialized from satellite derived cyanobacterial HAB concentration, using currents and diffusivity from an unstructured hydrodynamic model. The system can produce a 5-day forecast of the distribution and movement of HABs.
    - The UNCW Algal Resources Collection (UNCW-ARC) collaborates with researchers from the NC DEQ, UNC IMS, and NC State University Plankton Ecology Lab to isolate cultures of the cyanobacteria species causing CyanoHABs in the Pamlico and Albemarle Sounds. Microcystin production has been shown by liquid chromatography–mass spectrometry (LC-MS/MS) in several *Microcystis* spp. cultures and these strains will soon be available to the HAB research community through the UNCW-ARC website (www.algalresourcescollection.com).
    - The Drug DISCOvery group, in collaboration with UNCW's Aquatic Ecology Lab and the UNCW-ARC, has monitored and examined bloom waters from over 10 different regional

freshwater bodies for several years. The team has detected and purified both CyanoHAB toxins as well as emerging bioactive HAB compounds. As of 2022, the group is contracted by the EPA to perform untargeted mass spectrometry-based metabolomics for new bioactive discovery and semi-quantitative toxin assessment of freshwater CyanoHABs and marine dinoflagellate blooms in Northwestern Florida. The group also conducts water quality assessments of urban stormwater retention ponds in the Wilmington area. A key objective of this project is to identify the biogeochemical parameters facilitating harmful or nuisance algal blooms.

  - The UNCW Center for Marine Science (CMS) produces a suite of HAB toxins that are provided to researchers, government agencies, and resellers all over the southeastern United States. CMS is a named provider of standards in the North Carolina Biotoxin Contingency plan provided by the NC Division of Marine Fisheries. They also provide assays for detection and toxicity, including the only ELISA approved by Florida Fish and Wildlife Research Institute- an NSSP-approved lab.
- The partnership of the Albemarle Resource Conservation and Development Council (ARC&D), Albemarle Commission, Chowan-Edenton Environmental Group (CEEG), Green $aves Green Little River Keepers, Soil and Water Conservation Districts (SWCD), state agencies, local governments, and universities are monitoring water quality in rivers and creeks in the region to determine and address the sources of nutrients.
- The Albemarle-Pamlico National Estuary Partnership (APNEP) has a comprehensive conservation and management plan that outlines goals and objectives for an ecosystem-based approach to protect and restore the Albemarle-Pamlico estuary. This plan includes the required monitoring and assessment measures needed to maintain healthy coastal ecosystems and protect human health.
- Currently, NOAA's Plankton Monitoring Network (PMN) includes sampling sites in the state of North Carolina.

3.1.3. Educational Resources in North Carolina

- The NC DEQ Division of Water Resources has created a HAB Identification Guide.
- The NC Sea Grant Algal Blooms Things to Know provides information about HABs in North Carolina. This informational flier was produced collaboratively by NC Sea Grant, NC DEQ, and several of the research labs mentioned above.
- The UNCW-ARC, in collaboration with UNCW's Department of Art and Art History and MarineQuest program (K-12 education program), is developing an e-game ("Bloom Busters") to teach K-12 students about the importance of reducing the nutrient load to water bodies to decrease the frequency and magnitude of CyanoHABs. As of 2022, the game is in the beta testing phase.

3.2 South Carolina

3.2.1 Species of HABs in South Carolina

- CyanoHABs: *Dolichospermum, Microcystis, Aphanizomenon sp,* and *Cylindrospermopsis*, Anatoxins and Saxitoxins (EPA, 2022).
  - Blooms can result in hypoxic conditions leading to fish and submerged aquatic vegetation die-offs.
  - Blooms can produce toxins including microcystins, cylindrospermopsin, anaxtoxins and saxitons. Ingesting or contact through recreation in contaminated water can lead to illnesses and infections in pets, livestock, wildlife and humans.

