

Office of National Marine Sanctuaries  
National Oceanic and Atmospheric Administration

GRAY'S REEF NATIONAL MARINE SANCTUARY



# GRAY'S REEF

## CONDITION REPORT

2008–2022

U.S. Department of Commerce  
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National Oceanic and Atmospheric Administration

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**NATIONAL  
MARINE  
SANCTUARIES**

Cover photo: Gray's Reef is a representative area of natural, live-bottom habitat commonly found in the coastal southeast. Photo: Greg McFall/NOAA

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## Office of National Marine Sanctuaries

The Office of National Marine Sanctuaries (ONMS), part of the National Oceanic and Atmospheric Administration (NOAA), serves as the trustee for a system of underwater parks encompassing more than 629,000 square miles of ocean and Great Lakes waters. The 18 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sanctuaries range in size from less than one square mile to more than 582,000 square miles. They serve as natural classrooms, are cherished recreational spots, and are home to valuable commercial industries.

### Gray's Reef National Marine Sanctuary

About 19 miles off the coast of Georgia lies the 22-square-mile Gray's Reef National Marine Sanctuary (GRNMS). The sanctuary protects a dynamic, live-bottom ocean area that supports almost 900 species of invertebrates and 200 species of fish, in addition to other iconic species like sea turtles and migrating whales. Some 60 to 70 feet below the Atlantic Ocean's surface, this vibrant ecosystem is cherished by scuba divers, anglers, scientists, and conservationists. GRNMS strives to protect this unique place for current and future generations through scientific research, education, and conservation initiatives.

## Framework for Condition Reports

Condition reports are used by NOAA to assess the condition and trends of national marine sanctuary resources and ecosystem services. These reports provide a standardized summary of resources in NOAA's sanctuaries, driving forces and pressures on those resources, and current conditions and trends for resources and ecosystem services. These reports also describe existing management responses to pressures that threaten the integrity of the marine environment. Condition reports include information on the status and trends of water quality, habitat, living resources, maritime heritage resources, and the human activities that affect them. They present responses to a set of questions posed to all sanctuaries (Appendix A). The reports also rate the status and trends of ecosystem services (Appendix B). Resource and ecosystem service status are assigned ratings ranging from good to poor, and the timelines used for comparison vary from topic to topic. Trends in the status of resources and ecosystem services are also reported, and unless otherwise specified, are generally based on observed changes in status since the prior condition report.

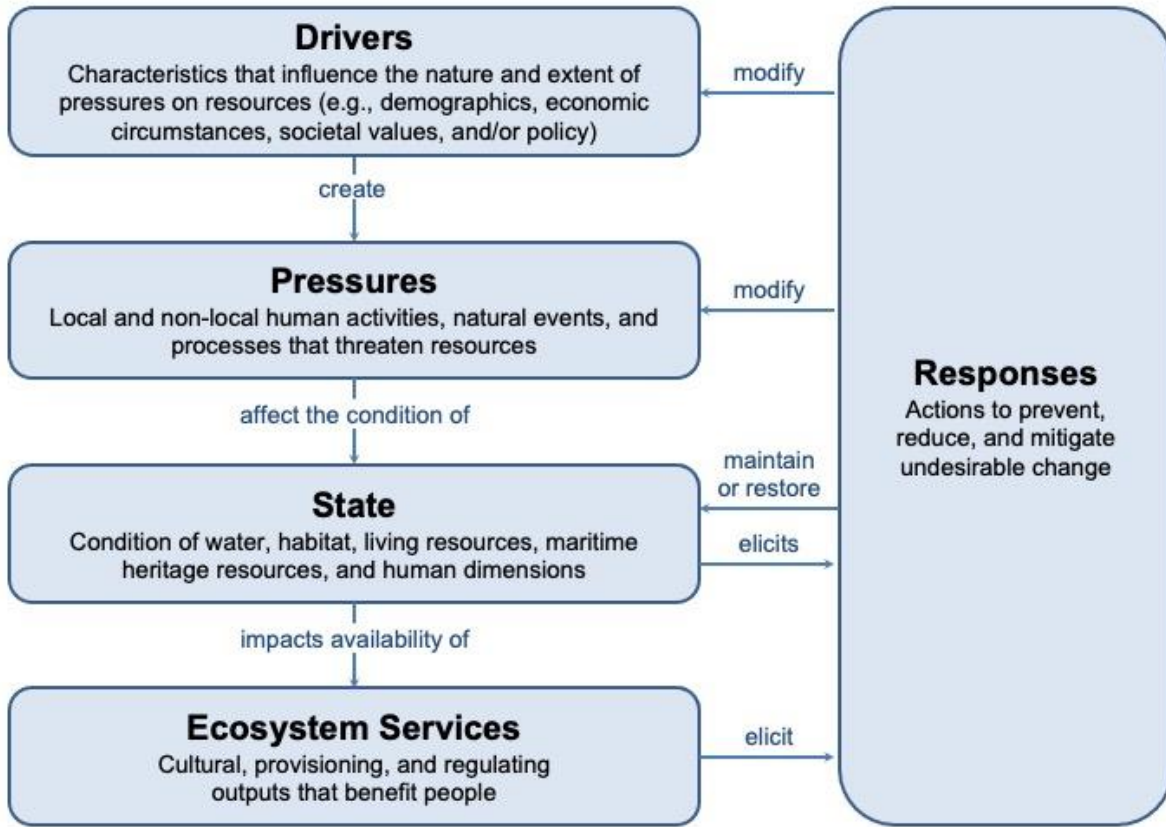
Sanctuary condition reports are structured around two frameworks: 1) a series of questions posed to all national marine sanctuaries; and 2) a management-logic model called the Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response (DPSEER) framework (detailed below). The questions are derived from a conceptual generic model of a marine ecosystem. The DPSEER framework defines the structure of condition reports.

Although the National Marine Sanctuary System's 17 national marine sanctuaries and two marine national monuments are diverse in many ways, including size, location, and resources, condition reports allow ONMS to consistently analyze the status and trends of resources and ecosystem services in each site's ecosystem to inform place-based management. To that end, each unit in the sanctuary system is asked to address the same set of resource questions and ecosystem services, located in Appendix A and Appendix B, respectively. The evolution of the condition report process is described in greater detail below.

### ***DPSEER Framework***

In 2019, ONMS began restructuring sanctuary condition reports based on a model that describes the interactions between driving societal forces (Driving forces), resulting threats (Pressures), the influence of these threats on resource conditions (State), the relationships between resources and people, which may include benefits provided to people (Ecosystem services), and management responses (Response) to control pressures or improve resource conditions. Earlier condition reports were structured around a Pressures-State-Response framework; however, this approach was expanded to better understand the drivers that influence pressures as well as resulting changes in ecosystem service benefits and how these might influence management actions (Office of National Marine Sanctuaries [ONMS], 2018). The DPSEER framework recognizes that human activities, the focus of management actions, are linked to demographic, economic, social, and institutional values and conditions (collectively called drivers). Changes in these drivers influence pressures on natural and heritage resources, affecting their condition. This, in turn, impacts the availability of benefits that humans receive

from the resources (ecosystem services<sup>1</sup>), prompting management responses aimed at preventing, reducing, or mitigating undesirable changes (see Figure FCR.1).



**Figure FCR.1.** This diagram of the DPSER framework illustrates the functional connections between components and the targets of management responses designed to modify driving forces, pressures, and resource conditions. Image: NOAA

<sup>1</sup> For the purposes of this report, ecosystem services are defined as benefits that humans desire from the environment (e.g., recreation, food). They are what link humans to ecosystems, can be goods (e.g., food) or services (e.g., coastal protection), are valued to varying degrees by various types of users, and can be regulated directly by the environment or managed by controlling human activities or ecosystem components (e.g., restoring habitats). Whether or not specific services are rendered can be evaluated directly or indirectly based on attributes of the natural ecosystem that people care about. For example, recreational scuba divers care about water clarity and visibility in coral reef ecosystems. These are attributes that can be measured and factored into status and trend ratings to assess ecosystem services.

## About This Report

The purpose of a condition report is to use the best available science and most recent data to assess the status and trends of various parts of the sanctuary's ecosystem. The first condition report for GRNMS was released in 2008 (ONMS, 2008), and select questions were updated in a 2012 condition report addendum (ONMS, 2012); ratings from those reports are provided in Appendix D. This updated condition report marks a second comprehensive description of the status and trends of sanctuary resources and the first evaluation of the sanctuary's ecosystem services. The findings in this condition report document status and trends of water quality, habitat, living resources, and ecosystem services from 2008–2022 or 2012–2022, depending on whether a given topic was last assessed in the comprehensive 2008 report or in the 2012 addendum. The report helps identify gaps in current monitoring efforts, as well as causal factors that may require monitoring and potential remediation through management actions in coming years. The data presented will not only enable sanctuary resource managers and stakeholders to acknowledge and have a shared perspective on prior changes in resource status, but will also inform management efforts to address challenges stemming from pressures, such as increasing coastal populations and changing ocean conditions.

The findings in this condition report will provide critical support for identifying high-priority sanctuary management actions and will specifically help to shape updates to the GRNMS management plan. The management plan helps guide future work and resource allocation decisions at GRNMS by describing strategies and activities designed to address priority issues and advance core sanctuary programs. The next update to the sanctuary management plan will build on the 2014 management plan, which details a number of actions to address issues and concerns (ONMS, 2014). Updating the management plan will involve significant public input, agency consultation, and environmental compliance work, and, depending on the complexity of the actions proposed, may take one to three years to complete.

The State of Resources section of this document reports the status and trends of water quality, habitat, and living resources from 2010–2022, unless otherwise noted. The State of Ecosystem Services section includes an assessment of human benefits derived from science, education, heritage, sense of place, consumptive recreation, and non-consumptive recreation within the sanctuary.

In order to rate the status and trends of resources, human activities, and ecosystem services, ONMS staff consulted with a group of non-ONMS experts familiar with resources, activities, and services in the sanctuary (Appendix C). These experts also had knowledge of previous and current scientific efforts in the sanctuary. Evaluations of status and trends were based on the interpretation of quantitative and, when necessary, qualitative assessments, as well as observations of scientists, managers, and users.

Two other important changes to the condition report process since the publication of the previous condition report and addendum should be noted. First, in response to feedback provided to ONMS, the process used to generate the current condition report is more quantitatively robust and repeatable. This was achieved by using the NOAA Integrated Ecosystem Assessment framework (National Oceanic and Atmospheric Administration [NOAA],

2020), which takes a data-driven approach to developing indicators for key components of the ecosystem. Status and trend assessments can then be made for the selected indicators over time. This approach ensures that, whenever possible, the expert community has quantitative data representative of core ecosystem components available to them as they contribute to assessment ratings. These indicators continue to be tracked over time, and updated time series data can be used in subsequent assessments.

The second improvement pertains to communication of confidence, which was not done in a consistent way in earlier reports. Determination of confidence is now based on an evaluation of the quality and quantity of data used to determine the rating (e.g., peer-reviewed literature, expert opinion) and the level of agreement among experts (Appendix C). The new approach allows for a consistent and standardized characterization of confidence. The symbols used for status and trend ratings have been modified to depict levels of confidence as judged by the expert panel.

This condition report meets the aforementioned standardized format and framework prescribed for all ONMS condition reports. To the extent possible, authors have attempted to make each section's narrative consistent and comparable in terms of content, detail, and length; however, it is important to understand that each section contains different types and amounts of information given the realities and confines of data sets and expert opinions that were available during this process. Finally, ratings reflect the collective interpretation of sanctuary staff and outside experts based on their knowledge and perception of local conditions. When the group could not agree on a rating, ONMS staff determined the final rating with an acknowledgement of the differences in opinion noted in the report. The interpretation, ratings, and text in this condition report are final and the responsibility of ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report. This report has been peer reviewed and complies with the White House Office of Management and Budget's peer review standards, as outlined in the Final Information Quality Bulletin for Peer Review (White House Office of Management and Budget, 2004).

## Executive Summary

Gray's Reef National Marine Sanctuary (GRNMS), located off the coast of Georgia, was designated in 1981 to protect one of the largest known nearshore "live-bottom" reefs of the southeastern United States. The sanctuary encompasses approximately 22 square miles and is situated roughly 19 miles east-southeast of Sapelo Island, Georgia on the eastern continental shelf of the United States.



GRNMS is an entirely offshore sanctuary, located off the coast of Georgia. Image: NOAA

This condition report uses the best available information to assess the status and trends of the sanctuary's resources and ecosystem services from 2008 to 2022. The report is structured around a Drivers-Pressures-State-Ecosystem Services-Response model (see the earlier section, DPSEER Framework, and Figure FCR.1 for more information on the model). It assesses water quality, habitat, and living resources, as well as the human activities that affect them, and also includes the first evaluation of the status and trends of the sanctuary's ecosystem services—the benefits that humans derive from different ecosystem attributes for their lives, lifestyles, and livelihoods.

### ***Status and Trends of Drivers and Pressures***

The primary pressures on GRNMS water quality, habitat, and living resources were visitation and use; coastal development and nearshore construction; nonpoint source pollution; changing ocean conditions (including ocean warming and acidification); and non-indigenous species. The primary focus of sanctuary management is on activities that can be controlled at the site, such as non-indigenous species and visitation and use. Other pressures act at regional or global scales, and are thus not the focus of local management efforts; however, their impacts on sanctuary resources are addressed in the Status and Trends of Sanctuary Resources section of the report.

### **Human Activities**

The primary human use of GRNMS is recreational fishing, which is an important way that visitors experience and connect with the sanctuary. Recreational fishing and associated vessel use can impact sanctuary water quality, habitat, and living resources through waste disposal and pollution, introduction of marine debris, illegal anchoring, wildlife strikes, noise disturbance, and harvest. Some metrics suggested vessel and recreational angler activity have increased at GRNMS, but most available data sets were regional and not specific to the sanctuary. Passive acoustic monitoring showed that vessel use in the sanctuary elevated ambient noise levels during the study period. Additionally, lost fishing gear was the most common type of marine debris observed in sanctuary habitats; however, no data were available to understand how the introduction of marine debris may have changed over time. Enforcement records showed that illegal fishing and anchoring occurred during the study period, but enforcement patrols and the detection of these violations were both few in number.



Recreational fishing is the most common type of human use at GRNMS. Photo: NOAA

Other common uses of the sanctuary are recreational scuba diving and scientific research. One recreational dive charter is known to visit GRNMS, and the number of private and charter recreational divers at the sanctuary is relatively low due to the site's distance from shore and challenging oceanographic conditions. The majority of scuba diving at GRNMS is for scientific research. Both recreational and scientific diving are believed to have minimal impacts on sanctuary habitats. Broader research activities, such as sample collection and installation of monitoring equipment, can impact habitats and living resources, but GRNMS permitting controls helped ensure no major disturbances occurred during the assessment period. Marine research often requires the sustained presence of large research vessels within the sanctuary. While this increases the risk of impacts to the sanctuary from spills, no significant spills or discharges occurred within the sanctuary from this or other vessel activity during the study period.



Installation of scientific instruments can affect GRNMS habitats, but impacts are believed to be minimal. Photo: G. McFall/NOAA

Coastal development can negatively impact water quality via increased runoff and associated introduction of contaminants, and can also negatively impact nearshore nursery habitats for species that use the sanctuary as adults. During the study period, areal cover of saltwater marsh habitat in coastal Georgia remained stable, while areal cover of impervious surfaces grew slightly.

## ***Status and Trends of Sanctuary Resources***

In addition to evaluating human activities, the condition report rates the status and trends of water quality, habitat, living resources, and ecosystem services in GRNMS based on data indicators for each focal area. Criteria for indicator selection included: long-term data availability, importance to the ecosystem and culture, responsiveness to changes in environmental conditions, measurability, relevance to standardized sanctuary condition report questions, and responsiveness to management actions. The section below summarizes the most noteworthy results.

## Water Quality

No evidence of eutrophication was observed at GRNMS. Indicators of eutrophication, including chlorophyll *a* concentrations and anomalies, dissolved oxygen, and turbidity, generally exhibited consistent and expected seasonal patterns. Sanctuary-specific data on human health indicators were limited; available data, including regional data, suggest sanctuary waters pose few risks to human health. Recommendations to limit consumption of king mackerel and black sea bass, two commonly fished species at the sanctuary, were issued during the study period due to elevated levels of mercury and arsenic, respectively. Although there was little evidence to suggest human health impacts, increased monitoring of human health indicators within sanctuary boundaries is needed to fully inform this question.



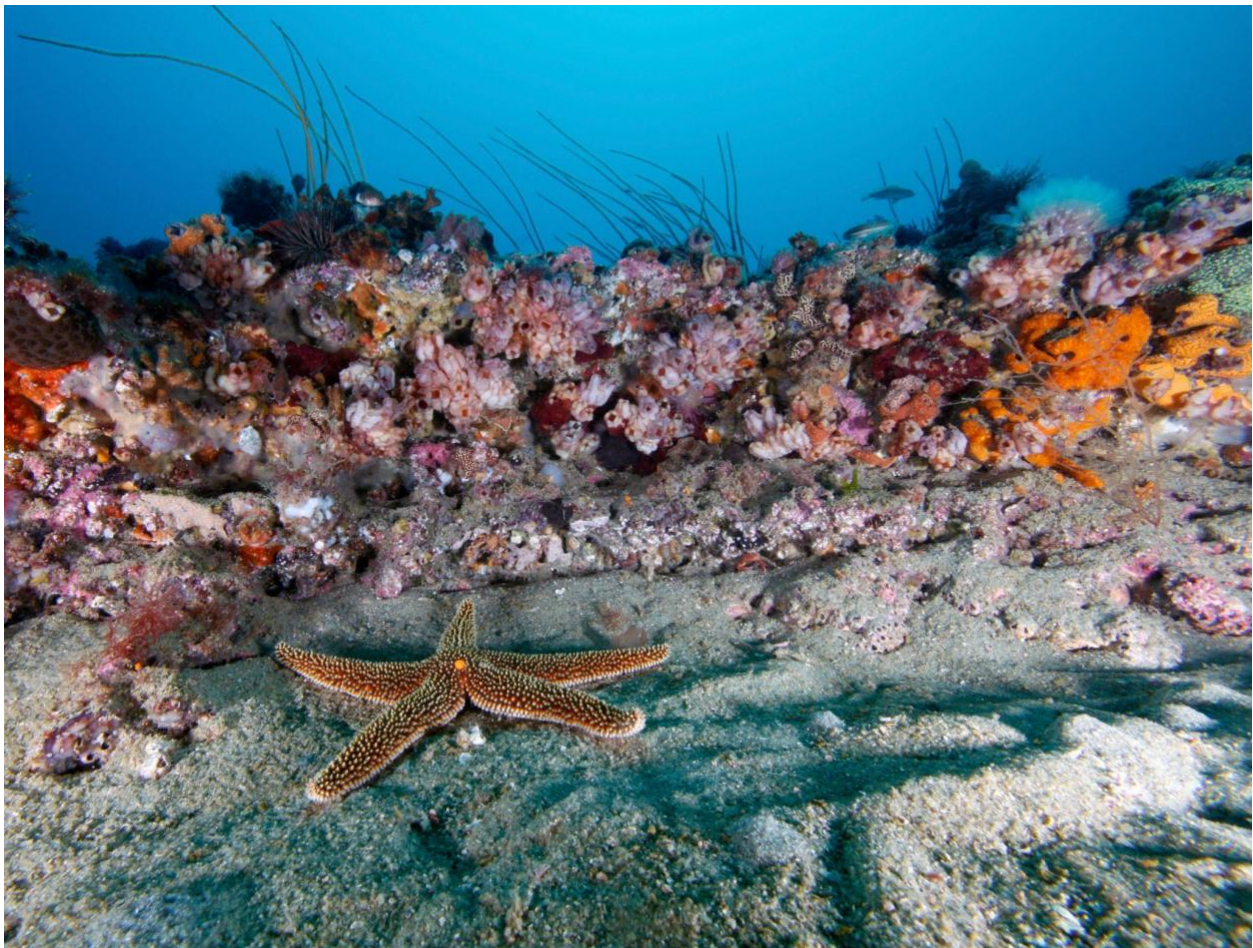
Black sea bass are a popular target species among fishers at GRNMS. Photo: G. McFall/NOAA

Although changing ocean conditions did not result in measurable resource impacts at GRNMS during the study period, changes in a number of parameters occurred on a regional scale. Sea surface temperature increased, marine heatwaves became more frequent, and the number of annual storms increased. Additionally, atmospheric CO<sub>2</sub> increased, resulting in greater transfer of CO<sub>2</sub> into sanctuary waters, which makes water more acidic, threatening marine organisms.

Contaminant discharges from vessels were another concern for GRNMS water quality. Although some spills occurred regionally during the study period, none were reported within sanctuary boundaries, nor was any spilled material observed in the sanctuary. However, the impact of regional events on sanctuary waters remains unknown due to a lack of sampling for contaminants in the water column.

## Habitat

Although GRNMS is known for its live-bottom reefs, most of the seafloor within the sanctuary's boundaries is composed of unconsolidated soft sediment, which provides habitat for a wide variety of infaunal invertebrates. Changes to habitats in the sanctuary, including physical attributes of live-bottom ledge structures, which are associated with species richness, diversity, and abundance, are largely believed to be driven by natural processes. However, there is a need to analyze and compare more recent benthic profile data to understand whether any substantial changes in habitat distribution occurred; this constitutes an analysis gap for this report. Cover of habitat-forming sessile benthic invertebrates, including sponges, tunicates, and the coral *Oculina arbuscula*, was stable. Anthropogenic noise was detected in acoustic studies of the sanctuary, but was relatively low compared to some other national marine sanctuaries, and was largely attributed to short-duration vessel transits through the sanctuary.



Live-bottom habitats in the sanctuary are characterized by cover of a wide range of benthic invertebrate species. Photo: G. McFall/NOAA

Data on contaminants in sanctuary habitats were limited, but available studies indicated most contaminants were undetectable or below thresholds for concern in GRNMS sediments. However, microplastics were found in all sediment samples collected in 2021, and are an emerging concern. Some samples of biota from the sanctuary had elevated levels of

contaminants, including cadmium and arsenic, suggesting the presence of contaminants in the local environment. Testing of sediment and biota samples for a full suite of contaminants last occurred in 2012–2013; newer data are needed to fully assess the status and trends of contaminants in the sanctuary.

### Living Resources

Focal species are those important for economic, cultural, spiritual, recreational, ecological, or conservation-related reasons, as well as those that may be subject to special state or federal protections. Some GRNMS focal species reside in the sanctuary year-round (red snapper, tomtate, black sea bass, king mackerel, the coral *Oculina arbuscula*, and *Halymenia* spp. algae), while others are wide-ranging species known to transit through the sanctuary (loggerhead sea turtles, North Atlantic right whales, and sand tiger sharks). Given the diversity of indicator species assessed, the status and trends of focal species were mixed. Resident fish species and *Oculina arbuscula* remained stable or improved within the sanctuary (however, sanctuary-specific trends may not match regional trends for these species). Conversely, North Atlantic right whales remained endangered and experienced an unusual mortality event during the study period. Data gaps precluded a complete understanding of the status and trends of loggerhead sea turtles, sand tiger sharks, and *Halymenia* spp. within the sanctuary.



Loggerhead turtles are charismatic focal species at GRNMS. Photo: G. McFall//NOAA

The abundances of non-indigenous species, including lionfish, titan acorn barnacle, and orange cup coral, were low. However, species typically found in tropical waters have been newly observed or are becoming more abundant in GRNMS, likely as a result of increases in seawater temperatures in the sanctuary. These species include lane snapper, red grouper, yellowtail snapper, the branching vase sponge *Callyspongia aculeata*, and the macroalgae *Platoma gelatinosum*. More systematic and frequent monitoring is needed to fully understand any impacts of these potential range shifts on GRNMS biodiversity. Available data suggest fish and benthic community structure has remained stable. However, most biodiversity data have been collected in the summer season; year-round monitoring is needed to better understand how biodiversity metrics may change seasonally.

### **Status and Trends of Ecosystem Services**

Ecosystem services evaluated in the report included science, education, heritage, sense of place, consumptive recreation, and non-consumptive recreation.

GRNMS is valued as a longstanding scientific research site in the South Atlantic region. Most indicators of scientific research activity, including the number of permits issued, publications, and active projects, were stable. However, the availability of vessel platforms for conducting research was limited during the study period, and was insufficient to meet GRNMS science goals. Similarly, educational programming was hindered by staffing shortages during the study period. However, programming and exhibits by partner institutions, as well as virtual engagement through the GRNMS webpage, social media accounts, and interactive touchscreen kiosks, provided key opportunities to learn about the sanctuary. In 2022, the Gray's Reef Ocean Discovery Center was dedicated; though this occurred at the end of the study period, it represents a significant improvement in the ability of GRNMS to provide education and outreach.

Increasing recognition and awareness of past and modern human connections to GRNMS have helped to define its heritage. Artifacts recovered from the sanctuary provide evidence of human habitation of the area now designated as GRNMS when it was fully terrestrial (approximately 3,000 to 13,000 years before present). Information on more recent heritage ties between Indigenous Peoples and the sanctuary remains a data gap. Within the past century, the heritage of GRNMS has largely been shaped by its marine research legacy; Milton "Sam" Gray, the sanctuary's namesake, conducting trailblazing studies of the sanctuary's unique ecology. These studies and many since have helped to expand recognition of the sanctuary's value for scientific research, ultimately supporting the establishment of the sanctuary's designated Research Area in 2011. GRNMS and the surrounding region also have strong heritage connections to fishing, which has remained important across generations. Fishing has also historically been an important component of Gullah/Geechee culture. The experiences of Gullah/Geechee and other fishers in coastal Georgia waters and GRNMS have been documented in oral histories.

Creating a sense of place for GRNMS has been challenged by a lack of awareness about the sanctuary among most people, although indications of improvement were documented during the study period. Increased public awareness of the sanctuary has been promoted through news, journal, and magazine articles; research publications; television programs; video documentaries; educational exhibits; social media; and special outreach events. GRNMS is

known among anglers as a valued sport fishing and recreational diving destination, and its sense of place is strengthened by the presence of iconic species valued for fishing and wildlife viewing, including red snapper, king mackerel, black sea bass, loggerhead turtles, and North Atlantic right whales. More information is needed to fully assess this ecosystem service, including dedicated studies of sense of place, and particularly information on sense of place among the Gullah/Geechee people as it relates to GRNMS.

Consumptive recreation, specifically recreational fishing, is an important ecosystem service provided by the sanctuary. Regional and sanctuary-specific data suggested that this service remained stable during the study period. Because of its distance from shore, recreational fishers visit GRNMS less frequently than inshore sites. Those who do visit the sanctuary had mixed opinions about the status of pelagic fish populations, with approximately equal proportions reporting they perceived these resources were improving, not changing, or getting worse.

Non-consumptive recreational activities at GRNMS include scuba diving and boating, however these activities are also somewhat limited by the sanctuary's distance from shore, as well as ocean conditions and weather. Although the number of divers known to visit the sanctuary may be limited, those who do visit value it, as evidenced by numerous repeat dive charter customers. Awareness of the uniqueness of GRNMS as a diving destination has also increased over time.



GRNMS is highly valued as a recreational diving destination, but relatively few divers visit due to its distance from shore and challenging ocean conditions. Photo: G. McFall/NOAA

## ***Response to Pressures***

During the study period, GRNMS responded to pressures through regulatory measures, education and outreach, and other initiatives. One of the most significant regulatory changes during the study period was the designation of a dedicated Research Area in the southern third of the sanctuary. Fishing, diving, transporting unsecured fishing gear, and stopping a vessel are prohibited within the Research Area. Additionally, GRNMS maintained sanctuary-wide prohibitions on activities that may harm the sanctuary, including anchoring of vessels and harvest of marine organisms by methods other than rod and reel.

GRNMS has also worked to inform the public about the sanctuary's unique ecology and regulations in place to protect it. Education and outreach efforts have included virtual reality dive tours of GRNMS; web and social media content; magazine articles; interpretive signage at boat ramps and marinas; and collaborative sanctuary exhibits at partner institutions. The GRNMS Sanctuary Advisory Council includes representatives from a wide variety of user and other interest groups, including the sport fishing and recreational diving communities, two of the biggest sanctuary user groups. GRNMS has developed specific outreach materials for fishers and divers to share information and best practices for responsible use of the sanctuary.



Management responses are designed to protect all GRNMS resources. Photo: G. McFall/NOAA

Scientific research activities during the study period have helped to inform management action. For example, studies of vessel activity at GRNMS have aided in understanding patterns of use. Sanctuary managers rely upon data streams from National Data Buoy Center station 41008 (located within the sanctuary), which provides real-time weather and safety information to sanctuary users, but also generates key oceanographic data to aid GRNMS in monitoring and understanding changing ocean conditions. Scientific partnerships with government, academic, and nonprofit organizations have helped to leverage these data and generate new information about sanctuary biology, ecology, chemistry, paleolandscapes, and more. The potential impacts of scientific research itself continue to be managed through careful permitting and review of after-action reports.

Although GRNMS does not have management authority over coastal and offshore development, it works with various partners and the Sanctuary Advisory Council concerning activities that may affect the sanctuary. For example, the advisory council sent a letter to the U.S. Bureau of Ocean Energy Management in 2015 opposing a proposed draft oil and gas leasing program for the continental shelf within the Atlantic Region due to potential negative impacts on the sanctuary. The GRNMS Advisory Council has also worked to develop marine conservation recommendations and needs for the South Atlantic Bight in response to the America the Beautiful initiative, which aims to protect 30% of U.S. lands and waters by 2030. GRNMS also coordinates with law enforcement agencies to optimize patrols of the sanctuary based on known vessel use patterns to ensure compliance with protective regulations.

## Conclusion

The sanctuary's offshore location limits direct human pressures on water quality, habitat, and living resources, and most data suggest that observed changes in the sanctuary have been largely driven by natural factors, resulting in status ratings of good to good/fair for GRNMS resources. However, temperature, CO<sub>2</sub> levels, and storm frequency increased, and some focal species for GRNMS, such as North Atlantic right whales, faced ongoing problems. A number of data gaps precluded a full assessment of trends in some aspects of water quality, contaminants, and the status and trends of some focal species. Ecosystem services were in good/fair to fair condition. Particular challenges included a lack of staff capacity to provide sanctuary education and outreach opportunities during the study period and a lack of awareness of the sanctuary among the general public. However, increasing awareness and the recent dedication of the Gray's Reef Ocean Discovery Center resulted in an improving trend for both education and sense of place. This condition report will support the development of a new management plan, and its findings will serve as an important foundation to help GRNMS set future priorities based on identified needs and ensure current management and regulatory responses are adequate. GRNMS staff will be fully evaluating the data gaps and information needs highlighted in this report to ensure the next management plan addresses the highest priority topics and management actions.



Colorful invertebrates are part of the diverse resources protected by GRNMS. Photo: G. McFall/NOAA

# Gray's Reef National Marine Sanctuary

## Summary of Resource Conditions

The various resource status and trend evaluations presented in this report are summarized below. Each question used to rate the condition of and trends in sanctuary resources is listed, followed by:

- 1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status, the next symbol indicates trend, and a shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
- 2) The status description, which is a statement that best characterizes resource status and corresponds to the assigned color rating and definition as described in Appendix A. The status description statements are customized for all possible ratings for each question.
- 3) The rationale, which is a short statement or list of criteria used to justify the rating.

<b>Status:</b>	
<div style="display: flex; justify-content: space-around; margin: 0 auto; width: 80%;"> <div style="background-color: #008000; color: white; padding: 5px 10px; border: 1px solid black;">Good</div> <div style="background-color: #90EE90; padding: 5px 10px; border: 1px solid black;">Good/Fair</div> <div style="background-color: #FFD700; padding: 5px 10px; border: 1px solid black;">Fair</div> <div style="background-color: #FFA500; padding: 5px 10px; border: 1px solid black;">Fair/Poor</div> <div style="background-color: #DC143C; padding: 5px 10px; border: 1px solid black;">Poor</div> <div style="background-color: #D3D3D3; padding: 5px 10px; border: 1px solid black;">Mixed</div> <div style="background-color: #696969; padding: 5px 10px; border: 1px solid black;">Undetermined</div> </div>	
<b>Trend:</b>	
<div style="display: flex; justify-content: space-around; margin: 0 auto; width: 80%;"> <div style="text-align: center;">▲ = Improving</div> <div style="text-align: center;">— = Not Changing</div> <div style="text-align: center;">▼ = Worsening</div> </div> <div style="display: flex; justify-content: space-around; margin: 0 auto; width: 80%; margin-top: 10px;"> <div style="text-align: center;">◄ = Mixed</div> <div style="text-align: center;">? = Undetermined</div> <div style="text-align: center;">NR = Not Rated</div> </div>	
<b>Confidence Scale:</b> <div style="margin-top: 5px;">             Very High = <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000; margin-right: 5px;"></span> <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000; margin-right: 5px;"></span> <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000; margin-right: 5px;"></span> <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000; margin-right: 5px;"></span> <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> </div> <div style="margin-top: 5px;">             High = <span style="display: inline-block; width: 15px; height: 10px; background-color: #808080; border: 1px solid #000; margin-right: 5px;"></span> <span style="display: inline-block; 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justify-content: center; align-items: center; gap: 10px;"> <span style="display: flex; gap: 2px;"> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> </span> <span style="background-color: #FFD700; padding: 5px 10px; border: 1px solid black; font-weight: bold;">Fair</span> <span style="text-align: center;">▼</span> <span style="display: flex; gap: 2px;"> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> <span style="width: 15px; height: 10px; background-color: #808080; border: 1px solid #000;"></span> </span> </div> </div>

## Pressures

**What are the levels of human activities that may adversely influence water quality and how are they changing?**



**Status Description:** Few or no activities occur that are likely to negatively affect water quality.

**Rationale:** Salt marsh cover remained stable in coastal Georgia, although impervious surface cover increased slightly. Vessel registrations in coastal Georgia increased from 2015–2021, potentially increasing the risk of vessel discharge within the vicinity of the sanctuary. However, no spills were reported in GRNMS from 2008–2022.

**What are the levels of human activities that may adversely influence habitats and how are they changing?**



**Status Description:** Some potentially harmful activities exist, but they have not been shown to degrade habitat quality.

**Rationale:** Activities that could harm habitats, including recreational fishing, research activities, and scuba diving, occur regularly at GRNMS. However, available data suggest they did not occur at levels that resulted in measurable habitat impacts during the study period.

**What are the levels of human activities that may adversely influence living resources and how are they changing?**



**Status Description:** Some potentially harmful activities exist, but they have not been shown to degrade living resource quality.

**Rationale:** Vessel registrations and activity increased during the study period, but vessel activity was generally seasonal, peaking in summer. The majority of vessels visiting the sanctuary engaged in fishing. The number of recreational fishing trips and landings in federal waters offshore of Georgia were higher during the current study period compared to historical levels; trends were stable during the study period, except for an increase in the number of fish caught and released. Recreational fishing information and fishery-independent data specific to GRNMS were lacking, but experts agreed that although fishing pressure should be further examined in the sanctuary, it likely occurred at sustainable levels during the study period.<sup>2</sup>

<sup>2</sup> Due to time constraints, a status rating for this question was not determined during the expert workshop. This status rating was determined later by GRNMS staff, who reevaluated the indicators, data sets, and expert input provided during the workshop.

## Water Quality

### *What is the eutrophic condition of sanctuary waters and how is it changing?*



**Status Description:** Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

**Rationale:** Chlorophyll concentration and anomalies varied seasonally but were stable overall, nutrient levels were low, evidence of short-term hypoxia events was limited, and seasonal trends in turbidity and riverine input were consistent.

### *Do sanctuary waters pose risks to human health and how are they changing?*



**Status Description:** One or more water quality indicators suggest the potential for human health impacts, but human health impacts have not been reported.

**Rationale:** Mercury contamination advisories were issued for one targeted fish species, and one study found heavy metals in biota that exceeded some consumption advisories. No ciguatera fish poisoning cases were reported, and only one day of favorable conditions for *Vibrio* spp. was observed during the study period for this report. No offshore phytoplankton data were available to assess harmful algal blooms. Many available human health metrics rely on data from outside the sanctuary.

### *Have recent, accelerated changes in climate altered water conditions and how are they changing?*



**Status Description:** Climate-related changes are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** Changes in a number of key climate parameters (e.g., increasing temperature, increasing storm frequency, increasing CO<sub>2</sub>) were detected, but no large impacts on or measurable degradation of resources were observed from 2012–2022.

***Are other stressors, individually or in combination, affecting water quality and how are they changing?***



**Status Description:** Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** No contaminant discharges from vessels were reported within the boundaries of GRNMS during the study period. Discharge of contaminants (primarily petroleum) did occur within 100 kilometers of the sanctuary, although there was no trend in the number of incidents or volume of material released during the study period. No direct sampling of GRNMS waters for contaminants associated with these regional events has occurred, representing an important knowledge gap.

**Habitat**

***What is the integrity of major habitat types and how are they changing?***



**Status Description:** Habitats are in near-pristine condition.

**Rationale:** Available data suggest no changes to habitat at GRNMS other than those likely from natural processes (e.g., storm activity, sand movement). New and ongoing monitoring is required to increase understanding of the dynamics of sanctuary habitat integrity.

***What are contaminant concentrations in sanctuary habitats and how are they changing?***



**Status Description:** Selected contaminants are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** Some contaminants were present in GRNMS sediments and biota, but they were detected at low levels that would not be expected to significantly degrade ecological integrity. However, data on contaminants were limited to one or few time points.

## Living Resources

### What is the status of other focal species and how is it changing?



**Status Description:** Conflicting signals from indicators prevent the selection of a singular status rating.

**Rationale:** Select focal fish (red snapper, tomtate, black sea bass, king mackerel) and coral (*Oculina arbuscula*) species remained stable or improved within GRNMS during the study period. Conversely, North Atlantic right whales are endangered and experienced an unusual mortality event during the study period. For other species, including loggerhead sea turtles, sand tiger sharks, and *Halymenia* spp. algae, data were too limited to determine status or trends.<sup>3</sup>

### What is the status of non-indigenous species and how is it changing?



**Status Description:** Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.

**Rationale:** To date, the abundances of non-indigenous species in GRNMS have been low, and impacts have not been observed nor are they suspected. Limited data suggest high variability and no consistent trends across most indicators.

### What is the status of biodiversity and how is it changing?



**Status Description:** Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

**Rationale:** Biodiversity data were available for fish and invertebrates, but were limited for infauna and macroalgae, which are particularly important, as they are indicators for climate change. Metrics for observed species appeared to be stable; however, there is lack of information regarding species turnover, as well as for observed increases of tropical fishes.

<sup>3</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

## Gray's Reef National Marine Sanctuary Summary of Ecosystem Services

The various ecosystem service evaluations presented in this report are summarized below. Each ecosystem service is listed, followed by:

- 1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status, the next symbol indicates trend, and a shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
- 2) The status description, which is a statement that best characterizes status and corresponds to the assigned color rating and definition as described in Appendix B.
- 3) The rationale, which is a short statement or list of criteria used to justify the rating.

<b>Status:</b>	
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="background-color: #008000; color: white; padding: 5px 10px; border: 1px solid black;">Good</div> <div style="background-color: #90EE90; padding: 5px 10px; border: 1px solid black;">Good/Fair</div> <div style="background-color: #FFD700; padding: 5px 10px; border: 1px solid black;">Fair</div> <div style="background-color: #FFDAB9; padding: 5px 10px; border: 1px solid black;">Fair/Poor</div> <div style="background-color: #DC143C; color: white; padding: 5px 10px; border: 1px solid black;">Poor</div> <div style="background-color: #D3D3D3; padding: 5px 10px; border: 1px solid black;">Mixed</div> <div style="background-color: #696969; padding: 5px 10px; border: 1px solid black;">Undetermined</div> </div>	
<b>Trend:</b>	
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">▲ = Improving</div> <div style="text-align: center;">— = Not Changing</div> <div style="text-align: center;">▼ = Worsening</div> </div> <div style="display: flex; justify-content: space-around; align-items: center; margin-top: 10px;"> <div style="text-align: center;">◄ = Mixed</div> <div style="text-align: center;">? = Undetermined</div> <div style="text-align: center;">NR = Not Rated</div> </div>	
<b>Confidence Scale:</b> <div style="margin-left: 20px;">             Very High = <span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span> </div> <div style="margin-left: 20px; margin-top: 5px;">             High = <span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span> </div> <div style="margin-left: 20px; margin-top: 5px;">             Medium = <span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span> </div> <div style="margin-left: 20px; margin-top: 5px;">             Low = <span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span> </div> <div style="margin-left: 20px; margin-top: 5px;">             Very Low = <span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span><span style="display: inline-block; width: 15px; height: 10px; background-color: #000; margin-right: 5px;"></span> </div>	<b>Example:</b> This symbol indicates the condition was rated "fair" with "medium confidence" and a "worsening" trend with a "very high confidence." <div style="margin-top: 10px; text-align: center;"> <div style="display: flex; justify-content: center; gap: 10px; font-size: 0.8em;"> <span>Confidence</span> <span>Status</span> <span>Trend</span> <span>Confidence</span> </div> <div style="display: flex; justify-content: center; align-items: center; gap: 10px; margin-top: 5px;"> <span style="display: flex; gap: 2px;"> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> </span> <span style="background-color: #FFD700; padding: 5px 10px; border: 1px solid black; font-weight: bold;">Fair</span> <span style="text-align: center;">▼</span> <span style="display: flex; gap: 2px;"> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> <span style="width: 15px; height: 10px; background-color: #000;"></span> </span> </div> </div>

## Cultural Services (Non-Material Benefits)

### Science — *The capacity to acquire and contribute information and knowledge*



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** GRNMS has supported scientific activities throughout the study period and is a valued site for scientific research in the South Atlantic region. Research activity, publications, and public support for research remained consistent throughout the study period; however, some limitations on vessel availability may have affected the overall capacity for science during the study period.<sup>4</sup>

### Education — *The capacity to acquire and provide intellectual enrichment*



**Status Description:** The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

**Rationale:** Staffing limitations hindered the ability of GRNMS to provide some education programming and community events during the study period; however, external partnerships and volunteers aided in filling this gap. Virtual engagement via the GRNMS website and social media generally remained stable, and a website redesign in early 2023 increased site traffic. Exhibits at partner institutions provided key opportunities to learn about the sanctuary, and interactive kiosks helped increase engagement. The dedication of the Gray’s Reef Ocean Discovery Center in 2022 was an important step toward increasing site capacity for education and outreach.