- Specific to humans, exposure can lead to gastrointestinal illness, respiratory illness, muscle weakness, infections, dermatitis, and more.
- *Prymnesium parvum* (Golden Algae)
    - Blooms can result in wildlife deaths (i.e., fish kills).
- *Kryptoperidinium sp.* (Carolina Red Tide)
- Raphidophytes
    - Several genera including *Heterosigma*, *Chattonella*, and *Fibrocapsa*
    - Blooms can result in fish kills and harm to shellfish.

Figure 5 - Image of a fish kill event as a result of Prymnesium parvum or Golden Algae, an emerging HAB of concern in SC. Image Credit: Mike Hooper, USGS

3.2.2 Coastal HABs in South Carolina

There are limited records of the occurrence of coastal HABs in SC, with most HAB monitoring occurring in freshwater environments, such as rivers, lakes, and coastal stormwater ponds. There is concern that HABs can incubate in coastal stormwater ponds and then move into local estuaries via tidal creeks. Increased coastal flooding from increasing frequency, duration and magnitude of storms and even sunny day flood events can result in overland transport of waters from stormwater ponds to estuarine receiving waters. For example, from 2004-2005 water quality measurements were taken from a freshwater pond, Lake Edmonds, and an adjacent tidal creek, Kushiwah Creek, both located on James Island, just south of Charleston, SC. *Anabaena* species and *Microcystis* species were observed in both water bodies throughout the two-year study period (DeLorenzo and Fulton, 2009).

Pfiesteria shumwayae and *P. piscicida* were confirmed in dead fish related to a fish kill in a brackish pond on Hilton Head Island in 2001 (DeLorenzo and Fulton, 2009). A *Kryptoperidinium* bloom was first discovered in Bulls Bay, SC in 1998 and it was identified in estuaries from Georgetown to Hilton Head (Wolny et al. 2008). Monitoring conducted in 2001 found *Kryptoperidinium* present in additional estuaries along the SC coast as early as February during the year.

3.2.3 Monitoring and Sampling in South Carolina

- SCDHEC performs monthly sampling for chlorophyll-a and microcystin annually from May through October at 44 permanent estuarine ambient surface water quality monitoring sites.
- SCDHEC Algal Bloom Monitoring provides a GIS-based map with HAB Monitoring, HAB Watch, and HAB Advisory notices to the public.
- SC Department of Natural Resources (SC DNR) collects a broad range of water, sediment and biological resource samples from 30 randomly selected tidal creek and open water sites as part of the South Carolina Estuarine and Coastal Assessment Program (SCECAP) once each summer. The samples provide nutrient and chlorophyll-a levels as indicators for HAB potential.
- The South Carolina HAB Network (SC HABNet) is a multi-institutional volunteer network of agencies and academic institutions, led by SCDHEC, to monitor and study HABs in SC. Their website is an information portal to learn about HABs, HAB identification, human health consequences of exposure to HABs, impacts of HABS on wildlife, livestock and pets, and contacts for the SCDHEC HAB program. A full listing of collaborators can be found on the information portal.
- NOAA's Plankton Monitoring Network (PMN) includes sampling sites throughout the US including the state of SC.

- University of South Carolina's Arnold School of Public Health administers a National Institute of Environmental Health Sciences-funded Center of Excellence for Oceans and Human Health and Climate Change Interactions (OHHC^{2}I). Specifically, OHHC^{2}I research is focused on the development of tools to model, detect, and assess the human and environmental health risks associated with bacterial and HABs microorganisms.
    - One of four research foci of the OHHC^{2}I is HABs and the Center has established the Harmful Algal Bloom Project which supports research that focuses on the effects of climate change on the growth of HABs and HABs related toxins. The HAB project focuses on cyanobacteria impacts to drinking water, recreational water quality, and seafood safety and associated human health concerns and works with the OHHC^{2}I Community Engagement to develop and disseminate community and culturally relevant science-based information in support of improved decision making.
    - The Environmental Toxicology Project at OHHC^{2}I has assessed the effects of HAB toxins in mammals and the resulting effects on human health.
- Coastal Carolina University's Environmental Quality Lab and Waccamaw Watershed Academy conduct HAB monitoring and sampling along the Grand Strand area of SC and make the data and derived information available via their website.