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<sup>4</sup> Due to time constraints, a trend rating and associated confidence score for this question were not determined during the expert workshop. This trend rating and associated confidence score were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

**Heritage — Recognition of historical and heritage legacy and cultural practices**



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** Recent research has improved the understanding of past human connections and demonstrated that the region that is now GRNMS was used by prehistoric cultures. In recent history, GRNMS has developed a legacy as an important site for scientific research. Coastal Georgia and GRNMS have strong heritage connections to fishing, documented in recent years through development of extensive oral history archives. Gullah/Geechee cultural ties to fishing, ocean use, and scientific discoveries at GRNMS have also been documented through oral histories. While knowledge and understanding of heritage connections to GRNMS and surrounding waters have increased, more information is needed, particularly to understand the connections between the sanctuary and Indigenous peoples, both in the past and today.

**Sense of Place — Aesthetic attraction, spiritual significance, and location identity**



**Status Description:** The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

**Rationale:** For people who are aware of and appreciate Gray’s Reef, the sanctuary’s aesthetic attraction, significance, and location identity remain strong. Proxy measures such as recreational fishing activity, popularity of iconic marine species, and interest in scuba diving reflected this value. Although awareness of the sanctuary improved during the study period, lack of awareness among most people remained a problem. Appreciation of Gray’s Reef predates GRNMS, but efforts to measure the sense of place ecosystem service are new. Ocean user surveys have not previously targeted sense of place values, so more complete and direct data for understanding this service is needed.<sup>5</sup>

<sup>5</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

**Consumptive Recreation — Recreational activities that result in the removal of or harm to natural or cultural resources**



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** Surveys of fishing permit holders, observations of vessels, vessel registration data, and recreational landings data indicate that waters off the coast of Georgia, including GRNMS, continue to provide opportunities for recreational fishing. However, many available data sets were not specific to the sanctuary. Experts noted that while some key species remain plentiful in the sanctuary, the ability to harvest others has declined due to new federal regulations. The available evidence, though limited for GRNMS specifically, does not suggest significant changes in use of the sanctuary for consumptive recreation.

**Non-Consumptive Recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources**



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

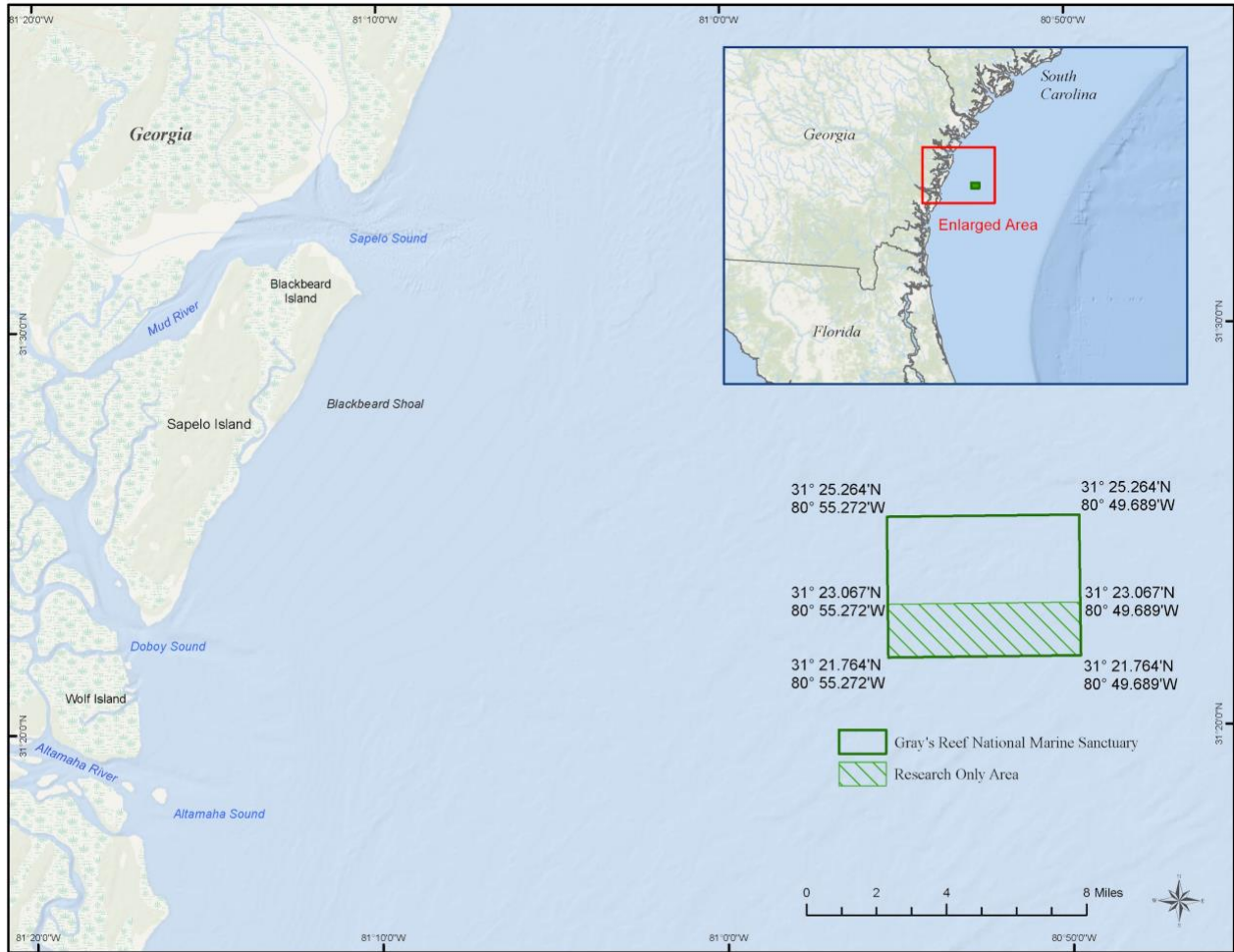
**Rationale:** Opportunities for non-consumptive recreation, specifically boating and scuba diving, are available in GRNMS. However, some opportunities are limited by a lack of infrastructure (i.e., mooring buoys for diving), the sanctuary’s distance from shore, and economic factors (e.g., cost to get to the sanctuary). Although data were limited, vessel presence and transits, as well as awareness of and demand for diving in the sanctuary have increased.

## Sanctuary Setting

### Overview

Gray's Reef National Marine Sanctuary (GRNMS), located off the east coast of Georgia, is one of the largest known nearshore “live-bottom” reefs of the southeastern United States. Live bottom refers to hard or rocky seafloor that typically supports high numbers of large invertebrates, such as sponges, soft corals, and sea squirts. The sanctuary encompasses approximately 22 square miles (about 5.5 by 4.0 miles) and is situated roughly 19 miles east-southeast of Sapelo Island, Georgia on the eastern continental shelf of the United States, west of the Blake Plateau (Figure SS.1). The depth of the sanctuary ranges between 55 and 70 feet below mean sea level. GRNMS is currently the only protected natural reef area on the continental shelf off the Georgia coast, and one of only a few natural marine protected areas in the ocean between Cape Hatteras, North Carolina and Cape Canaveral, Florida.

Although GRNMS comprises just a small part of the U.S. territorial Atlantic Ocean, its value as a natural marine habitat is recognized nationally and internationally, and it has served as a living laboratory for the long-term study of live-bottom habitats and ocean conditions in the South Atlantic Bight. The sanctuary's legacy of scientific research began prior to designation, continued with the establishment of a research-only area in 2011 (the “Research Area”), and includes studies that have produced critical scientific knowledge on regional climate change and ocean acidification, weather modeling, the dynamics of invertebrate and fish populations, and continental shelf live-bottom bathymetry. Its unique biodiversity also draws recreational fishers and scuba divers. Although GRNMS is an offshore sanctuary accessible only by boat, its well-known location and detailed mapping make it easier to visit than other offshore reefs. Sanctuary managers promote its sustainable recreational use.



**Figure SS.1.** The location of GRNMS relative to the coastline of Georgia and the southeastern United States. Image: Tony Reyer/NOAA

## History

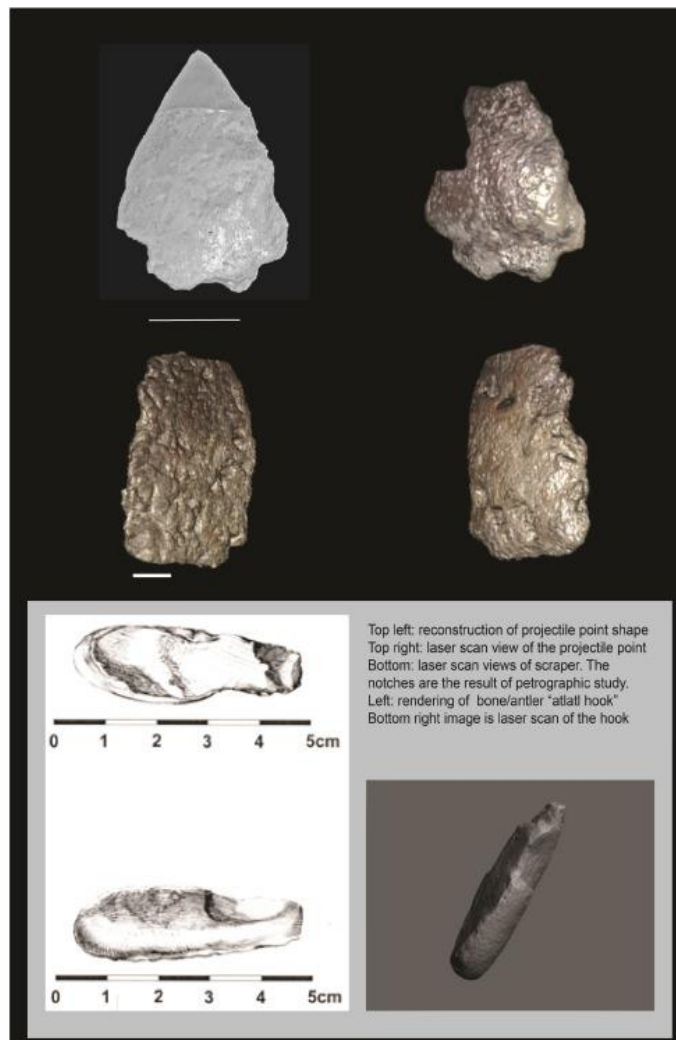
### Geologic History

The earliest relevant formation of the eastern continental shelf, including Gray's Reef, began during the Pliocene epoch (5.3–2.6 million years BP; Garrison et al., 2016), with the consolidation of ocean and terrestrial sediments (sand, shell, and mud) that were laid down as loose aggregate. Following consolidation of these sediments during the Pleistocene epoch (2.6 million–11,700 years BP), the coastal plain and continental shelf saw multiple changes in sea level. Driven by glacial periods, sea level rose and fell at least seven times, periodically exposing the sanctuary and surrounding continental shelf as land. This cycle caused layers of sediments to collect while underwater and compact when exposed to air, gradually building the calcareous sandstone strata below Gray's Reef. The rocky ledges and outcrops within the sanctuary were last exposed as land 11,500 to 10,800 years BP. Notably, periods in which Gray's Reef was exposed as land resulted in the accumulation of mammalian fossils, including horse, camel, deer/antelope, extinct species of gray whale, mammoth, and bison, as well as artifacts associated with human habitation (Garrison et al., 2016).

## Regional Cultural History

The state of Georgia is the closest shoreline to GRNMS. The cultural history of coastal Georgia and the South Atlantic Bight region spans centuries of interactions that connect people and cultures, from Indigenous tribes and nations to European settlers and enslaved Africans and their descendants.

Prior to European colonization, Indigenous peoples, including the Muscogee (Creek), Yuchi, and Guale (pronounced “wah-leh”), inhabited the coastal plains and barrier islands. These Indigenous peoples established societies with unique cultural practices, including intricate pottery, shell mound construction, and ceremonial rites that reflected their deep connection to the land and sea. Cultural artifacts from the Clovis Period (13,050 to 12,750 years BP), including an arrowhead and a scraper, have been found at GRNMS (Figure SS.2). These objects would have been used by Indigenous peoples when humans inhabited the area that is now Gray’s Reef as land (Garrison et al., 2016).



**Figure SS.2.** Laser scans and renderings of artifacts found at GRNMS. Scale bars for projectile point and scraper are each 10 mm. Laser scans furnished by the Laboratory of Archeology, University of Georgia. Image: Garrison et al., 2016

The arrival of European explorers and settlers in the 16th century brought significant changes to the region's cultural landscape. Spanish missionaries established missions along the coast, with the intent to convert Indigenous peoples to Christianity and assimilate them into Spanish colonial society. Meanwhile, British colonization efforts led to the establishment of Georgia as a British colony in 1733, with James Oglethorpe founding the city of Savannah as its capital. The City of Savannah was founded on the traditional lands of the Yamacraw Tribe.

The plantation economy that emerged in coastal Georgia relied heavily on the labor of enslaved people who originated primarily from West Africa through kidnapping and forced migration. Varied cultural influences of these peoples, including languages, religions, and culinary traditions, are integral components of the American South's cultural heritage. The Gullah/Geechee Nation, descendants of enslaved Africans, preserved their unique language, Gullah, and cultural practices, contributing to the region's unique blend of cultures.

The Gullah/Geechee Nation has a spiritual connection with the waters of the South Atlantic Bight. The often heard Gullah Geechee proverb “de wata bring we and de wata gwine tek we bak” connects the nation's ancestral traditions with these waters (Suatoni et al., 2024). The South Atlantic Bight ocean region is also the resting place of Gullah/Geechee ancestors who did not survive the forced migration across the Atlantic, known as “the Middle Passage.”

The American Civil War and Reconstruction era marked a tumultuous period in the region's history, with coastal Georgia experiencing significant social and economic upheaval. Following the abolition of slavery, the rise of Jim Crow segregation laws fostered continued societal divisions and disparities that persist today. In the 21st century, the legacies of Indigenous tribes and nations, African peoples, and European settlers continue to contribute to the cultural tapestry of coastal Georgia.

### Sanctuary History

GRNMS is named in honor of Milton B. “Sam” Gray, a biological collector, taxonomist, and curator at the University of Georgia Marine Institute. Gray conducted the first known survey of the reef in 1961 (see Heritage in the Status and Trends of Ecosystem Services chapter of this report for more information). Previously known as “Sapelo Live Bottom,” the reef's current name was first proposed in a thesis by graduate student Jesse Hunt, which resulted from his first intensive study of the reef in 1974 under the direction of Dr. V.J. Henry. The Georgia Department of Natural Resources adopted the name when it nominated the reef for consideration as a national marine sanctuary in 1978. The designation process officially began in 1980, and included formal consultations with agency partners, as well as public hearings and feedback, and GRNMS was ultimately designated the following year (Moore, 2022).

Following the designation of GRNMS, studies of geology (Harding & Henry, 1990), paleoecology (Noakes et al., 2013), fish assemblages (Nelson & Parker, 1986), benthic assemblages (Cooksey et al., 2004), and predator-prey fish behavior (Auster et al., 2009) continued to shape knowledge of the sanctuary and the South Atlantic Bight. In 1997, the National Data Buoy Center deployed an ocean data buoy in GRNMS to monitor wind, waves, and weather. Buoy 41008 (referred to hereafter as the “GRNMS data buoy”) provides continuous, real-time atmospheric data, allowing visitors to evaluate weather and safety conditions at the sanctuary,

and also allowing scientists to conduct time-series analyses and calibration of marine technologies (Monacci et al., 2019).

The 8.27-square-mile Research Area was designated in 2011 to enhance the ability to discriminate scientifically between natural and human-induced change to species, communities, and associated habitats (Kendall & Eschelbach, 2006). The ability to conduct investigations in a marine environment relatively free of direct human influences is critical to meet the resource protection and scientific research mandates of GRNMS. Although allowable fishing gear is limited in the sanctuary, recreational fishing continues to exert pressure on targeted sanctuary resources (Roberson et al., 2020).

### **Physical Setting**

#### **Oceanography**

GRNMS is influenced by three main oceanographic processes: coastal river input, semidiurnal tides, and ocean currents. The interplay between these establishes a dynamic setting at GRNMS, making it a hotspot of biodiversity and a vital component of the larger Atlantic Ocean ecosystem. In winter, water temperatures range between 57–68°F, and in summer, water temperatures range from 77–86°F. These seasonal temperature ranges affect fish community composition in the sanctuary throughout the year (Roberson et al., 2020).

#### **Rivers**

Five Georgia rivers play an important role in freshwater input to coastal marshes and live-bottom habitats like those within GRNMS (Figure SS.3). From north to south along the Georgia coast, the Savannah, Ogeechee, Altamaha, Satilla, and St. Mary's rivers drain approximately 26.4 million acres of South Carolina, Georgia, and Florida into the Atlantic Ocean. The Altamaha River is the closest to the sanctuary and discharges an annual average of 10,500 cubic feet per second (U.S. Geological Survey, 2023). River discharge ranges between approximately 2,000 cubic feet per second in winter and approximately 50,000 cubic feet per second in spring. For more information on water quality and freshwater input influencing GRNMS, see Water Quality in the Status and Trends of Sanctuary Resources chapter of this report.

## Sanctuary Setting



**Figure SS.3.** Coastal Georgia has five rivers that drain in the vicinity of GRNMS. Image: Tony Reyer/NOAA

The rivers drain through coastal salt marshes of Georgia and the southeastern United States, shaping their ecology and dynamics. These marshes, where freshwater from rivers meets the saline waters of the Atlantic Ocean, create a diverse ecosystem and play an important role in filtering nutrients and pollutants (Figure SS.4). Nutrient-rich sediment carried by rivers nourishes marsh grasses and supports a variety of marine life, from fish and crustaceans to birds and mammals. Some of the animals found at GRNMS spend their juvenile years in coastal salt marshes, where the grasses, oyster reefs, and tributaries act as a nursery for some ocean species. As the rivers carry sediments and nutrients downstream, they also play a crucial role in nourishing the live-bottom reefs that thrive along the Atlantic coast.



**Figure SS.4.** Coastal salt marshes are vital coastal ecosystems that support vibrant marine life, feed into live-bottom habitats in the ocean, and provide essential nutrients and shelter for diverse marine species. Photo: Matt McIntosh/NOAA

### ***Tides***

The South Atlantic Bight tides are semidiurnal, featuring two high tide peaks and two low tide troughs over a 24-hour period. This is typical of tidal patterns along the southeast Atlantic coast. Tides in Georgia range from 6–9 feet, which is atypical compared to the areas around Cape Hatteras or Miami, the northern and southern bounds of the bight, where tidal ranges are one-third of those on the Georgia coast. The geography of Georgia, as the westernmost point of the Atlantic coast region, drives these tidal patterns. The large tidal range and semidiurnal timing means that millions of gallons of water are regularly moving from the coastal rivers, coastal salt marshes, and barrier islands to offshore environments.

### **Currents**

The Gulf Stream, a northward-flowing, powerful warm ocean current, influences the water temperatures, nutrient transport, and biodiversity in GRNMS. The Gulf Stream flows along the edge of the continental shelf while in the Georgia Bight, and diverges northeastward and offshore into the north Atlantic Ocean at Cape Hatteras. The strongest section of the Gulf Stream lies approximately 60 miles east of GRNMS, but eddies spin off from the main flow to affect habitats and life in the sanctuary.