3.2.4 Educational Resources in South Carolina

- SCDHEC has a webpage of HAB Resources and Advisory Warnings.
- SCDHEC has created an educational flyer for public distribution.
- The SC HABNet information portal provides access to HAB information on environmental and human health concerns for a range of users, from residential, to agricultural, to drinking water utilities.
- The OHHC^{2}I Community Engagement Core uses an Educate → Alert → Inform → Involve strategy in working alongside communities, organizations, and agencies affected by HABs and climate change (i.e., Lake Wateree Water Watch and Lake Wateree Property Owners Association, Low Country Alliance for Model Communities, Charleston Community Research to Action Board, EJ STRONG) and those responsible for managing the potential human health consequences associated with exposure to HABs (i.e., Interstate Shellfish Sanitation Conference, EPA, FDA, NIH, SCDHEC). Tools developed include internet content analysis of websites on HABs, environmental report cards, and development of community-relevant decision-support tools.
- The OHHC^{2}I study "Health Communication Blindspot: A Case Study of Harmful Algal Blooms in the Southeast (HABITS)" determined that the readability of online HAB content should be based on environmental health literacy principles (King 2021). Health communicators and water resource managers can use the principles from the study (e.g., bullet points, short take home messages, FAQs) to better communicate HAB threats to communities.

3.3 Georgia

3.3.1 Species of HABs in Georgia

- Dinoflagellate HAB species
    - *Akashiwo sanguinea*
    - *Heterocapsa rotundata*
    - Non-toxic blooms, but linked to fish and bird mortality
- *Heterosigma sp.*
    - Raphidophyte species linked to fish kills and harm to shellfish

- *Pseudo-nitzschia*
    - Produces Domoic acid, a neurotoxin, that can build up in shellfish (Fire and VanDolah, 2012).
    - When humans ingest shellfish infected by domoic acid, it can cause Amnesic Shelling poisoning. This can lead to mild to severe gastrointestinal and neurological disorders (Harmful Algae, 2019b).

Figure 6 - Photo of baby oysters at the UGA Skidaway Institute of Oceanography, where there was a die-off event from a HAB exposure. Image Credit: UGA

3.3.2 HABS in Georgia's Coastal Waters

HABs within the coastal and intercoastal regions of Georgia (GA) are largely undocumented; although, this does not suggest that HABs have not occurred, or will not occur in the future (GDPH, 2015). Increases in nutrient runoff are hypothesized to be increasing the number of HAB dinoflagellates in coastal GA waters (Verity, 2010).

Few instances of coastal HABs have been reported in GA. Historical reports include HABs observed in the coastal estuaries of Sapelo Island in 1956 and 1972 where *Kryptoperidinium* blooms were documented (Young, 2020 and Pomeroy et al. 1956, 1972). More recently in 2017, an *Akashiwo* bloom occurred in the Skidaway River resulting in an oyster fishery die-off event (Pfeiler, 2020). The Georgia Department of Public Health has created a Coastal Georgia HAB Response Plan to address the potential threat of HABs in the region.

3.3.3 Current Monitoring in Georgia's Coastal Waters

- NOAA's Plankton Monitoring Network (PMN) includes sampling sites in GA.
- University of Georgia Skidaway Institute of Oceanography is monitoring HABs in the Skidaway River Estuary through cell counts obtained via FlowCAM imaging systems and taking water quality samples daily in summer and weekly in non-summer months. Dissolved nitrate and phosphate are also measured bi-weekly over the summer months and during any observed HAB elevated cell density events. Ammonium concentrations will be measured daily over the summer and weekly over non-summer months.

3.3.4 Educational Resources in Georgia

- The GA Department of Environmental Protection has created an educational HAB Story Map.
- The GA Department of Public Health has a HAB webpage, with general educational information.