### **Biological Setting**

GRNMS is characterized by two benthic habitat types: live bottom and sandy seafloor. These habitats support diverse and abundant wildlife. Ledges and bedrock are densely colonized by sponges, tunicates, macroalgae, and other organisms (Figure SS.5). These ledges are surrounded by sandy substrates teeming with infaunal invertebrates such as worms, clams, and anemones. These habitats, both biogenic and abiotic, provide food and shelter for many invertebrates and fishes (Kendall et al., 2005, 2007; Gleason, 2020) and also represent key bottom types of the South Atlantic Bight's shelf region (Kendall et al., 2005; Kendall & Eschelbach, 2006).

GRNMS is a dynamic area, influenced by daily tidal patterns and seasonal north-south currents. These physical characteristics result in changes over multiple time scales and weathering events, including scouring by storms, the collapse of ledges, ledges becoming exposed and colonized, and burial of ledges by shifting sand. The ledges of GRNMS have been described as “ribbons of life in a sea of sand;” however, the sand is also abundant with life, most of it living hidden below the subsurface (Kendall et al., 2005, 2007).

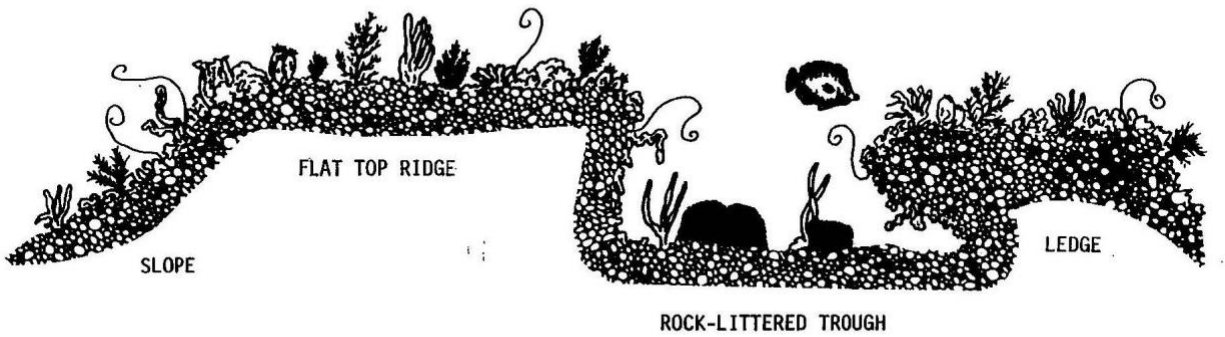
### **Live Bottom**

Live-bottom habitats, mostly composed of a dense carpet of vibrant and diverse invertebrates, are present in roughly 26% of the sanctuary (Kendall et al., 2005). Natural and artificial reefs dot the seafloor across the South Atlantic Bight; however, GRNMS is the only protected natural reef in this region. Within the bight as a whole, it is estimated that natural reefs cover 1,025 square miles (2.57% of the bight, roughly the size of the state of Rhode Island), and artificial reefs cover just over one square mile (<0.01% of the bight; Steward et al., 2022). GRNMS represents approximately 0.5% of this natural cover, and is one of the largest known nearshore live-bottom reefs in the southeast United States.

Live bottom is classified into two types: sparsely and densely colonized. Densely colonized live bottom consists of higher-relief, exposed sandstone carbonate that is colonized with nearly continuous, and sometimes multi-layered, coverage of sessile benthic organisms such as bivalves, stony and soft corals, sponges, and tunicates (Kendall et al., 2005). Features of densely colonized live bottom include undercuts, scoured ledge facies, and ledges with vertical relief of about 1.5–6.5 feet (Figure SS.6). Various morphological features encountered at GRNMS include higher-relief structures, such as ledge tops and flat-top ridges, and lower-relief areas, such as rock-littered troughs and slopes. The various morphologies of the reef create space for burrowing animals or cryptic fish species to live (Hunt, 1974).



**Figure SS.5.** Densely colonized live bottom consists of intricate high-relief ledges, undercuts, and rocky seafloor covered with a carpet of marine life that includes algae, sponges, tunicates, and soft corals. Photo: Greg McFall/NOAA



**Figure SS.6.** Cross-section illustration of live-bottom habitat at GRNMS. Image: Hunt, 1974

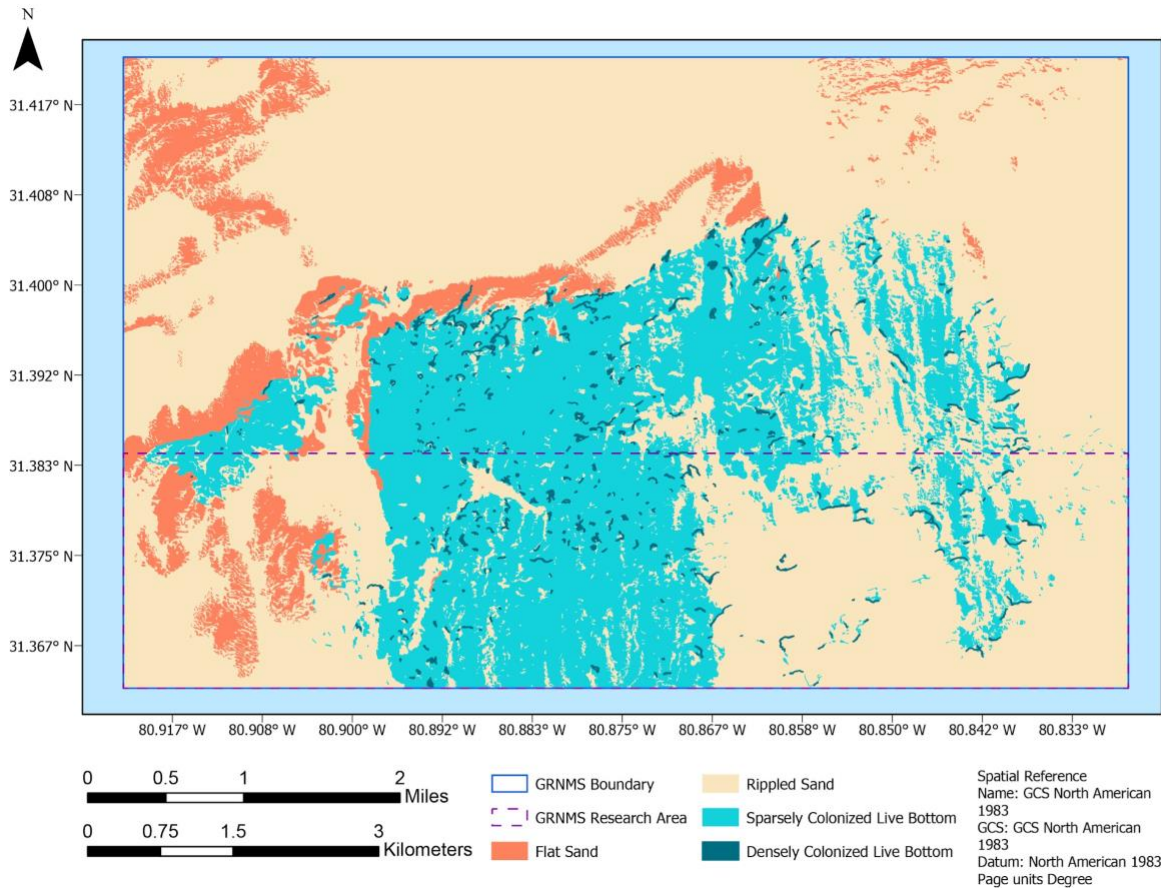
Sparsely colonized live bottom consists of low-relief and partially exposed calcareous sandstone substrate that is colonized with a sparse assemblage of sessile benthic organisms with a thin veneer of sand covering much of the bottom (Kendall et al., 2005; Figure SS.7).



**Figure SS.7.** Sparsely colonized live bottom consists of partially exposed substrate occupied by invertebrates, such as small sponges, soft corals, and small hard corals. Photo: Greg McFall/NOAA

### Sandy Seafloor

Nearly three-quarters of the GRNMS seafloor consists of unconsolidated sediments, which are categorized as flat or rippled sand (Figure SS.8; Kendall et al., 2005). The locations and dynamics of sandy areas are driven by waves and tidal currents. Throughout these sandy habitats, bioturbation caused by polychaetes, echinoderms, and burrowing fishes is visible, ranging from reworking of surface material to mound building and other excavations (Kendall et al., 2005).



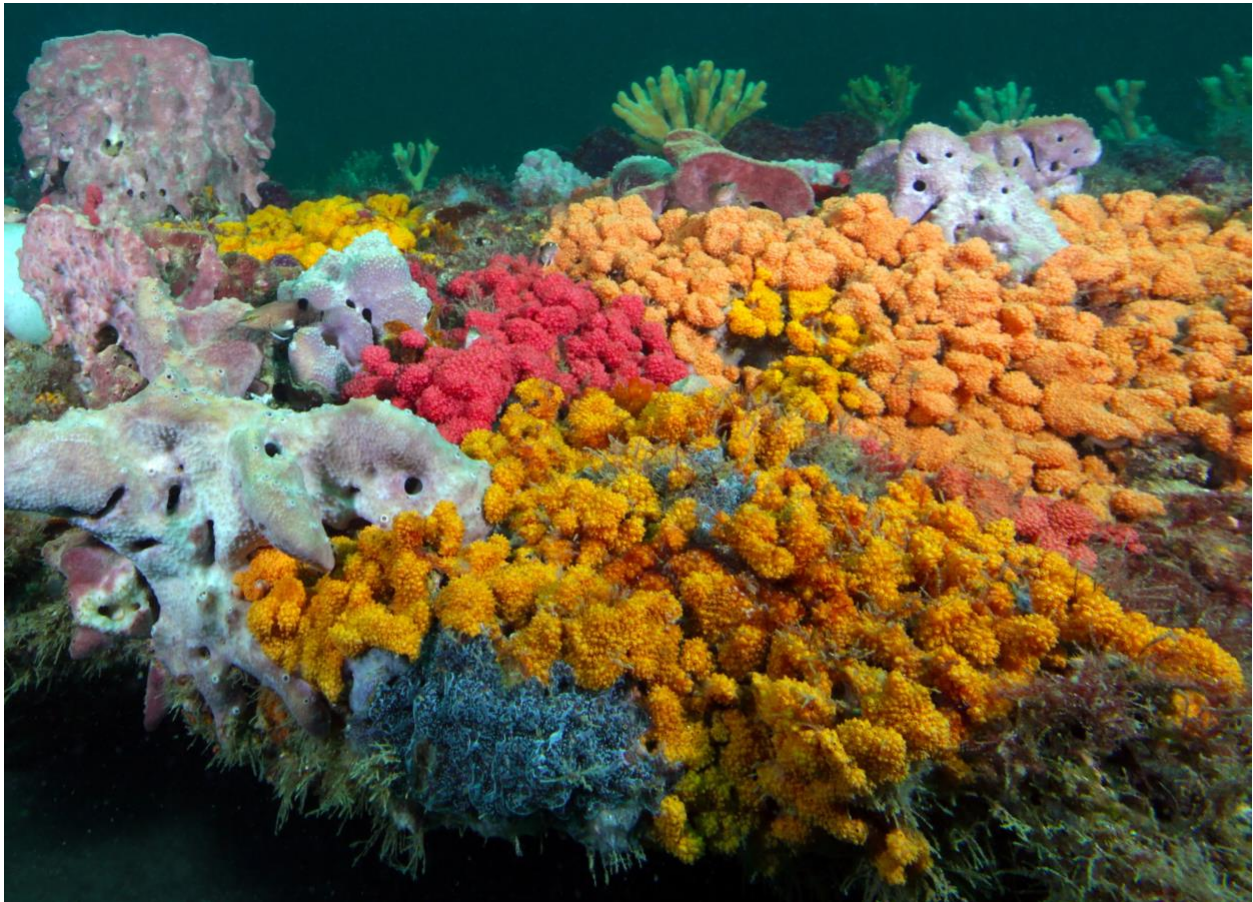
**Figure SS.8.** There are two bottom habitat types within the sanctuary: sand (flat and rippled) and live bottom (sparsely and densely colonized). Image: Kendall et al., 2007

### Living Resources

The geologic bedrock and oceanographic transport via the Gulf Stream current and associated eddies provide an ideal setting for the formation of live-bottom ecosystems at GRNMS. These ecosystems are particularly renowned for their iconic ledges formed by the unique geological structure of the reef. These ledges create a complex and varied underwater landscape, offering numerous nooks and crannies that serve as shelters and breeding grounds for marine life. Many of these species use Gray's Reef as a permanent home, while others use it as a crucial temporary habitat during their migrations. The intricate ledges play a key role in the biodiversity and ecological significance of GRNMS, making it a vital national marine sanctuary in the South Atlantic Bight.

## ***Benthic Fauna***

Algae and invertebrates grow on exposed rock surfaces in the sanctuary. The foundation of the GRNMS seafloor habitat is its carpet of invertebrates that attach to the sanctuary's iconic ledges. Over 900 species of invertebrates have been described at GRNMS, including bryozoans (moss fauna), ascidians or tunicates (sea squirts), sponges, stony and soft corals, barnacles, and hard-tube worms, which provide essential habitat and refuge for numerous marine organisms (Figure SS.9). These sessile invertebrates filter feed on plankton, contributing to the reef's overall productivity while serving as a food source for other animals. In flat and rippled sand areas, infaunal communities of burrowing worms, bivalves, gastropods, and echinoderms are distinguished by numerous burrows (Kendall et al., 2007; Hyland et al., 2006). Mobile invertebrates like crabs, sea cucumbers, sea stars, and sea urchins use burrows within the reef for protection and foraging. Their presence not only adds to the sanctuary's biodiversity, but also facilitates nutrient cycling and sediment turnover, essential processes for maintaining ecosystem health (Gleason, 2020).



**Figure SS.9.** Tunicate colonies carpet the rock ledges of Gray's Reef, providing food for reef life, shelter for small fishes, and stability to the rocky substrate. Photo: Greg McFall/NOAA

### ***Planktic Communities***

Shelf waters in the South Atlantic Bight are significantly influenced by terrestrial watersheds, with variations in rainfall and storm activity affecting them seasonally and annually (López-Figueroa et al., 2023). Phytoplankton are primary producers along the shelf, and copepod-dominant zooplankton communities provide a dominant food source for reef-dwelling organisms. GRNMS frequently experiences tropical storms, which cause strong wave action, deep mixing, and heavy rainfall. Additionally, water exchanges between the shelf and the slope impact flushing rates and nutrient flux, which in turn affect plankton community composition.

### ***Fishes***

Gray's Reef attracts numerous species of benthic fishes, which live on or near the substrate, and pelagic fishes, which swim in the water above. These include black sea bass, snappers, groupers, and mackerels. Because GRNMS lies in a transition area between temperate and tropical waters, fish community composition changes seasonally. Topographically complex sandstone carbonate live-bottom ledges within GRNMS provide protection and foraging opportunities for over 200 species of fishes (Kendall et al., 2008; Roberson et al., 2020). Fish species may use the sanctuary as year-round home or as a temporary stop during migration (Williams et al., 2019). The most commonly observed fish at GRNMS include tomtate, black sea bass, and schooling scad (Figure SS.10). Other common fishes include Atlantic spadefish, oyster toadfish, red snapper, and various species of groupers, wrasses, and blennies (Muñoz et al., 2020). Migrating fishes that have been identified in GRNMS include Atlantic bluefin tuna, Atlantic sturgeon, and various species of sharks, such as great hammerhead, sand tiger, blacktip, and bull (Williams et al., 2019). Common pelagic fishes observed in GRNMS include tunas, mackerels, cobia, and other species of sharks (Auster, 2020; Williams et al., 2019).



**Figure SS.10.** Tomtate, scad, and porgy are among the many schooling fish that live at Gray's Reef. Photo: Greg McFall/NOAA

## **Marine Mammals**

Marine mammals such as Atlantic spotted dolphins and common bottlenose dolphins feed at GRNMS, taking advantage of the abundance of prey in the sanctuary’s protected waters. Their occasional visits serve as a reminder of the sanctuary’s interconnectedness with larger marine ecosystems and its importance for a wide range of marine life. GRNMS is also within the only known winter calving ground of the critically endangered North Atlantic right whale (Figure SS.11). Between mid-November and mid-April, female right whales migrate south to the coasts of North Carolina, South Carolina, Georgia, and Florida to give birth and nurse calves. For more information about marine mammals at GRNMS, see Living Resources in the Status and Trends of Sanctuary Resources of this report.



**Figure SS.11.** Right whale “Halo” (Catalog #3546) and her calf, sighted on January 14, 2024 approximately 8.4 nautical miles east of St. Catherines Island, Georgia. Photo: Clearwater Marine Aquarium Research Institute (taken under NOAA permit #26919)

## **Turtles**

Sea turtles, primarily loggerhead sea turtles, commonly traverse the sanctuary’s waters, foraging on sponges and algae within the live-bottom habitat. Loggerhead sea turtles have been observed wedged under the ledges of Gray’s Reef (Figure SS.12). Other species of turtles less commonly observed at GRNMS include green, leatherback, Kemp’s ridley, and hawksbill sea turtles. Loggerhead sea turtles have been observed to rest continuously at GRNMS for up to 144 minutes, primarily during twilight and night periods (Auster et al., 2020a).



**Figure SS.12.** Loggerhead sea turtles are commonly observed foraging on and resting under the ledges at GRNMS. Photo: Greg McFall/NOAA

### ***Marine and Coastal Birds***

Ocean birds of the southeastern United States, including shearwaters, petrels, and albatrosses, are often seen gliding effortlessly over the Atlantic Ocean. The GRNMS data buoy inadvertently serves as an aggregator and resting spot for many species of terns, gulls, and gannets. These birds sometimes act as surface predators during bait ball hunts initiated by predatory fishes or dolphins.

## Drivers and Pressures on the Sanctuary

For the purpose of condition reports, drivers, or driving forces, are defined as societal values, policies, and socioeconomic factors that influence human pressures on the ecosystem. By shaping the ways that humans interact with the marine environment, driving forces can result in either positive or negative impacts (pressures) on the condition of resources like water, habitat, living resources, and maritime heritage resources. In turn, the condition, or state, of resources determines the flow of benefits that humans are able to derive from that ecosystem. Accordingly, understanding driving forces can be useful for anticipating, evaluating, and reacting to changes in the condition of resources and ecosystem services.

### *Drivers on the Sanctuary*

Although pressures on sanctuary resources occur locally, drivers emerge at many different scales, from local to global. A pressure may be affected by one or more drivers, and a driver may affect multiple pressures. For example, human population growth at all scales can increase demand for seafood and, as a result, fishing pressure. Fishing pressure is also influenced by drivers like fuel prices and ocean policy, and population drivers simultaneously influence other pressures like marine debris and vessel traffic. Drivers and pressures vary from sanctuary to sanctuary. Relevant drivers and associated pressures were identified in consultation with GRNMS staff and based on past experience identifying drivers and pressures at other sanctuary sites. Table D.1 summarizes the drivers that influence pressures at GRNMS and the scales at which they occur.

Drivers affect pressures by influencing demand for marine-based goods and services like food, energy, recreational opportunities, and transportation. Drivers that influence demand in GRNMS include population, per capita income, trade policy, and societal values and conservation ethic. Other factors that influence demand may include consumer tastes and preferences. As demand for marine resources increases, higher prices and/or quantity demanded create incentives for higher levels of extraction or use, which can impact the state of resources.

Other drivers influence the supply of or access to marine resources. Examples include fuel prices, technological advancement, ocean policy, and regulatory exemptions. Fuel prices and technology determine the cost and feasibility of exploiting marine resources and, subsequently, levels of activity and use. The other drivers relevant to GRNMS relate to the governance of marine resources. Ocean policy (e.g., permitting for offshore energy, vessel speed reduction zones, fishing regulations), along with regulatory exemptions, may increase or decrease pressures on resources. Many of these drivers do not act in isolation, but are interconnected and may result in cumulative impacts on pressures.

## Drivers and Pressures on the Sanctuary

**Table D.1.** Drivers and their relationship to pressures that affect GRNMS resources. Each row begins with a pressure that is known to act at GRNMS, and bullets across the row indicate each driver that affects that pressure. Each column begins with a driver, and the bullets indicate the range of pressures upon which that driver acts. The letter(s) following each driver indicate the geographic scale(s) at which that driver originates to affect pressure (G = global, N = national, R = regional, L = local). The following narrative describes each driver and pressure in detail.

<b>Drivers (→) Pressures (↓)</b>	<b>Population</b> (G, N, R, L)	<b>Per-capita Income</b> (G, N, R, L)	<b>Gross Domestic Product</b> (G, N, R, L)	<b>Fuel Prices</b> (G, N, R, L)	<b>Demand for Seafood</b> (G, N, R, L)	<b>Regulatory Exemptions</b> (N, L)	<b>Societal Values and Conservation Ethic</b> (N, R, L)	<b>Trade Policy</b> (N, R, L)	<b>Ocean Policy</b> (N, R, L)	<b>Technological Advancement</b> (G, N, R, L)
<b>Fishing</b>	•	•	•	•	•		•	•	•	•
<b>Coastal development and nearshore construction</b>	•	•	•			•	•		•	•
<b>Nonpoint source pollution</b>	•	•			•		•		•	•
<b>Marine debris</b>	•	•	•	•	•		•		•	•
<b>Vessel discharges</b>	•	•	•	•	•	•		•	•	
<b>Changing ocean conditions</b>	•	•	•	•	•		•	•	•	
<b>Visitation</b>	•	•	•	•	•		•		•	
<b>Non- indigenous species</b>	•	•	•		•		•		•	•
<b>Research activities</b>	•						•		•	

### Population and Per Capita Income

International and domestic demand for goods and services, at all scales, ranging from local to global, is directly tied to changes in population and real per capita income. Demand is a ubiquitous, primary driver of pressures on sanctuary resources. A growing population and increasing per capita income are likely to increase demand for consumer goods, which may lead to additional fishing and shipping. The data provided in this section are from the U.S. Bureau of Economic Analysis (2024).

Higher real incomes enable consumers to buy more of the products that they already purchase and/or substitute preferred, more expensive products for cheaper ones. Activities required to meet increased demands could include fishing, transportation, construction, land development, and visitation. Basic economic theory states that as per capita income or population increases, demand for normal goods (such as seafood) increases. Thus, over the past decade, this increased demand likely resulted in increased pressures on GRNMS resources, created by higher demand for products and services. From 2008 to 2022, the population in the 10-county GRNMS study area grew by roughly 19.6%, nearly doubling the rate of population increase for the United States (9.6%) and outpacing the rate of population increase for the states of Georgia (14.8%) and South Carolina (16.7%); thus, population-driven pressures in the study area may have increased. As of 2022, approximately 4.75% of South Carolina residents and 5.51% of Georgia residents lived in the study area. These population changes can influence land-based pressures on the marine environment, such as land use and waste management. From 2008 to 2022, real per capita income in the GRNMS study area increased by 15.7%, a smaller rate of change relative to the U.S. (20.7%). This change was smaller than both Georgia and South Carolina, where real per capita income increased by 23.4% and 22.0%, respectively.

## Drivers and Pressures on the Sanctuary

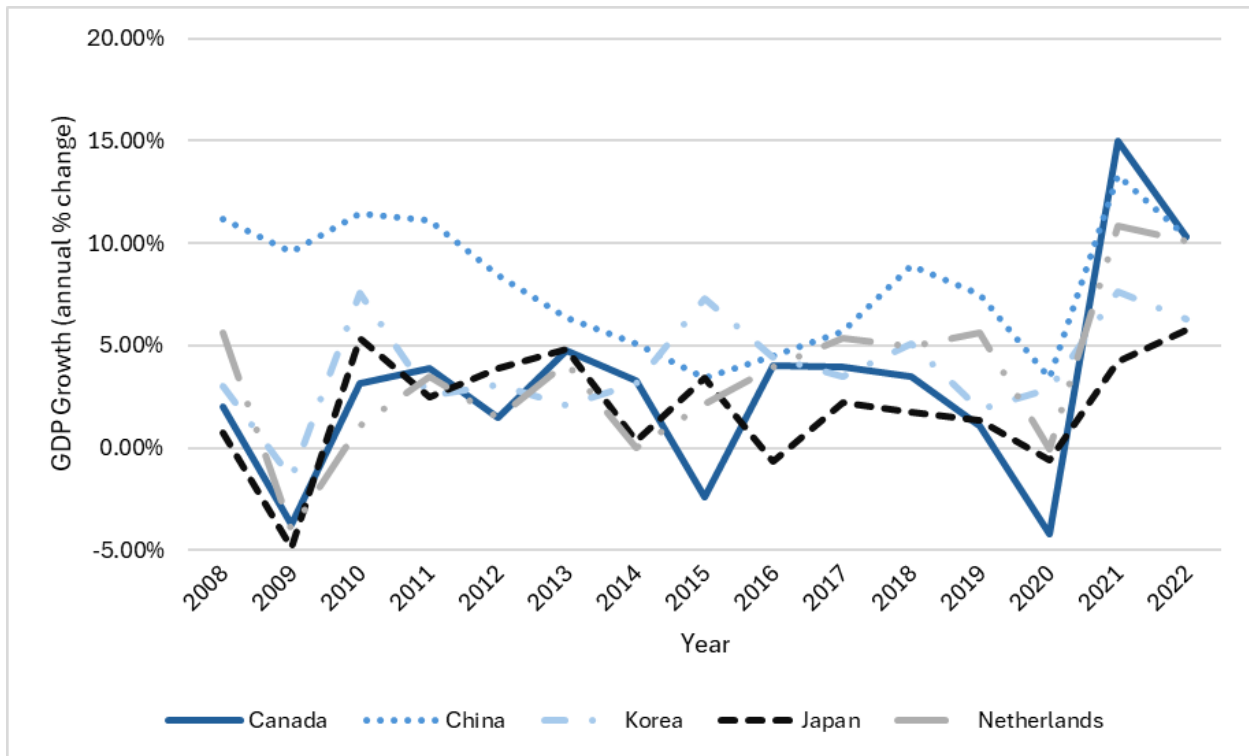
**Table D.2.** Population and mean per capita income in the 10-county study area<sup>6</sup> associated with GRNMS. The study area included Chatham, McIntosh, Glynn, Effingham, Bryan, Liberty, and Brantley counties in Georgia, as well as Beaufort, Jasper, and Hampton counties in South Carolina. Monetary values were inflation-adjusted to 2024 dollars. Source: U.S. Bureau of Economic Analysis, 2024; U.S. Bureau of Labor Statistics, 2024

Year	Population	Population (% change)	Mean Per Capita Income	Per Capita Income (% Change)
2008	708,630	–	\$54,271	–
2009	727,597	+2.68%	\$52,338	-3.56%
2010	732,725	+0.70%	\$51,600	-1.41%
2011	743,225	+1.43%	\$53,459	+3.60%
2012	752,660	+1.27%	\$52,396	-1.99%
2013	758,037	+0.71%	\$51,922	-0.90%
2014	771,129	+1.73%	\$53,175	+2.41%
2015	781,118	+1.30%	\$55,598	+4.56%
2016	791,114	+1.28%	\$55,716	+0.21%
2017	798,564	+0.94%	\$56,459	+1.33%
2018	804,083	+0.69%	\$57,669	+2.14%
2019	814,084	+1.24%	\$59,154	+2.57%
2020	819,556	+0.67%	\$62,162	+5.09%
2021	830,785	+1.37%	\$66,827	+7.51%
2022	847,368	+2.00%	\$62,767	-6.08%

<sup>6</sup> Primary counties included those with shoreline in closest proximity to GRNMS (McIntosh, Glynn), plus those that were known to provide access to GRNMS via infrastructure like ports and marinas (Chatham, Jasper, Beaufort), identified in consultation with site leadership. After these primary counties were identified, secondary counties were selected using commuter flow data from the 5-Year American Community Survey. If a large number of people in a county commute to or from primary counties, that county was considered a secondary county. Specifically, if total flows to or from a non-primary to a primary county represented 10% or more of the primary county’s labor force, the non-primary county was identified as a secondary county. Secondary counties included Hampton, Effingham, Bryan, Liberty, and Brantley.

## Gross Domestic Product

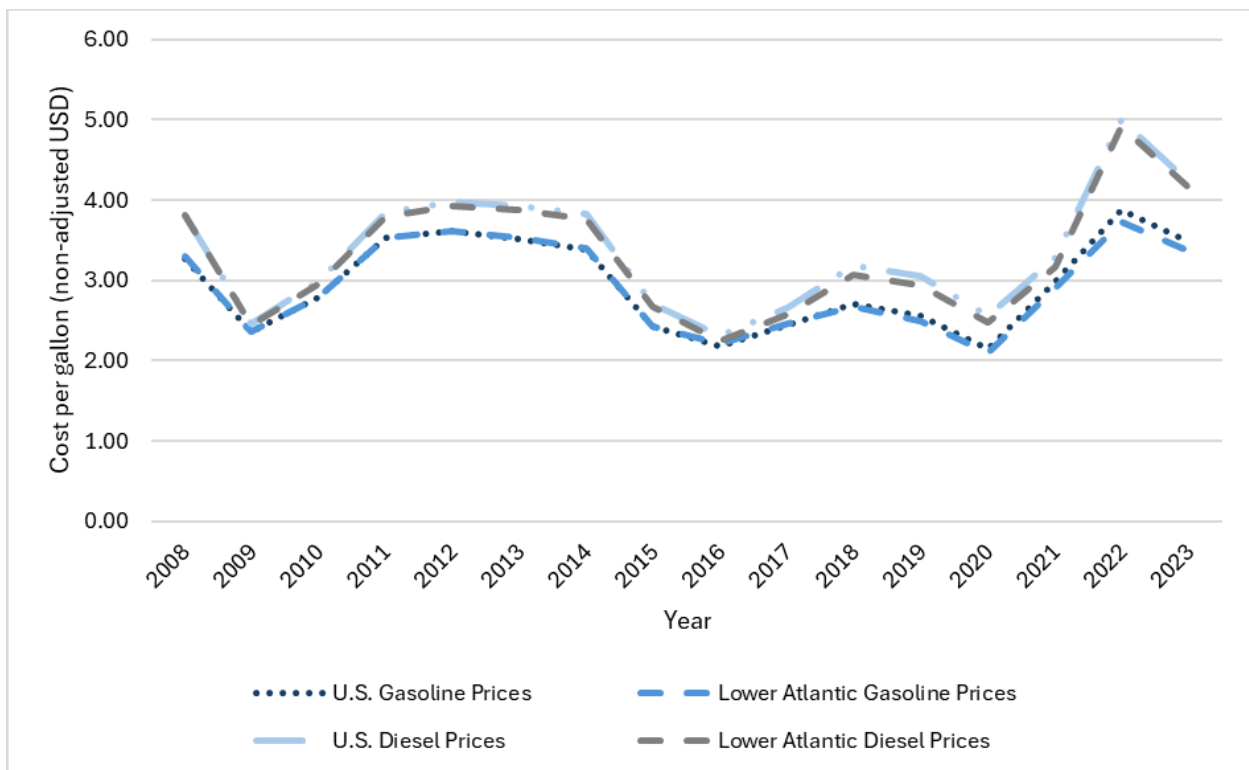
Another high-level driver that can affect all sanctuaries is the gross domestic product (GDP) of trade partners. Between 2008 and 2022, the top importers of U.S. seafood and other fishery products by both weight and value were Canada, China, Japan, South Korea, and the Netherlands (Food and Agriculture Organization of the United Nations, 2023; NOAA Fisheries, 2024a). Changes in GDP in these countries have historically affected the demand for all goods. Additionally, seafood is bought and sold in a global market such that changes to demand directly affect prices of species caught in GRNMS, which may affect fishing behavior in and around the sanctuary itself. GDP growth for each of these trading partners is shown in Figure D.1. These countries have experienced fluctuations in annual GDP change, with all five countries experiencing declines in GDP after the COVID-19 pandemic. Since then, however, each country has experienced an increase in GDP relative to their GDP prior to the pandemic, indicating there may be an increase in pressure and demand for seafood imports at a national level moving forward.



**Figure D.1.** GDP growth in the top five countries that import U.S. seafood products. Source: Organisation for Economic Cooperation and Development, 2024

## Fuel Prices

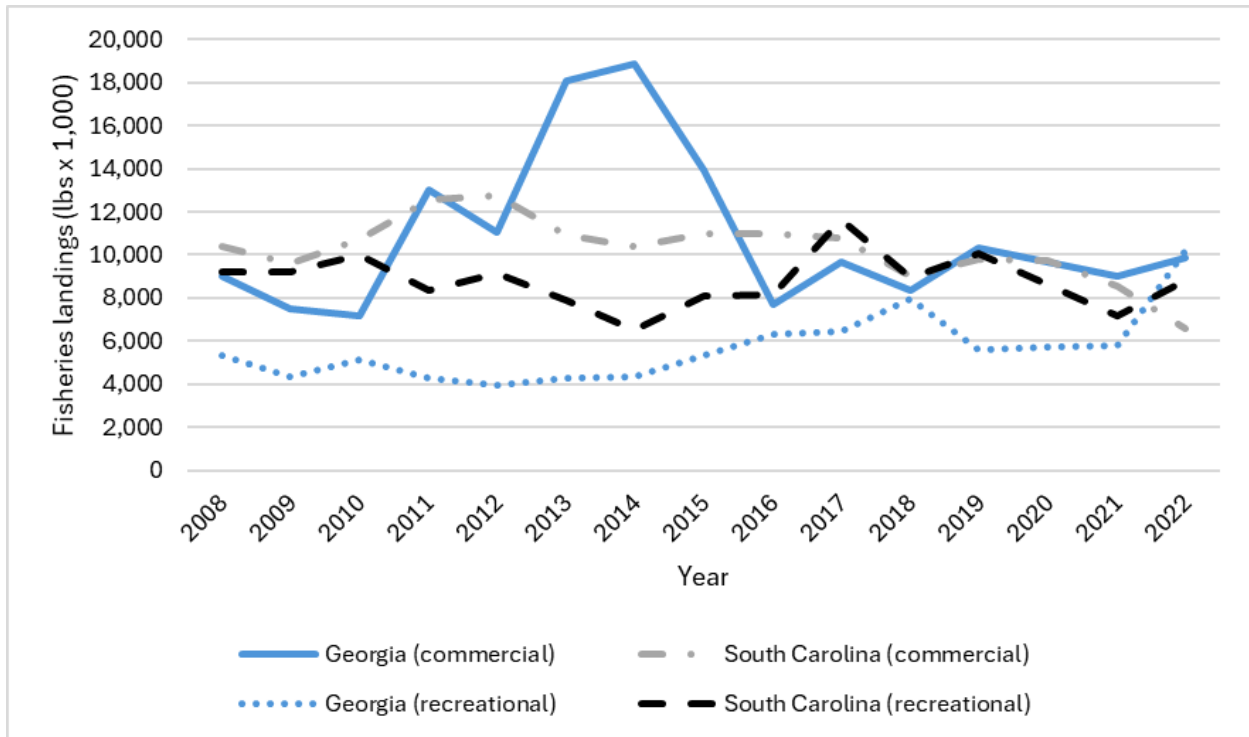
Fuel prices are an important and often immediate driver of many ocean activities. Ocean users consider fuel prices in their decisions about whether and how to conduct activities like commercial fishing, recreational boating, and shipping (e.g., Sumaila et al., 2008; Maloni et al., 2013). In turn, those decisions determine the intensity of pressures, such as vessel traffic, discharges, noise, and resource extraction. Importantly, changes in fuel prices do not impact all fisheries equally. Globally, fisheries targeting crustaceans or flatfish and those employing pots/traps or trawl gear have the highest intensity of fuel use in terms of volume of fuel per live weight landed (Parker & Tyedmers, 2014). The price of retail gasoline and diesel in the Lower Atlantic region (as defined by the U.S. Energy Information Administration [Petroleum Administration for Defense District 1C, which includes Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia]) and the United States remained variable between 2008 and 2022 (U.S. Energy Information Administration, 2024; Figure D.2). Because the sanctuary’s westernmost boundary is a 70-mile round trip from the closest mainland harbor (Darien) and crosses open ocean, fuel price is a prominent factor when considering travel to the site. Highly volatile fuel prices can thus drive relatively rapid changes in the rate of visitation to the sanctuary.



**Figure D.2.** Average retail price for diesel and gasoline (all grades) in the Lower Atlantic region and the U.S., 2008–2023. Dollar values are non-adjusted and represent the price paid for retail gasoline and diesel at the time of the transaction. Source: U.S. Energy Information Administration, 2024

## Demand for Seafood

Seafood is one of the top traded food commodities globally, with the United States documented as a top importer and top five exporter of seafood (Froehlich et al., 2021). Global seafood catch increased by an estimated average annual rate of 3.1% from 1961 to 2017 (Food and Agriculture Organization of the United Nations, 2023). There is an important commercial fisheries industry in both South Carolina and Georgia that has contributed to seafood production, and consequently, pressures on resources in the region. Between 2008 and 2022, Georgia experienced a 9.84% increase in commercial landings (by weight), with an average annual increase of 5.34% (NOAA Fisheries, 2024a). Despite these positive trends, Georgia’s commercial fisheries industry experienced some variability, particularly between 2010 and 2016 (Figure D.3). Conversely, South Carolina experienced a 36.5% reduction in landings between 2008 and 2022, with an average annual decrease of 2.56% (NOAA Fisheries, 2024a). The recreational fishing industry is considerable in both Georgia and South Carolina, compared to other regions of the country. Recreational landings even surpassed commercial landings in both states in 2022 (Figure D.3).



**Figure D.3.** Total fisheries landings in pounds for South Carolina and Georgia’s state and federal waters for both commercial and recreational fishing modes, 2008–2022. Source: NOAA Fisheries, 2024a

## Regulatory Exemptions

Federal agencies implement regulations as appropriate per their respective statutes and mandates. In some cases, individuals, entities, or certain activities are exempt from statutory or regulatory requirements. The Department of Defense, for example, has a general exemption from GRNMS regulations for any pre-existing Department of Defense activities in the sanctuary area at the time of its designation in 1981 (15 C.F.R. § 922.92). Sanctuary regulations allow for

additional Department of Defense exemptions upon consultation with ONMS. The sanctuary lies within the western edge of the Navy's Jacksonville Operating Area and partially within Special Use Airspace W-136 B and W-136C. Although aircraft overflights, vessels and in-water devices, active sonar, air and surface explosions, military expended material (from exempted activities), and electromagnetic sources are allowed within GRNMS under the military exemption, the Navy follows procedural mitigations specific to various activities that reduce negative environmental impacts. Additionally, the Navy has maintained a 2.7-nautical-mile (5-kilometer) buffer around the sanctuary's boundaries since 2009 to avoid exposing sanctuary resources to acoustic and explosive activities that could result in injury/harm to sanctuary resources at closer ranges. Activities not planned to be conducted within the sanctuary or the 2.7-nautical-mile buffer include underwater explosives detonations, discharge of military expended materials resulting from "non-exempted activities," and deployment/operation of seafloor devices.

NOAA Fisheries has established and enforces seasonal vessel speed restrictions to aid the recovery of critically endangered North Atlantic right whales that pass through GRNMS, but the regulation (50 C.F.R. § 224.105) excludes all U.S. government and state law enforcement vessels to facilitate national defense, enforcement, search and rescue, and other government functions.

GRNMS regulations include specific prohibitions against activities considered a threat to sanctuary resources and qualities, such as disturbance or alteration of submerged lands, discharges, collection of marine life, and use of explosives or electric charges. Six sanctuary prohibitions applicable outside the sanctuary's Research Area allow narrow exceptions to facilitate public use, access, and safety (15 C.F.R. § 922.92). For example, although sanctuary regulations in GRNMS prohibit the placement of any matter on the seafloor, exemptions are allowed for temporary deployment of weighted marker buoys used by divers and fishers for reference points in the sanctuary's open ocean environment. Anchoring is prohibited, except for emergencies. Discharges into the sanctuary are prohibited, but exceptions exist for boat cooling water and marine sanitation device effluent, as well as chum, bait, and fish discards incidental to lawful fishing. Collection of, or injury to, marine organisms is prohibited by any means except the use of rod-and-reel and handline gear for fishing. Though possession in the sanctuary of most types of fishing gear is prohibited, presence of such gear is an exception if it is properly and securely stowed aboard a vessel.

Lastly, GRNMS regulations include general exceptions throughout the sanctuary for otherwise prohibited activities that are authorized and conditioned by a valid sanctuary permit or necessary to respond to an emergency threatening life, property, or the environment.