3.4 Florida

3.4.1 Species of HABs in Florida

- CyanoHABs: *Dolichospermum, Microcystis,* and *Cylindrospermopsis*, Anatoxins and Saxitoxins (EPA, 2022).
    - Blooms can result in hypoxic conditions leading to fish and submerged aquatic vegetation die-offs.
    - Ingesting or recreating in contaminated water can kill pets, livestock, and other animals.
    - Exposure to humans can lead to gastrointestinal illness, respiratory illness, muscle weakness, dermatitis, and more.
    - In some instances, presence can cause Paralytic Shellfish poisoning.

- *Karenia brevis* (Florida Red Tide)
  - Blooms have the potential to cause respiratory illness in humans
  - Blooms can result in wildlife deaths (i.e., fish kills)
  - Presence can cause Neurotoxic Shellfish poisoning
  - Oyster and scallop harvesting closures in the Apalachicola area due to domoic acid.
- *Aureoumbra lagunensis* (Brown Tide)
  - While not a toxin producer, Brown tide blooms occur in extreme bloom concentrations which blocks sunlight and has led to the extensive seagrass die-offs in estuaries (Judice et al. 2020).
- *Pseudo-nitzschia* spp.
  - Produces Domoic acid, a neurotoxin, that can build up in shellfish (Fire and VanDolah, 2012).
  - When humans ingest shellfish infected by domoic acid, it can cause Amnesic Shelling poisoning. This can lead to mild to severe gastrointestinal and neurological disorders (Harmful Algae, 2019b).
- *Gambierdiscus toxicus*
  - Presence can cause Ciguatera Fish Poisoning
- *Pyrodinium bahamense*
  - Presence can cause Paralytic shellfish poisoning
- *Sargassum* spp.
  - Impacts are primarily related to negative aesthetic impacts to recreational beaches, including visual and olfactory.
  - Significant accumulation of algal mats can also clog pipes and narrow canals in impacted waters.

3.4.2 Coastal HAB Hotspots in Florida

Florida Red Tide – Gulf of Mexico (GOM)

When aerosolized, brevetoxins produced by *Karenia brevis,* also referred to as Florida red tide, have the potential to cause respiratory illness in humans, and when found in shellfish can lead to Neurotoxic Shellfish Poisoning in humans (WHOI 2019). Red tide has become a nearly annual event in the Gulf of Mexico (GOM). Red tide has resulted in widespread mortality of fish, sea turtles, marine mammals, and other wildlife (HAB Task Force, 2020). Within the GOM, red tide is most common between Clearwater and Sanibel Island, FL (FWC, 2021a). Red tide blooms generally last 3-5 months, affecting hundreds of miles of beach; however, there have been multiple red tide events that have persisted for 18 months or more (FWC, 2021a, FWC, 2022).

Figure 7 - Image of Florida Red Tide along the coastline. Image Credit: NOAA

K. brevis is persistent in the GOM and as such, the state of FL has allocated resources for predicting, tracking, and monitoring blooms. In 2019, the Florida Red Tide Mitigation & Technology Development Initiative was enacted by the state legislature to establish an independent public and private research program to develop prevention, control, and mitigation measures to address the impacts of red tide on coastal environments and communities. The Florida Red Tide Mitigation & Technology Development Initiative is led by the Mote Marine Laboratory and Aquarium (MML) and the FL Fish Wildlife Conservation Commission (FWC). The Initiative hosts competitive grants specifically targeting innovative Red Tide monitoring and mitigation. The Initiative also works closely with the FWC Harmful Algal Bloom/Red Tide Task Force. The Task Force evaluates current policies and procedures related to Red Tide monitoring and forecasting and also has a HAB Grant program for projects that address Task Force recommendations.

Currently, there is extensive coastal *K. brevis* monitoring in the GOM (e.g., satellite remote sensing, glider deployments) but limited offshore water quality sampling. The Florida HAB Task Force (HAB Task Force, 2020) identified the need for updates to existing monitoring activities, as well as identification of technologies that can be scaled to incorporate automated monitoring, emphasizing the importance of early warning.

Sargassum (Atlantic Ocean, Caribbean Sea, Gulf of Mexico, Florida Beaches)

Sargassum, a type of brown macroalgae, grows naturally in the Atlantic Ocean and feeds off natural nutrient sources. Beginning in 2011, the Caribbean Sea experienced major blooms of the Sargassum macroalgae (or seaweed) almost every year (Lapoint et al. 2021). Satellite observations showed that the increased Sargassum in the Caribbean Sea was only part of the Great Atlantic Sargassum Belt (Wang et al., 2019) that extended from west Africa to the Gulf of Mexico. Annually, mats of Sargassum wash up onto beaches along the east coast of FL. In 2022 over 25 million tons of Sargassum washed ashore (Florida Today, 2022) leaving many beaches covered by smelly, decomposing seaweed.

In response to the emerging *Sargassum* blooms, a satellite-based *Sargassum* Watch System (SaWS, Hu et al., 2016) has been established to provide timely information to various stakeholders to make informed decisions. The SaWS produces daily updates, with summary bulletins distributed to stakeholders every month since February 2018.

HABs in the Indian River Lagoon (IRL)

HABs have devastated the Indian River Lagoon's (IRL) seagrass population killing over 47,000 acres of seagrass (Florida Today, 2020). A shift in the IRL began in 2011 as a major CyanoHAB outbreak was observed. This was followed in 2012, by a major *Aureoumbra lagunensis* (brown tide) event. Since 2012, brown tide has occurred almost every year within the IRL. In 2016, the HABs in the IRL resulted in the death of thousands of fish. Continued excess nutrient pollution in the waterways have contributed to an ecological disaster (Florida Today, 2018). Most recently, in 2021, the effects of a HAB-induced seagrass die-off has led to the deaths of hundreds of manatees. The indirect impacts of the loss of seagrass contributed to the starvation and ultimate death of over 1,000 Florida manatees. Since 2003, *Pyrodinium bahamense* blooms have also been reported in the IRL (Badylak et al 2004). *Pyrodinium bahamense* is a bioluminescent bloom-forming dinoflagellate, that is known for producing saxitoxins which can cause Paralytic Shellfish Poisoning (PSP). Due to the initial bloom in 2003, FWC instituted routine monitoring for PSP toxins in shellfish in the IRL, Tampa Bay, and other Florida bays to protect public health.

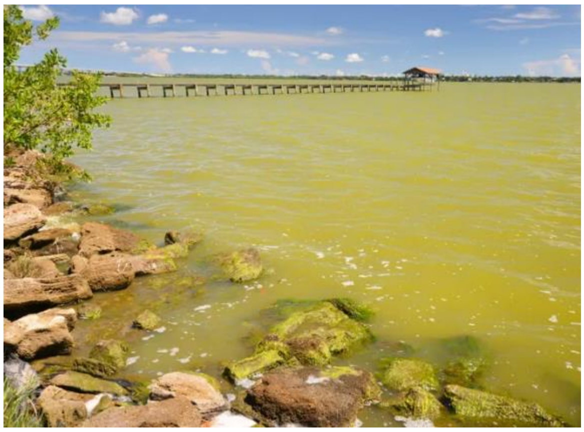

Figure 8 - Image of a CyanoHAB bloom in the IRL from 2020. Image Credit: Malcolm Denemark - Florida Today

As a form of HAB source control, in 2021 the State of Florida committed $53 million to restore water quality in the IRL (Florida Today, 2021). This funding will be used to remediate nutrient pollution by upgrading wastewater treatment and converting septic systems to sewer systems. The University of Florida and Florida Atlantic University - Harbor Branch Oceanographic Institute are supporting long-term HAB monitoring within the IRL. The IRL National Estuary Program (NEP) is developing a comprehensive HAB monitoring plan, the One Lagoon Monitoring Plan. The IRL NEP will use Geocollaborate, a communication platform, to create a geospatial platform to integrate IRL HAB data. This project will help support HAB monitoring, tracking, data sharing, and emergency response. IRL NEP is also working with St. Johns River Water Management District and Florida Fish and Wildlife Conservation Commission (FL FWC) to evaluate analytical techniques and develop new tools to enhance HAB detection (FWC, 2021b).