### **Societal Values and Conservation Ethic**

Information on societal values related to conservation can be obtained from various national or local opinion polls. A national poll conducted by the National Marine Sanctuary Foundation and the National Opinion Research Center at the University of Chicago (2022) found that Americans' highest priorities for ocean conservation were protecting ocean wildlife (68%), stopping uses that harm the ocean life and habitat (67%), and protecting the ocean from extractive uses that damage ecosystems and species (62%). Stefanski and Shimshack (2016) conducted a national survey of U.S. households and found that there was a willingness-to-pay

for the expansion of Flower Garden Banks National Marine Sanctuary. These results indicate that U.S. households have value for marine protection, especially in relation to marine reserves and nationally protected sanctuaries. Several survey efforts have been made to understand the societal values and perceptions toward resources in and around GRNMS. Samonte et al. (2023) surveyed 367 Georgia residents who engaged in saltwater recreational fishing during 2019 in Georgia's coastal and ocean waters, with the objective of understanding these individuals' knowledge, attitudes, and perceptions of GRNMS. The findings from this study indicated that recreational anglers were supportive of the protection of ocean and coastal resources. Specifically, pollution, coral health, and marine animal health were found to be some of the top concerns of recreational anglers inside GRNMS. Along with these, pollution, habitat loss from development, and marine animals were some of the top concerns for the area surrounding GRNMS. The respondents also indicated that they were supportive of the protection of ocean and coastal resources in and around Georgia. This was a large shift from recorded recreational angler perceptions in 2010, which indicated that anglers' opinions on these issues were more neutral (Leeworthy, 2013). Lemmen et al. (2023) also conducted a survey to understand the knowledge, attitudes, and perceptions of those who use the area in and around GRNMS. This study found that these resource users<sup>7</sup> were most concerned about threats to resources from pollution, and also supported marine protection and were willing to adjust consumption habits to ensure sustainable use of resources.

### Trade Policy

Foreign trade policies can have a substantial impact on U.S. seafood harvesters and producers. These policies may reduce demand for U.S. exports, while import bans on foreign goods to the U.S. could increase demand for domestic goods. Because import competition can alter incentives for resource use, harvesters are also affected by domestic trade policies that affect the competitiveness of domestic U.S. seafood (Asche et al., 2022). Although trade policy occurs at a national and international level, the impacts may be felt by individual businesses operating within and around GRNMS. In 2019, the seafood industry faced a major disruption due to the trade war with China, the largest consumer of seafood and a top importer of international seafood products (Froehlich et al., 2021; Food and Agriculture Organization of the United Nations, 2023). In addition, the Russian ban on all food imports from the U.S. has continued to impact the domestic seafood industry since it began in 2014. On March 11, 2022, President Biden issued Executive Order 14068, which prohibits the transportation of seafood originating in Russia. In 2022, however, the U.S. and the European Union allowed for the resumption of bilateral trade in bivalve molluscan shellfish for the first time since 2011. This has allowed for U.S. producers (beginning in the states of Massachusetts and Washington as of February 4, 2022) to export live, raw, and processed bivalve molluscan shellfish to the European Union, while European Union producers in Spain and the Netherlands are eligible to export these products to the U.S. Trade policy might also affect pressure on sanctuary resources by influencing the volume of trade flows and shipping activity between ports.

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<sup>7</sup> The survey population was defined as persons who held a saltwater fishing license (i.e., Saltwater Information Program permit) in the state of Georgia and visited GRNMS in calendar year 2019.

### Ocean Policy

The U.S. is party to numerous agreements that establish international entities composed of member governments that focus on various topics ranging from managing shipping (i.e., International Maritime Organization), global whale stocks (i.e., International Whaling Commission), fishing (i.e., International Convention for the Conservation of Atlantic Tunas), and oil spill response (i.e., Canada-United States Joint Marine Pollution Contingency Plan). Each of these organizations can potentially change policy, resulting in pressures being placed on GRNMS.

The South Atlantic Fishery Management Council (SAFMC) manages fishery resources in the federal waters of the South Atlantic, including East Florida, Georgia, North Carolina, and South Carolina. SAFMC manages over 64 species of finfish, crustaceans, and corals, and works with multiple federal agencies, including other regions' fishery management councils (South Atlantic Fishery Management Council [SAFMC], 2024). Many of the species that SAFMC manages are found within or transit through GRNMS. The council has also established an Essential Fish Habitat area, codified in NOAA regulations, that overlaps the sanctuary and provides additional protection for fishery habitat within its boundaries.

NOAA Fisheries uses a variety of administrative controls to enforce federal laws conserving whales, sea turtles, and other protected and managed species that frequent the sanctuary. For example, seasonal vessel speed restrictions have been established and are enforced to aid the recovery of the critically endangered North Atlantic Right Whale population that migrates through and around GRNMS to calving grounds overlapping a third of the sanctuary and beyond. The service is also testing ropeless fishing trap technologies that could potentially reduce whale entanglements in trap lines and improve the health of these seasonal sanctuary visitors.

The U.S. Fish and Wildlife Service, multiple state natural resources departments, and non-governmental organizations collaborate to protect South Atlantic coastal nesting habitats for protected sea turtle species that mature and become regular visitors to Gray's Reef, playing an integral part of the ecological system there.

### Technological Advancement

Technology can influence pressures on marine resources in several ways, including by lowering costs for existing marine-based industries. For example, technologies like electronic navigational aids, acoustic fish-finding equipment, and stronger polymers for line and netting have increased fishing efficiency (Marchal et al., 2006). For a given level of human activity or ocean use, certain technological advancements can also reduce levels of impact or pressure. Examples include low-emissions propulsion systems and carbon capture in shipping, waste management technologies (e.g., marine sanitation devices, bioremediation of wastewater, new materials to replace plastics), and bycatch reduction devices (e.g., turtle excluder devices), among others. The development of new technologies can also contribute to the growth or emergence of new sectors in the blue economy (e.g., offshore aquaculture, offshore wind), which may even substitute for traditional industries (e.g., wild-capture fisheries, offshore oil). Finally, technologies can allow for increased scientific efforts in the region. For example, the GRNMS

data buoy has been used for monitoring studies, such as Kendall et al. (2020) and Burns et al. (2022), to gather information on visitation at GRNMS.

### **U.S. National Security**

The ocean plays a critical role in the mobility and readiness of U.S. armed forces and in ensuring national security. The State Department, Department of Defense, Department of Homeland Security, National Security Administration, Department of Transportation, and others play key roles in national security. See the section on regulatory exemptions for a description of U.S. Department of Defense activities in and around GRNMS. The U.S. Navy developed a comprehensive environmental planning process nearly 20 years ago for its Atlantic Fleet training and testing activities and began publishing periodic environmental impact statements for the fleet's evolving activities starting in 2009. The most recent *Atlantic Fleet Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement* (U.S. Department of the Navy, 2018) was completed in 2018 in cooperation with NOAA Fisheries, and included consultation with ONMS. The statement evaluated potential incidental take of marine mammals under the Marine Mammal Protection Act, incidental take of threatened and endangered marine species under the Endangered Species Act, and mitigation measures for managed marine species and sanctuary resources and habitats. Potential naval training and testing activities include surface ship and submarine operations, surface and aerial gunnery, surface and air-based missile firing, bombing, air combat maneuvers, air-based chaff/flare and sonobuoy deployment, torpedo firing, and military expended materials that could result from any of the above listed activity types (e.g., shell casings from gunnery activities, torpedo components from torpedo firing, etc.). The Navy is currently preparing a supplement (update) to the 2018 *Atlantic Fleet Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement*, which is scheduled for final publication in late 2025.

### **Pressures on the Sanctuary**

Human activities and natural processes affect the condition of natural and cultural resources in national marine sanctuaries. The following section discusses the most prominent pressures impacting habitat, resources, and qualities of GRNMS, including visitation and use, scientific research activities, fishing, marine debris, vessel discharges, changing ocean conditions, non-indigenous species, and nearshore activities (coastal development/nearshore construction and nonpoint source pollution) that can impact offshore water quality in the sanctuary, as well as critical nearshore nursery habitat for species that subsequently mature and migrate to GRNMS.

### **Visitation and Use**

GRNMS is regularly visited by users conducting recreational fishing and diving, boating, enforcement, monitoring, and scientific research (e.g., hydrographic or scuba surveys; placement and recovery of instruments and survey equipment; and sampling of water, substrate, flora and fauna). The southern third of the sanctuary is closed to all activities except permitted scientific research, for the purpose of providing a controlled study area largely free of direct human impacts.

Vessels are associated with all visitation and use at GRNMS and can have negative impacts, including discharges of petroleum, hazardous chemicals, sewage, and/or non-biodegradable

materials; noise; anchor damage; vessel casualties (e.g., sinking, grounding, drifting, etc.); wildlife disturbance; ship strikes on whales, turtles, and other species; and air and water pollution via exhaust gas emissions. Most visitors to GRNMS arrive in small boats (averaging 26 feet in length) with a center console/outboard engine design (Kendall et al., 2020). Some motor yachts, sailboats, and other recreational vessels pass through GRNMS solely for transit between ports of call, thus limiting time and potential impacts there. The sanctuary is well outside of commercial shipping routes, but ships up to 200 feet in length occasionally operate in the sanctuary for enforcement and research purposes and may remain longer than most small boats, posing unique potential impacts.

Scuba diving poses a potential risk of disturbance to marine life and habitat. Divers may accidentally or intentionally come into contact with reef organisms, sometimes causing physical damage (Barker & Roberts, 2004) or increased sedimentation, both of which can also increase susceptibility to diseases (Lamb et al., 2014). Recreational diving activity within the sanctuary is uncommon due to the reef's 20-mile distance from shore and the unique technical and logistical requirements to dive there. Additionally, because anchoring is prohibited, unless otherwise permitted, dive boats must conduct drift operations, which require more coordination than anchored dive operations. Lastly, spearfishing, which is a key draw for recreational divers at similar reefs in the region, is prohibited throughout the sanctuary. At present, only one commercial dive charter operator conducts trips to the sanctuary, with a frequency of about 20 bookings/year and a complement of six divers per trip.

Key pressures associated with visitation and use at GRNMS, specifically vessel discharges, scientific research (including scientific research diving), and recreational fishing are discussed in greater detail below.

### ***Vessel Discharges***

Water quality is negatively impacted by waste disposal and pollution from discharges of oil or other hazardous materials directly into the sanctuary or from distant spills that drift into the sanctuary. It is possible that some boaters discharge raw sewage directly into the sanctuary. Debris discarded from vessels can affect habitat and living resources via abrasion or smothering of benthic organisms, alteration of sediment composition, or ingestion by marine organisms (NOAA Marine Debris Program, 2016). Anecdotal observations, as well as a study by Kendall et al. (2007), have identified recreational fishing gear (monofilament line, hooks, lures, hand nets, rods, and reels) introduced by vessels fishing in the sanctuary as the most common type of marine debris found in GRNMS. Other debris discharged into the sanctuary from vessels includes aluminum cans, glass bottles, plastic wrappers, plastic and glass containers, dive gear, anchors, chain, and line.

### ***Scientific Research***

Research activities in the sanctuary by NOAA and other entities can affect resources in a number of ways. Vessel-based hydrographic surveys within the sanctuary emit sound that could disturb sea life such as marine mammals, and placement and recovery of instruments and survey equipment cause minor, and usually temporary, displacement of habitat and localized disturbance of flora and fauna. Some research sites are visited regularly by divers for monitoring and instrument maintenance. Research dives likely exceed 50% of total scuba diving activity at

GRNMS. From 2013 to 2022, the NOAA dive team for GRNMS logged between 102 and 270 dive hours annually. Minor damage to the substrate and reef structures at dive sites can occur, and could have cumulative impacts, which are considered in the issuance of permits for research. To avoid the concentration of research impacts, specialized sampling activities (e.g., tissue sampling or species collection, animal tagging, water sampling, and sediment collection/coring) are geographically dispersed. Temporary and semi-permanent survey markers and grids are sometimes fixed to the seafloor and reef.

Scientific research activities with potential to negatively impact protected resources must operate under a sanctuary permit with mitigating conditions that reduce impacts to either negligible or acceptable levels of disturbance. By contrast, the incidental, uncontrolled movement or destruction of scientific equipment during hurricanes or other strong storms can cause more significant damage than routine scientific investigation, and can also produce marine debris.

### **Recreational Fishing**

Fishing is the primary recreational activity in the sanctuary, and it is concentrated over reef habitats, which have the highest structural and ecological diversity of all GRNMS habitats. Such areas also tend to accumulate derelict fishing gear and other debris of fishing origin (Galgani et al., 2000; Kendall et al., 2007; see Figure S.HA.3). Kendall et al. (2020) reported that a majority (~85%) of vessels observed in GRNMS were engaged in fishing. Recreational fishing is generally concentrated on weekends and holidays during calm sea conditions. Virtually no fishing occurs at GRNMS during winter months. Currently, there are no known fishing charters that make regular trips to the reef. Due to the sanctuary's distance from shore and the logistical constraints and costs to fish there, fishing pressure is relatively low compared to inshore natural and artificial reefs. Though commercial fishing activity is not explicitly banned within the sanctuary, use of any fishing gear other than handline and rod-and-reel gear is prohibited (15 C.F.R. § 922.92). Consequently, commercial fishing opportunities within the sanctuary are limited. As previously noted, spearfishing is prohibited throughout the sanctuary, and no fishing of any kind is allowed in the Research Area (the southern third of the sanctuary).

### **Changing Ocean Conditions**

Globally, greenhouse gas emissions have increased over time, resulting in global increases in temperature (NOAA Global Monitoring Laboratory, 2024). Much of the excess heat trapped in Earth's atmosphere is absorbed by the ocean, and ocean heat content anomalies have thus also increased over time (National Centers for Environmental Information [NCEI], 2020). From 1980–present, sea surface temperature has been increasingly above the 1955–2006 average (NOAA, 2024; NCEI, 2020). Since 1824, annual average sea surface temperature at GRNMS has increased by 1.15 °C (Shein et al., 2019). Increasing temperatures have a variety of implications for GRNMS species. Mobile species like fish may shift into or out of the sanctuary (Fogarty et al., 2017; Gleason, 2010), potentially altering local ecology or resulting in broader implications for species unable to migrate or survive within novel ranges (Shein et al., 2019; Harley et al., 2006). While propagules of sessile sanctuary species, such as corals and sponges, may disperse to more favorable ranges, mature individuals must rapidly adapt to changing temperatures or are likely to experience mass mortality (Shein et al., 2019; Gleason, 2010; Hoegh-Guldberg et al., 2007).

Coral bleaching, a stress response involving the loss of intracellular symbiotic algae, can be triggered by elevated seawater temperature (Hoegh-Guldberg et al., 2007), but has not been observed within the sanctuary to date. However, increased temperatures can also result in sublethal effects among many species that are less easily observed, including reduced reproductive capacity and microbiome shifts (Carballo & Bell, 2017).

Concurrent with ocean warming, increased levels of carbon dioxide in the atmosphere have increased the rate at which carbon dioxide is dissolved in seawater, reducing pH and making the ocean more acidic (ONMS, 2020); this process is called ocean acidification. The global ocean, on average, has become 30% more acidic since the beginning of the industrial revolution (Haugan & Drange, 1996; Doney et al., 2009), and seawater CO<sub>2</sub> concentration is increasing faster than expected at GRNMS in particular, at an estimated rate of about 2.5% per year (Noakes, 2020). These conditions could be detrimental to many marine organisms, including mollusks, corals, and certain shell-producing plankton, all of which rely on carbonate from seawater to build their shells and other hard parts. Increasingly acidic waters make it difficult for these animals to make and maintain shells and supporting skeletons (Keeling et al., 2010). However, some GRNMS species, including the branching coral *Oculina arbuscula*, have exhibited resilience to moderate ocean acidification (Ries et al., 2010; Wang et al., 2020).

Climate change is also expected to alter some aspects of tropical storm activity, including increased storm intensity and rainfall (Walsh et al., 2016). Increased storm intensity could alter sediment transport dynamics in the sanctuary, which may have implications for ecosystem resilience. Low-salinity conditions, which may occur more frequently due to increased rainfall and associated coastal runoff, can also cause stress in many marine organisms, including coral bleaching (Ding et al., 2022).

As ocean waters warm, their ability to hold oxygen decreases and stratification occurs, which reduces mixing and limits the exchange of oxygen and nutrients (Chan et al., 2017). Although low oxygen can stress and kill bottom-dwelling organisms, particularly in offshore environments that are not frequently exposed to low-oxygen conditions (Vaquer-Sunyer & Duarte, 2008), dissolved oxygen is not expected to drop to harmful levels in the sanctuary by 2050 (ONMS, 2020; Shein et al., 2019).

### **Non-Indigenous Species**

Non-indigenous species are organisms that are not native to an area, but are introduced by human activities, either deliberately or accidentally (Olenin et al., 2010). Their presence may be temporary, if conditions don't allow survival or reproduction, or permanent. Non-indigenous species may also arrive as a result of factors associated with human-induced climate change (e.g., changing current regimes, storm patterns, and water properties, such as temperature and salinity). When non-indigenous species spread and have a negative impact on native species or ecosystem services, they are called invasive species (Olenin et al., 2010). Impacts typically result from space or resource competition, or predation. Invasive species can significantly upset local food webs and habitats, particularly if they have no native predators to regulate their population growth.

Once established, non-indigenous species can be extremely difficult or impossible to eradicate. Common mechanisms for the spread and introduction of non-indigenous species include attachment to vessel hulls, discharge of ship ballast water containing non-native wildlife, and release of aquarium pets (Olenin et al., 2010).

Lionfish (a carnivorous fish species native to the Indo-Pacific) were first observed in GRNMS in 2007. As generalist predators with a high reproductive capacity, they pose a threat to virtually all native fish species in the sanctuary (Muñoz et al., 2011; Shein et al., 2019). They can consume fish up to half their body size, which include adults of many species at GRNMS, as well as juveniles of species that become too large at maturity for lionfish to consume. Notably, some of the latter include commercially and recreationally targeted species.

Other non-indigenous species (titan acorn barnacle, Asian green mussel, and orange cup coral) have been found in the sanctuary. These species are known to outcompete native species elsewhere in the southeastern U.S. (Florida Fish and Wildlife Conservation Commission, 2024; Flower Garden Banks National Marine Sanctuary, 2024; Texas Invasive Species Institute, 2014), and are thus of concern for GRNMS. However, to date, these species have only been found on the GRNMS data buoy and have not been observed on the reef (ONMS, 2012; Reigel, 2015).

### **Coastal Development and Nearshore Construction**

Coastal development can have significant impacts on watersheds, estuaries, and nearshore and offshore waters. Coastal counties inshore of GRNMS are experiencing increased population growth (Table D.2), which results in the construction of more homes, docks, roads, utilities, and impervious surfaces, as well as runoff of contaminants from pavements, lawns, and commercial properties. Construction at or near shorelines can produce marine debris, noise, nighttime light pollution, and sediment- or contaminant-laden runoff that impacts coastal nursery habitats crucial to marine organisms that migrate to GRNMS later in their life cycles (Kusku et al., 2018; NOAA Marine Debris Program, 2016; Prosser et al., 2018; Silva et al., 2017; The Conversation, 2023; U.S. Environmental Protection Agency, 2021; Witherington & Bjorndal, 1991).

Approximately 86% of Georgia's shoreline is fronted by salt marsh (Alexander, 2016). These marshes trap and filter contaminants washed downstream from upland areas before they enter the ocean and move offshore via tides and currents. Research has shown that during high water flows of the Altamaha River, suspended particles and dissolved nutrients from the river mouth can reach GRNMS within three days (Gleason & Cohen, 2012). Furthermore, changes in water quality within marsh habitats could have significant and lasting repercussions at Gray's Reef. This is because some GRNMS fish species, including gag grouper and black sea bass, spend critical early stages of their lives in salt marshes.

Shoreline lighting near loggerhead turtle nesting beaches can cause disorientation for new hatchlings, extending their exposure to predators before they can scramble to the relative safety of the water (Witherington & Bjorndal, 1991). Loggerhead turtles are part of the ecosystem of GRNMS, and their vulnerable beginnings on nearby coastal shorelines can have a direct impact on their presence and role in live bottom habitats throughout the South Atlantic Bight.

## Nonpoint Source Pollution

Nonpoint source pollution (cumulative pollution from many disparate sources that enter water bodies and are carried to the sea) enters the sanctuary from both water- and land-based activities, and some components can accumulate in benthic habitats and organisms (Kendall et al., 2007; NOAA, 2016; Prosser et al., 2018; U.S. Environmental Protection Agency, 2021). Land-based pollution sources include stormwater runoff, failing sewer and septic systems, agricultural runoff, upland hazardous material spills or discharges, landfills, garbage discharge during transport, lawns, roadways, byways, and recreational and commercial activities. Ocean-based pollution sources include commercial and recreational vessels, fishing activities, ports/harbors/marinas, and marine construction sites. Nonpoint source pollution can also include a wide variety of debris, such as lost fishing gear, passenger and commercial shipboard waste, lost vessel cargo, marine structures and buoys, construction debris, metal debris, and common household goods. Nonpoint source pollution impacts occur in a number of ways, including water contamination; crushing, cutting, chipping, abrading, smothering, and scouring of habitats, flora, and fauna; displacement of marine organisms; and habitat alteration. It also diminishes natural aesthetic values. The most prominent nonpoint source pollution observed at GRNMS falls within the category of marine debris. The section below describes observations of marine debris and its impacts within the sanctuary. Other types of nonpoint source pollution, particularly contaminants originating from land, are difficult to quantify, and data gaps currently preclude an understanding of how this type of pollution may affect GRNMS.