3.4.3 HAB Monitoring and Sampling in Florida's Coastal Waters

- NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) is using subsurface automated dual samplers (SAS) to capture water quality data to evaluate the nutrients entering Biscayne Bay, which contribute to regional HABs.
- NOAA National Centers for Coastal Ocean Science provides a GOM HAB Forecast.
- NOAA's National Center for Environmental Information has created the Harmful Algal BloomS Observing System (HABSOS), which maps state-wide HAB sampling.
- NOAA's Plankton Monitoring Network (PMN) includes sampling sites in the state of Florida.
- NOAA National Centers for Coastal Ocean Science (NCCOS) Monitoring and Event Response for HABS (MERHAB) program and GCOOS are funding HABSCOPE which provides data on *K. brevis* abundance and informs models which provide *K. brevis* forecasts at the beach level.
- The FL DEP has created an Algal Bloom Dashboard that lists HAB observations within the last 30-days statewide.
- FL FWC established the Harmful Algal Bloom Task Force in 1999 and it was reactivated in 2019, with the top priority being red tide.
- The Florida Red Tide Mitigation & Technology Development Initiative is a partnership between MML and FL FWC to develop prevention, control, and mitigation technologies for Florida red tide.
- FL FWC provides the status of *K. brevis* blooms using tables, static maps, and interactive Google Earth maps. The statewide *Red Tide Current Status* site highlights when HAB concentrations are not present, very low, low, medium, and high for FL beaches.
- FWC/FWRI-MML Cooperative Red Tide Program conducts periodic offshore research sampling cruises to assess offshore blooms of *Karenia brevis* that can initiate and feed the coastal blooms.
- FL FWC collects and analyzes semi-weekly, shore-based water samples to determine the presence and concentration of harmful algal cells, which is used to inform *K. brevis* forecasts. These semi-weekly updates are posted on FWC's Red Tide Current Status webpage.
- The USF Ocean Circulation Lab, in coordination with FL FWC, provides seasonal *K. brevis* major bloom outlooks for the West Florida Shelf and daily automated short-term (4.5 day) HAB trajectory forecasts for the West Florida Shelf and Tampa Bay.
- Florida Gulf Coast University has coastal stations in Estero Bay and in 2023 will begin short term water quality buoy deployments in Estero Bay to track *K. brevis* movement into the Bay. Data from the area is provided via their Coastal Water Quality interface.
- MML, USF, and FL FWC, with funding from NOAA Ecology and Oceanography of HABs (ECOHAB) are working to determine factors that end *K. brevis* blooms.
- USF College of Marine Science is using NASA satellite imagery to track *Sargassum* and posts monthly bulletins with the *Sargassum* forecast.

3.4.4 Educational Resources in Florida

- SECOORA's Florida Red Tide Resources page provides information on *K. brevis* monitoring, modeling, and forecasting.
- NOAA NCCOS hosts the Gulf of Mexico: HAB Forecasting Resources website that includes Florida resources.
- The Beach Conditions Reporting System is a user-friendly app provided by Mote Marine Lab. The app provides a wealth of beach condition information including: watercolor, wind direction, flag status at

lifeguard-monitored beaches, locations where dead fish are present, and locations of respiratory irritation among beachgoers.

- FL DEP has created a HABs FAQs educational document for public distribution.
- FL FWC provides red tide status updates and maps.
- A red tide communications strategy is being developed by University of Florida and Florida Sea Grant. This strategy highlights the value of signs on beaches as a primary source of information for the public.
- The FL Department of Health HABs page provides information on several HAB species.
- Mote Marine Lab maintains the Florida Red Tide FAQs webpage.

4. SECOORA Investments in HABs Observing and Monitoring

4.1 Current SECOORA HAB Observing and Monitoring

SECOORA works with partners at the University of Georgia Skidaway Institute of Oceanography, University of South Florida College of Marine Science, Florida Fish and Wildlife Research Institute (FWRI), Florida Gulf Coast University, UGA Skidaway Institute of Oceanography, NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML), and Mote Marine Laboratory to monitor HABs. Specific areas of interest include the Atlantic Ocean, West Florida Shelf, the Skidaway River Estuary and even the Caribbean Sea (i.e., Sargassum tracking as it enters the Loop Current or Gulf Stream). Partners are working together to enhance in situ offshore monitoring of HABs using buoys, gliders, and ship-based field surveys targeting key bloom dynamics and they also use satellite remote sensing to observe surface optical properties.

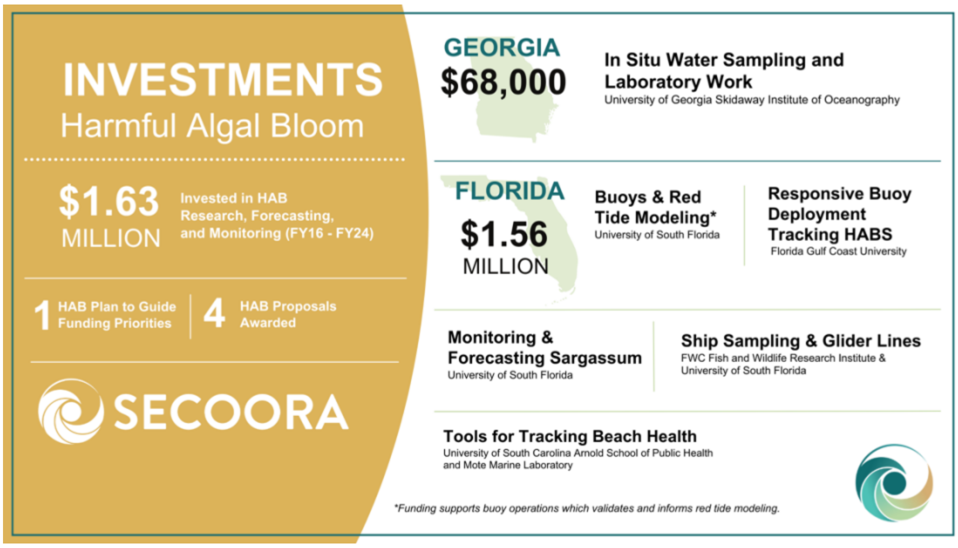

Figure 9 - SECOORA has invested in Harmful Algal Bloom monitoring and tracking in Florida and Georgia. Above is a summarization of HAB investments by state.

USF leads the physical and ecological modeling efforts to evaluate bloom dynamics and issue red tide forecasts. Each year, USF makes predictions of major red tide occurrences for the West Florida Shelf during late spring – early summer based on the machine learning analysis of satellite altimetry data with regard to the relevant patterns of the Gulf of Mexico Loop Current (Liu et al., 2016). USF produces daily automated 4.5-day (1-day hindcast, 3.5-day forecast) HAB trajectory forecasts for the West Florida Shelf with the West Florida Coastal Ocean Model (WFCOM) and for Tampa Bay with Tampa Bay Circulation Model (TBCOM). These forecasts are used in FL FWC HAB products and are available on the SECOORA Florida red tide resources page. USF is also in the process of developing a coupled physical-biological model of *Karenia brevis* bloom for the West Florida Shelf based on the high-resolution unstructured grid ocean circulation model WFCOM.

4.2 SECOORA HAB Investment Opportunities

The SECOORA Regional Coastal Ocean Observing System (RCOOS) Strategic Operational Plan 2020 – 2025 presents the SECOORA priorities for contributing to our improved understanding, management, and stewardship of valuable coastal ocean resources. The RCOOS plan identifies focus areas that guide our work. SECOORA will invest in data collection, product development, and applied research to better understand the environmental and societal concerns identified within each of the focus areas. HABs are listed as a sub-topic within the "Ecosystems: Living Marine Resources and Water Quality" focus area (pages 20-22). For each sub-topic listed within the focus area, the following information is provided:

- **Challenges**: defines key management challenges in the region
- **Priority Geographic Area(s)**: identifies the most critical geographic areas
- **Partner Activities**: examples of related efforts by state, federal, and NGO partners
- **Core Variables Required**: core variables as defined by IOOS with other data identified as needed
- **Current SECOORA Investments**: funded RCOOS components
- **Additional SECOORA Investment Opportunities**: needs defined by stakeholder engagement, subject matter expert discussion, and previous observing platform gap analyses

IOOS is partnering with NOAA NCCOS to support sustained HAB observing activities by the regional associations. Congress has supported this IOOS initiative, although the total funding via IOOS for all 11 regions is currently limited to $2M - $5M annually. SECOORA anticipates receiving a small annual allocation, initially in the $150,000 range, for investment in HAB monitoring and observing in the Southeast. The HABS section of the RCOOS plan identifies investment opportunities in observing assets, data management, and communications, products, emerging technologies, and education and outreach resources; however, the RCOOS plan does not specifically identify where SECOORA can have the greatest return on investment with limited funding available for HAB research and monitoring. Section 4.2.1 identifies near-term priorities to advance SECOORA efforts in the region. These efforts build upon many existing SECOORA resources and advance new technologies. With the available funding, SECOORA will target low-cost and leveraging options that enhance observing assets or predictive tools so that communities/states can better monitor HABs. Additionally, due to the limited initial funding, SECOORA will prioritize data management needs associated with expanded HAB monitoring rather than investing in educational resources.

This document will be reviewed every two years. During these reviews, the areas of future investment can be modified based on completed activities, changes in funding levels, availability of new technology or shifts in HAB patterns geographically.

4.2.1 SECOORA - Areas of Future Investment

The SECOORA RCOOS Plan highlights potential areas for investment based on the input from regional stakeholders. The SECOORA Science Committee reviews the RCOOS Plan annually, and updates can be made based on new information. This plan is a living document, that should be used as a guiding tool. The following are the current regional priorities as identified in RCOOS Plan.

Observing Assets

- Add additional biogeochemical and biological sensors to existing SECOORA moorings.
- Increase the number of onshore or nearshore coastal stations that collect meteorological and physical oceanographic core variables.
- Use drones to capture images/video footage at regular intervals for detection and tracking of HABs.
- Increase the number of standard and event driven SECOORA glider missions annually in the SAB and GOM.

- Work with partners to deploy autonomous surface vehicles (ASVs) or profiling gliders to collect physical oceanographic and biogeochemical measurements for HABs in ocean waters.

Modeling Assets

- Sustain existing SECOORA-funded coastal ocean circulation models to provide key information of physical oceanographic processes for HAB observing, short-term tracking, and integrated analysis.
- Develop high-resolution ecological or coupled physical-biological HAB models based on existing SECOORA-funded coastal ocean circulation models, specifically the West Florida Shelf Ocean Model and the Tampa Bay Circulation Model, both operated by the University of South Florida.
- Develop ecological models for forecasting HABs.

Data Management and Communications

- Support the analysis of satellite data for HABs detection and tracking.
- Coordinate data and communications with our neighboring regional associations.

Products

- Expand water quality and HAB data products regionally to meet stakeholder needs (e.g., beachgoers, fishermen, aquaculture, and coastal tourism).

Emerging Technologies

- Support development and implementation of emerging technologies to detect HAB species and their toxins.
- Investigate the use of the following technologies in the Southeast: Imaging FlowCytobot (IFCB), Environmental Sample Processor (ESP), and SPATT Bags.

SECOORA's priority will be to initiate, and then sustain, HAB observing, monitoring, and modeling in regional hotspots identified in Section 3 of this HAB plan. In 2022, SECOORA hosted a competitive request for proposals to award the available SECOORA HAB funds (initially $150,000) to support investments within the Southeast that meet priority HAB observing needs as identified in this plan. As future HAB funding is made available, SECOORA will host other grant opportunities to address key HAB species of concern within the region. Additionally, SECOORA will consider existing HAB monitoring activity and capacity within each state, as well as other relevant ongoing work. SECOORA will also work with our neighboring RAs to ensure we are collaboratively supporting HAB monitoring.

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