### *Marine Debris*

Marine debris is the final result of solid and semi-solid nonpoint source pollution, once it completes its journey to the sea. Plastic is the most prevalent type of marine debris found in the ocean. Fishing gear (rods and reels, spear gun parts, monofilament line, wire, hooks, metal leaders, and lead weights) is the most common type of marine debris observed at GRNMS (Kendall et al., 2007), and much of that debris is plastic-based. Plastic debris comes in all shapes and sizes, and items less than five millimeters in length are called “microplastics.” Plastics in the marine environment never fully degrade, and recent studies show that organisms consume plastic at all levels of the marine food web. Given the quantities of plastic debris adrift in the ocean, the potential for ingestion is significant. Sea turtles that feed on jellies have mistaken floating plastic bags for prey and ingested them by mistake. The ability for plastics to attract and transport contaminants into the marine food web has been documented (Arthur et al., 2009), and research also suggests that microplastics can accumulate in seafood (Avio et al., 2017). A recent study detected microplastics in multiple samples of GRNMS sediments (Geiger, 2021). Other debris observed in the sanctuary includes aluminum cans, glass bottles, party balloons, plastic wrappers, plastic and glass containers, scientific equipment components, dive gear, anchors, chain, boat line, fabric, mesh bags, rope, twine, electrical wire, and wood debris (Bauer et al., 2010; Kendall et al., 2007).

## Status and Trends of Pressures

This section answers questions related to the drivers and pressures described above. The status and trends of sanctuary resources are addressed in the next section.

A virtual expert workshop was convened by GRNMS staff on March 23, 2023 (see Appendix A and Appendix C) to discuss questions related to pressures and sanctuary resources. The assessments of the status and trends of key indicators in GRNMS are for the period from 2008–2022. During the virtual workshop, indicators for each topic were presented, accompanied by information and data sets assembled before the meeting. Attendees were asked to discuss the indicators, data, and interpretations; identify data gaps; and suggest any additional data sets or information sources that may be relevant. Following that discussion, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, they assessed their level of confidence for each rating based on: (1) the quality and amount of information they used to make judgments; and (2) the level of agreement among the experts participating in the discussion. The evidence and agreement ratings were then combined to determine the overall confidence ratings. Appendix C provides a detailed description of the methods used to develop this report.

For each question discussed, the responses summarize the key indicators considered, the supporting data sets, and the rationale for each status and trend rating. Where published or additional information exists, the reader is provided with relevant references. Workshop discussions and ratings were based on data available at the time (i.e., through 2022). However, in some instances, staff later reevaluated and/or incorporated newly available data to more accurately describe the current status and trends of resources. Situations where new information was incorporated or ratings were made or changed after the workshop are noted in the text.

For the purposes of this report, the term “study period” refers to the period from 2008–2022. The data sets presented in this report may or may not span the entirety of the study period, depending on data availability. When necessary, data from a subset of years may have been used to support status and trend determinations for the entirety of the study period. Additionally, some questions were most recently assessed in the 2008 comprehensive condition report (ONMS, 2008) while others were most recently assessed in the 2012 condition report addendum (ONMS, 2012). For this reason, data from either 2008–2022 or 2012–2022 may be presented to illustrate changes since the most recent assessment. The year and summary of the findings from the most recent assessment are provided at the start of each section, and additional information on previous assessments and ratings is also provided in Appendix D.

The question “What are the states of influential human drivers and how are they changing?” is normally posed in condition reports (see Appendix A), but was not rated for GRNMS. ONMS and GRNMS staff decided to discuss, but not rate, this question. The primary purpose of a condition report is to assess program effectiveness and influence management of human activities and natural resource quality. For the most part, drivers are not manageable, at least not under the authority of the National Marine Sanctuaries Act, nor do most of them originate at scales relevant to national marine sanctuary management. While understanding them is

important, rating them is not necessary to achieve the goals of the condition report. The primary drivers influencing pressures on GRNMS resources were previously described in the Drivers section of this report.

### Status and Trends of Human Activities

Human activities that adversely impact water quality are the focus of the first question in this section. Both onshore activities, primarily associated with coastal development, and offshore activities are considered.

The next question covers human activities that may adversely influence habitats. Human activities may alter or destroy the structure of habitats or contaminate them. Examples include recreational fishing, research activities, and scuba diving.

Human activities that have the potential to negatively impact living resources are the focus of the final question in this section. These include activities that remove wildlife, as well as activities that have the potential to injure or degrade the condition of living resources.

Human activities that have accelerated climate change at a global scale (i.e., those that produce greenhouse gases) are not evaluated in this section, even when they have impacts at the sanctuary level. The management of national marine sanctuaries focuses on local and regional activities that influence sanctuary resources, but they do not regulate or otherwise control causative activities that operate at a global scale. ONMS does recognize, however, that some activities in national marine sanctuaries that contribute to climate change (e.g., ship and boat traffic, facility construction, and the transport of harvested food and products) also have local and direct impacts on sanctuary resources. ONMS has a responsibility to minimize impacts of those activities, and they are thus considered in this report.

**Table S.HA.1.** Status, trend, and confidence ratings (where applicable) from previous (2008 or 2012) and present (2008–2022) condition report questions focused on pressures from human activities.

Previous Condition Report Questions	Year of Previous Rating	Previous Rating	2008–2022 Condition Report Questions	2008–2022 Condition Report Rating
Human activities and water quality	2008	Good —	Human activities and water quality	Good —
Human activities and habitat	2012	Fair ▲	Human activities and habitat	Good/Fair —
Human activities and living resources	2012	Fair ▲	Human activities and living resources	Good/Fair —

## What are the levels of human activities that may adversely influence water quality and how are they changing?



**Status Description:** Few or no activities occur that are likely to negatively affect water quality.

**Rationale:** Salt marsh cover remained stable in coastal Georgia, although impervious surface cover increased slightly. Vessel registrations in coastal Georgia increased from 2015–2021, potentially increasing the risk of vessel discharge within the vicinity of the sanctuary. However, no spills were reported in GRNMS from 2008–2022.

### ***Findings From the 2008 Condition Report***

In 2008, the status of human activities that may influence water quality was good and the trend was not changing. These ratings reflected that, while certain potentially threatening human activities had increased, there was little evidence of negative effects. This was attributed, in part, to the remote location of GRNMS. Though human activities were thought to have increased along the southeastern coastal zone, nutrient and contaminant concentrations measured in the sanctuary were not observed at levels that could impact sanctuary resources. There was concern for the ongoing threat posed by continuing coastal development and the report highlighted the need for continued monitoring and more research on impacts from human activities.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include coastal development (salt marsh and impervious surface cover) and the risk of vessel-based waste disposal and pollution (as indicated by vessel registrations and transits and known spill incidents in the region).

### **Coastal Development**

Coastal development can have significant impacts on watersheds, estuaries, nearshore waters, and offshore waters. Approximately 86% of Georgia’s shoreline is fronted by salt marsh (Alexander, 2016). Some fish species (such as gag grouper and black sea bass) that frequent GRNMS or become residents of the reef spend critical early stages of their life cycles in these salt marshes. Thus, changes in water quality at marsh nursery habitats could have profound and lasting repercussions at Gray’s Reef.

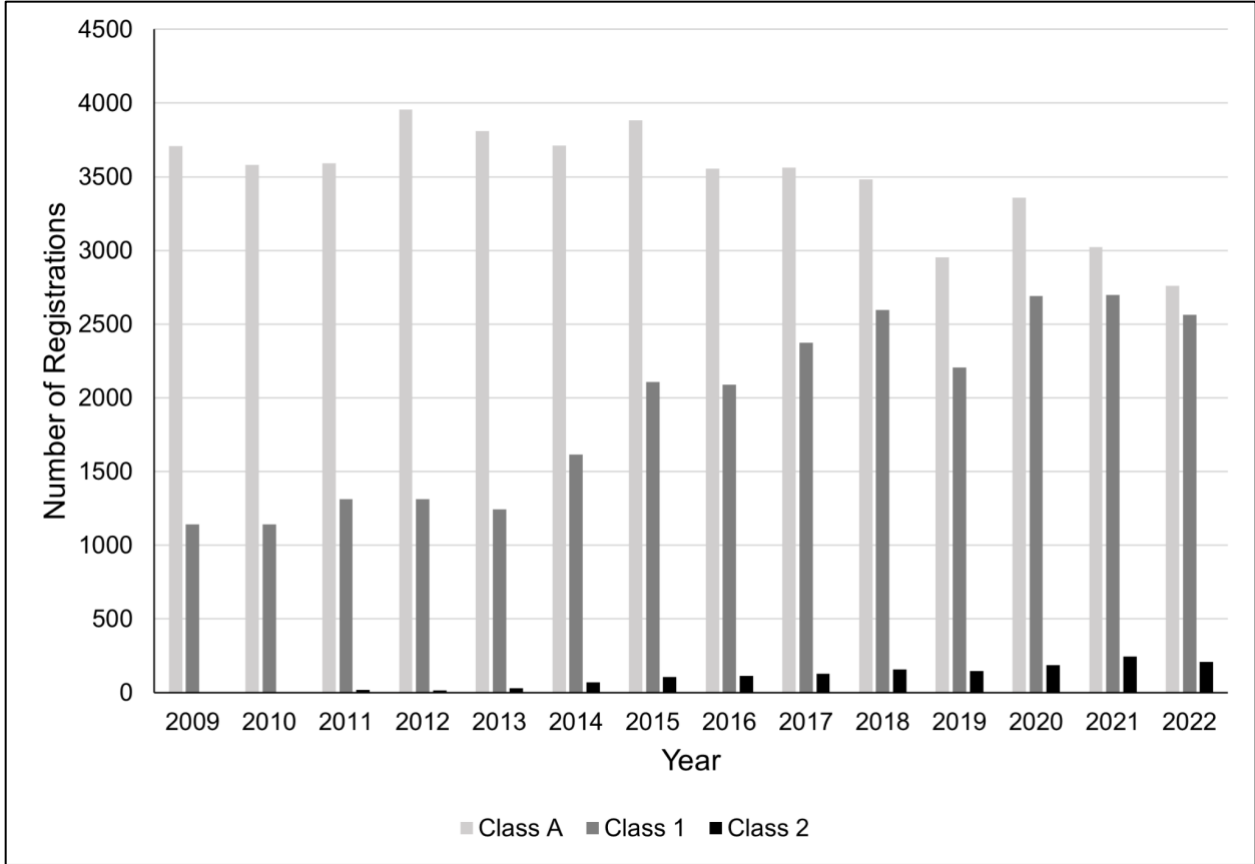
The Georgia Coastal Marshlands Protection Act of 1970 states that coastal marshes are “vital natural resource system[s],” important to ecology, filtration of pollutants, flood control, the economy, and recreation. The state of Georgia has the second largest expanse of saltwater marshes in the country (University of Georgia Marine Extension and Georgia Sea Grant, 2024). The law created permit requirements to regulate any fill or alteration of salt marshes. Further, the Georgia Erosion and Sedimentation Act of 1975 established a 25-foot (7.6-m) development buffer from salt marshes. This management regime has played a key role in preserving critical marsh habitat and protecting coastal water quality, and may protect GRNMS from increased contaminant loading. Salt marshes significantly trap and filter contaminants washed downstream from upland areas that would otherwise enter the ocean and migrate offshore via

tides and currents. Rhodamine tracer dye studies conducted in 2009, 2010, 2011, 2014, and 2015 demonstrated that during high water flows of the Altamaha River, suspended particles from the river mouth can reach GRNMS within three days (Gleason & Cohen, 2012). Monitoring data from the U.S. Geological Survey demonstrate that saltwater marsh habitat across Georgia's six coastal counties (Chatham, Bryan, Liberty, McIntosh, Glynn, and Camden) remained stable between 2006 and 2016, with a very slight reduction of 0.07% (about 243 acres, or 98 hectares) over that 10-year period (U.S. Geological Survey, 2022).

Between 2001 and 2019, impervious surfaces within Georgia's six coastal counties increased by 13.07 square miles, from 1.81% to 2.05% of total coastal county land area over 18 years, a slight increase since the last GRNMS condition report in 2008.

### **Waste Disposal and Pollution**

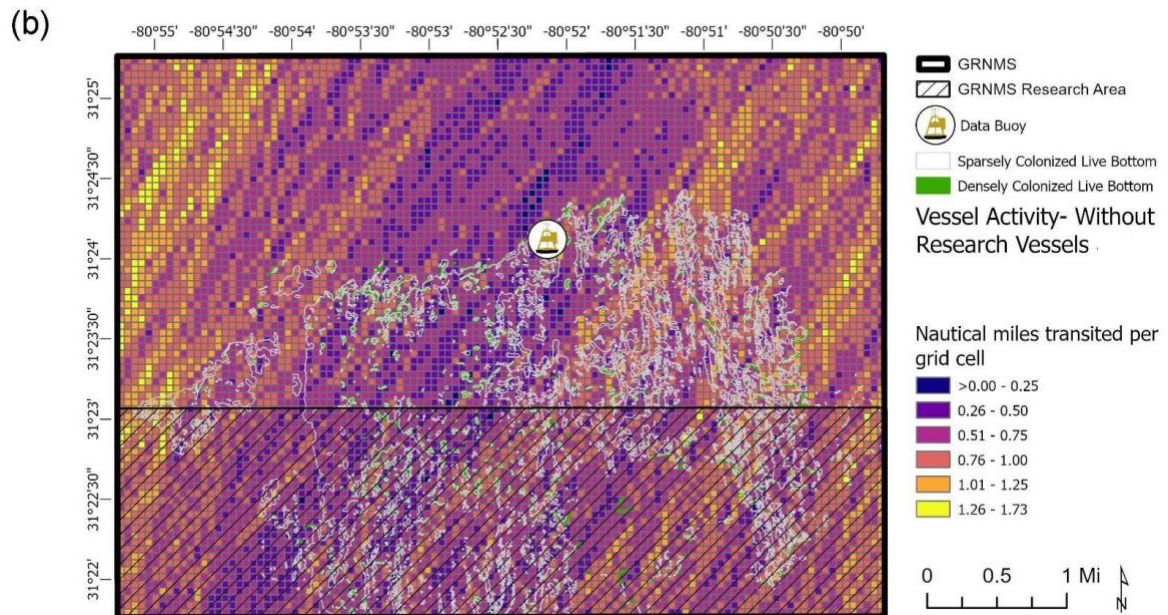
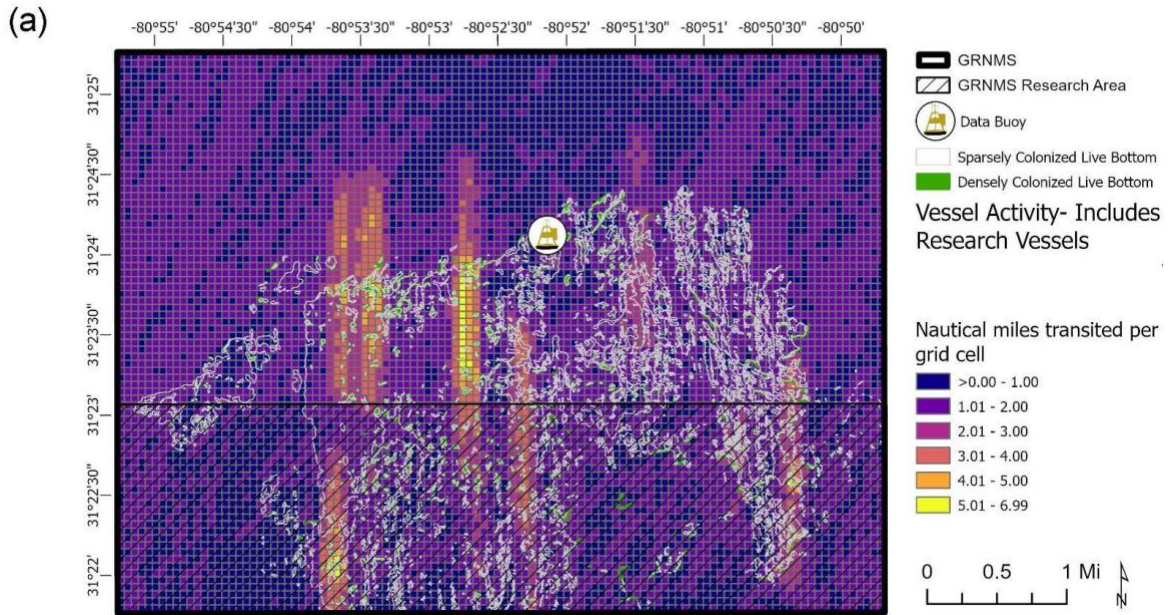
Waste disposal (e.g., sewage, gray water, garbage) and pollution (e.g., oil, hydraulic fluid, engine exhaust, brine) from vessels is a human activity that may influence water quality. Impacts could be from discharges directly into the sanctuary or from distant spills that drift into the sanctuary. Kendall et al. (2020) assessed vessel presence in GRNMS from June 1 to December 6, 2019 through satellite imagery, aerial and vessel-based monitoring, seafloor hydrophone data, camera images from the GRNMS data buoy, and automatic identification system (AIS) data. This study found that nearly all sanctuary visitors (~90%) arrived in Class 1 (16 to <26 ft in length, the most common type observed) or Class 2 (26 to <40 ft in length) recreational fishing boats averaging 26 feet in length with a center console/outboard engine design. To better understand how the use of small recreational vessels may have changed throughout the entirety of the study period, vessel registrations in Georgia coastal counties were assessed to understand regional trends as a proxy for vessel activity, and thus the threat of spills and discharges, in the sanctuary. Registrations of Class 1 vessels in the six counties on Georgia's coast increased from 2009–2022 (Figure S.HA.1). Of the Class 1 vessels registered in 2022, only 2.5% had fixed marine toilets, and although discharge of raw sewage is prohibited by GRNMS, it is possible that some is released into the sanctuary by visitors. Given the popularity of fishing at GRNMS (approximately 85% of vessels observed at GRNMS by Kendall et al. [2020] were engaged in some type of fishing), the number of recreational fishing trips in the region may also provide some broad insight into trends in vessel activity at GRNMS. The number of recreational angler trips in federal waters off Georgia varied without trend from 2008–2022 (Figure S.HA.6; NOAA Marine Recreational Information Program, 2022; see the subsequent section on human activities that may adversely influence habitat for additional information).



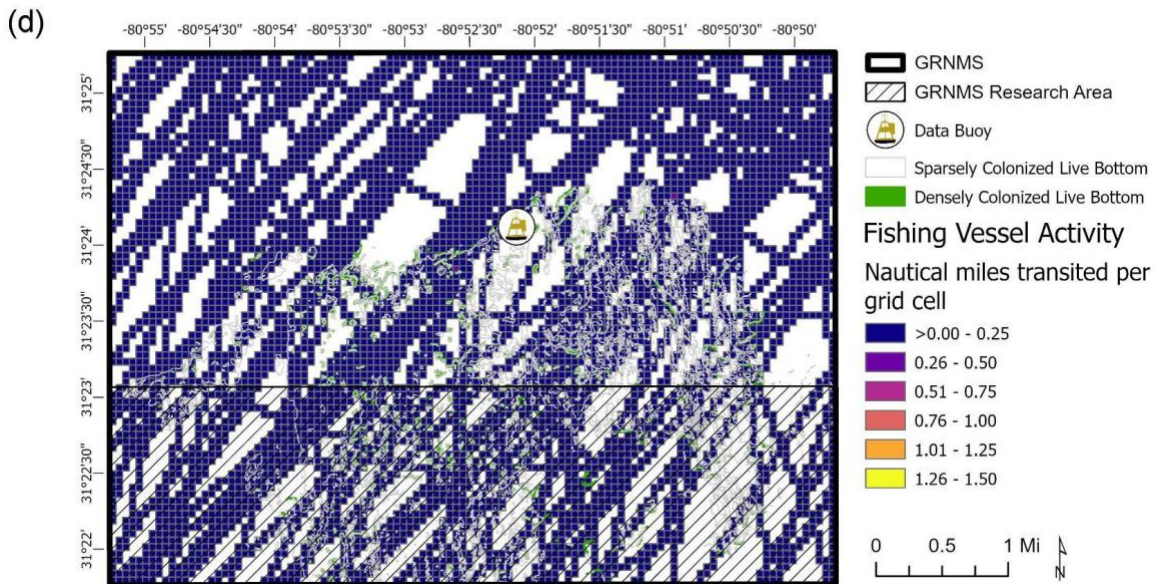
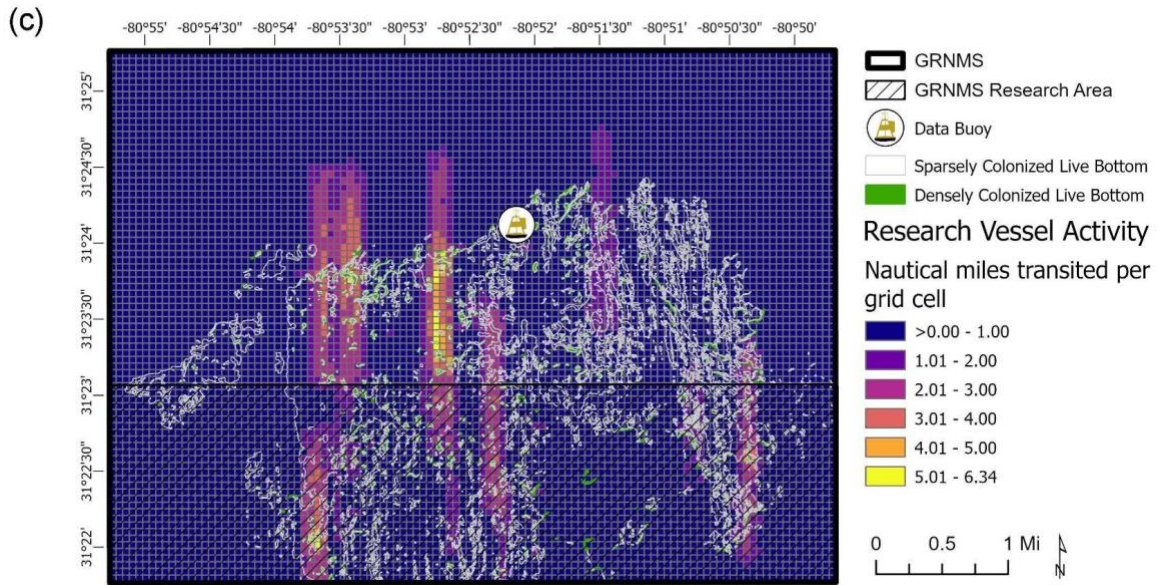
**Figure S.HA.1.** The number of Class A (<16 ft), Class 1 (16 to <26 ft), and Class 2 (26 to <40 ft) vessel registrations in the six Georgia counties adjacent to the coast (Chatham, Bryan, Liberty, McIntosh, Glynn, and Camden), 2009–2022. Source: Ozburn, 2023

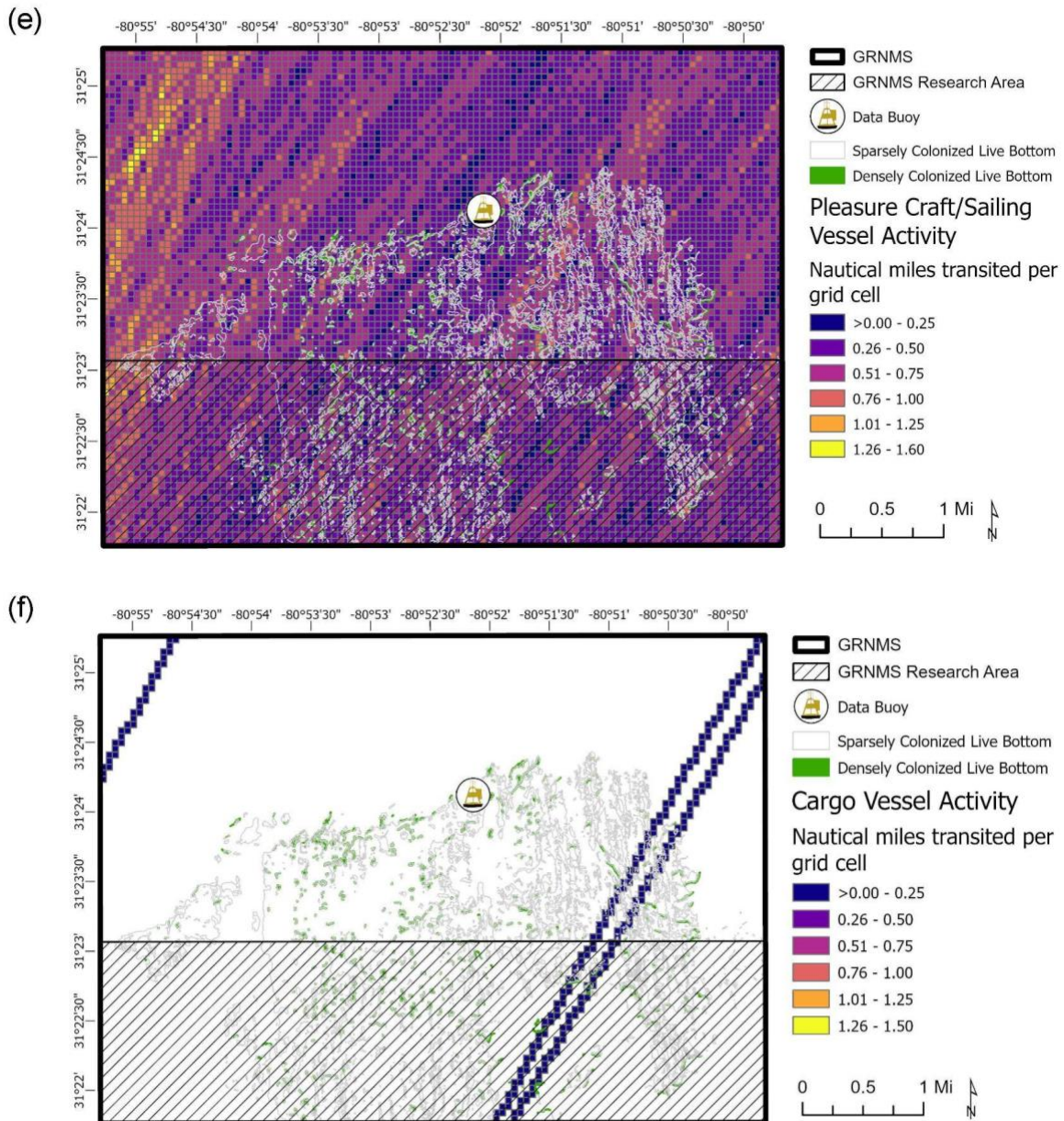
AIS-equipped vessels have transmitters that routinely broadcast their name, position, speed, and other information to other vessels and shore stations within radio range. Received transmission records can be stored and analyzed to understand vessel traffic patterns within given areas. U.S. Coast Guard AIS records indicate that from 2015 to 2021, 1,635 unique AIS-equipped vessels (~0.6 per day) transited nearly 9,800 nautical miles (~3.3 nm/day) through GRNMS (U.S. Coast Guard Navigation Center, 2022). Of these, 76% were pleasure craft (recreational and sailing vessels). The NOAA ship *Nancy Foster*, a primary platform for research in the sanctuary, accounted for 2,272 nautical miles of the total transit miles during this time period (Figure S.HA.2). According to AIS records, there was an increase in the number of vessels transiting the sanctuary over time, but this likely reflects an increase in the number of recreational vessel owners installing AIS for safety in recent years. The fact that hot spots for vessel traffic lie directly over the live-bottom habitat within the sanctuary boundaries (Figure S.HA.2) shows the preference by users of these habitats for fishing, research, and diving. However, it is important to note that small boats (<65 ft) are not required to carry AIS, and it is thought that less than 12% do (Kendall et al., 2020).

## Status and Trends of Pressures



## Status and Trends of Pressures





**Figure S.HA.2.** AIS-equipped vessel transits inside sanctuary boundaries by vessel type, 2015–2021. Panels illustrate transits by (a) all vessel types (including research vessels), (b) all vessel types (excluding research vessels), (c) research vessels, (d) fishing vessels, (e) pleasure craft/sailing vessels, and (f) cargo vessels.<sup>8</sup> Note that the scale of the legend differs in panels a and c (i.e., colors denote greater numbers of nautical miles transited in these panels). Source: U.S. Coast Guard Navigation Center, 2022

<sup>8</sup> Additional vessels classified as engaged in “dredging or underwater operations” were detected in the sanctuary on 2/24/2011, 4/19–22/2011, 5/25–26/2011, 6/13–15/2013, and 4/1/2020, but the specific nature of these vessels and the activities they were engaged in are unknown. Dredging is prohibited throughout the sanctuary (15 C.F.R. § 922.92) and is not believed to have occurred illegally on these dates given the sanctuary’s distance from shore.

AIS data revealed that in the years 2015 and 2017, two cargo vessels traveled a total of nine nautical miles in GRNMS (Figure S.HA.2). The sanctuary is well inshore of commercial shipping lanes, so these transits were unusual and caused some concern given the large draft of typical cargo vessels and shallow depth of the sanctuary.

Eleven incidents that either resulted in or may have resulted in notable marine spills occurred along Georgia's 100-mile coastline between 2008 and 2021 (Office of Response and Restoration, 2022). The nearest incident to GRNMS in that 13-year period was the grounding of F/V *Jimmy & Charlie Jr.*, 17 nautical miles west of the sanctuary in 2020; however, this grounding did not result in a spill. Other reported and mapped incidents were farther from the sanctuary, up to a maximum of 45 nautical miles away, or did not pose a significant spill threat (e.g., a recreational vessel that capsized in, but ultimately drifted out of, the sanctuary in 2019). All reported and mapped incidents occurred within two miles of shore or within inland waterways, except for a "mystery sheen" reported offshore in 2014.

### **Conclusion**

There were a limited number of human activities that were likely to adversely affect water quality in GRNMS from 2008–2022. The stable salt marsh cover suggests that any threats to sanctuary water quality from onshore construction or alteration probably did not change during the study period. Both vessel use data and regional spill information indicate limited threats from these activities, though more specific data are needed on vessel use patterns in the sanctuary and the volume and locations of spills.

## What are the levels of human activities that may adversely influence habitats and how are they changing?



**Status Description:** Some potentially harmful activities exist, but they have not been shown to degrade habitat quality.

**Rationale:** Activities that could harm habitats, including recreational fishing, research activities, and scuba diving, occur regularly at GRNMS. However, available data suggest they did not occur at levels that resulted in measurable habitat impacts during the study period.

### ***Findings From the 2012 Condition Report Addendum***

In 2012, the status of human activities that may influence habitat quality was fair and the trend was improving. This was based on increased visitation to GRNMS in prior decades, resulting in impacts from anchoring, fishing, marine debris, diving, and research activities; however, these impacts were typically localized to biologically structured habitats within the sanctuary. Regulatory actions, including a ban on anchoring in 2006, a ban on spearfishing in 2010, and the establishment of a Research Area in 2011, were believed to have reduced these impacts.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include recreational fishing patterns in the GRNMS region (as a proxy for the risk of damage to sanctuary habitats from fishing gear), research activities, and recreational scuba diving.

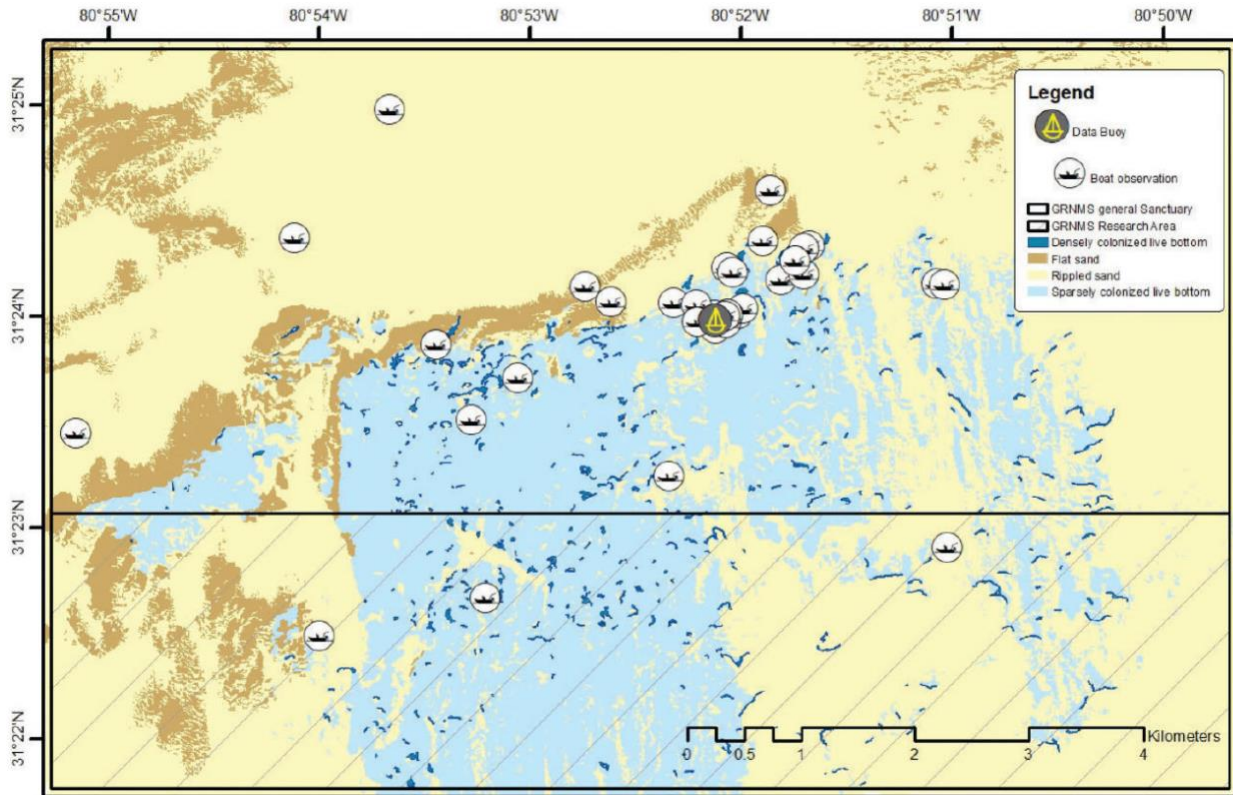
### **Recreational Fishing**

The unique habitats of GRNMS support a variety of fish and other marine organisms that draw visitors from all over Georgia, and sometimes farther afield. Fishing is the primary recreational activity in the sanctuary, and it is concentrated over reef habitats, which have the highest structural and ecological diversity of all sanctuary habitats. Such areas also tend to accumulate derelict fishing gear and other debris of fishing origin (Galgani et al., 2000; Kendall et al., 2007). Kendall et al. (2007) reported that fishing gear represented about two-thirds of all debris observed at GRNMS during surveys in 2004 and 2005, with other debris consisting of cans, bottles, rope, and miscellaneous other items (e.g., wood, electrical wire). No systematic assessment or monitoring of marine debris prevalence and composition has occurred since that study; however, methods for monitoring debris within the sanctuary have been published (Bauer et al., 2008, 2010). Anecdotal observations suggest that fishing gear remains the most common type of marine debris observed in the sanctuary (Figure S.HA.3). Given that fishing activity is linked to the discharge of debris that impacts GRNMS habitat quality, available information about recreational fishing levels in the sanctuary and surrounding region can shed light on the potential level of risk from marine debris, in the absence of direct measures.



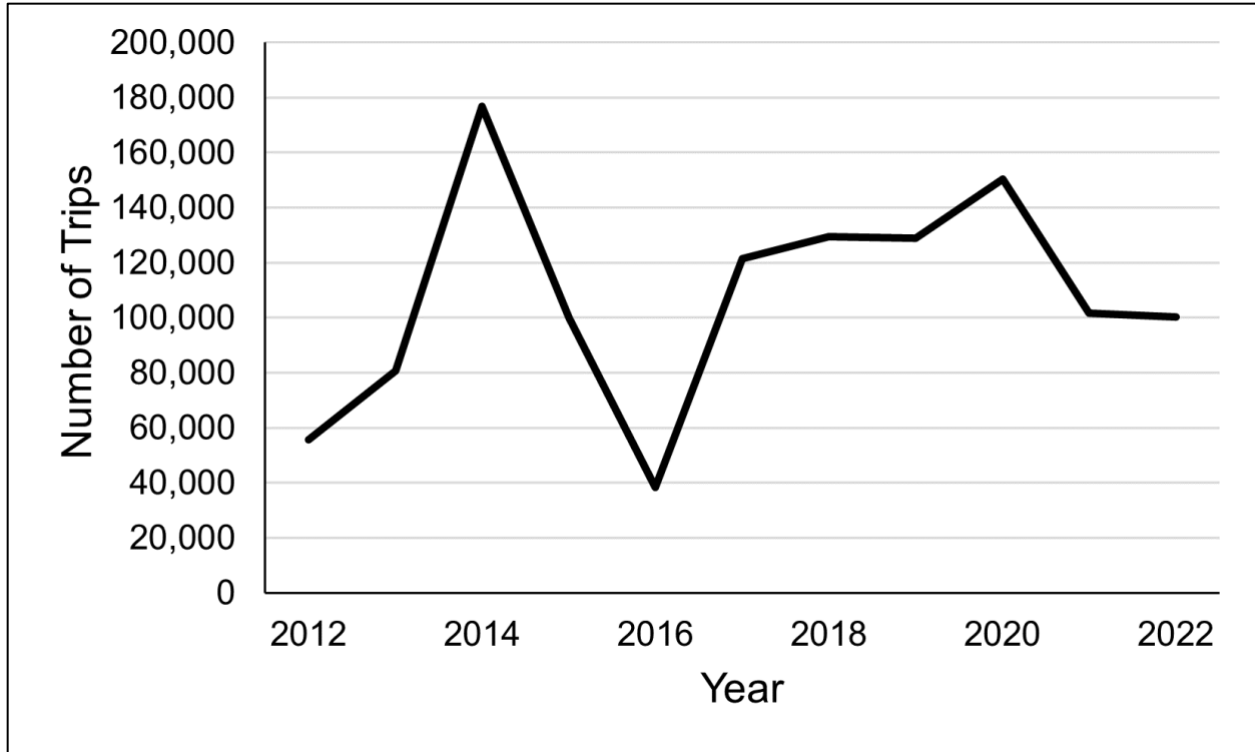
**Figure S.HA.3.** Examples of derelict fishing gear found at GRNMS. Photos: NOAA National Centers for Coastal Ocean Science (NCCOS)

Data specific to recreational fishing patterns within GRNMS were not available for the majority of the 2008 to 2022 study period. Kendall et al. (2020), however, provided a snapshot of vessel activity at GRNMS in 2019. A total of 34 boats were observed within the sanctuary using satellite imagery (Figure S.HA.4). Observational data suggest that ~60% of visitors were bottom fishing, ~25% were trolling, and ~15% were passing through the sanctuary. Three boats (9%) were observed in the Research Area. Enforcement records indicate that illegal anchoring has occurred; while these incidents were rare (a total of three detected violations among 191 vessels checked from 2012 to 2021), they are likely underreported (GADNR, 2022). The regular collection of spatial data in the future would enable the assessment of patterns and long-term trends in visitor use at GRNMS, including recreational fishing.



**Figure S.HA.4.** Map of the positions of all categories of boats observed in satellite imagery (April to October 2019). Image: Kendall et al., 2020

Although sanctuary-specific data were limited for the study period, state-level data can provide information on broader trends in recreational fishing. Data from NOAA’s Marine Recreational Information Program (2022) showed that the average number of recreational angler trips in federal waters off Georgia (inclusive of GRNMS) was significantly greater during the period since the last assessment of this question ( $107,547 \pm 12,093$  SE; 2012–2022) than in preceding years ( $76,368 \pm 6,545$  SE; 1990–2011), although there was no statistically significant trend in the number of recreational angler trips from 2012–2022 (Figure S.HA.5). However, the number of registrations of Class 1 vessels (16 to <26 feet in length), the most common type used for fishing in the sanctuary (Kendall et al., 2020), increased in Georgia during the study period (Figure S.HA.1; see previous section on human activities that may adversely influence water quality for additional information).



**Figure S.HA.5.** Recreational angler trips in federal waters off Georgia (which include GRNMS), 2012–2022). Source: NOAA Marine Recreational Information Program, 2022

### Research Activities

Research conducted at GRNMS requires a permit from NOAA, and research activities that may impact sanctuary habitats are limited. Examples of research conducted at GRNMS include the installation of anchor bases for acoustic receiver arrays and the collection of biological specimens. From 2009–2022, GRNMS issued 42 permits to 24 researchers, and there was no apparent trend in the number issued over that period (ONMS, 2023). Fourteen of those 24 researchers (58%) obtained more than one permit through renewals or new applications, returning to the sanctuary year after year for continued underwater activities. Specific activities known to impact the habitat for research purposes, such as coring and physical sampling, are strictly controlled, with GRNMS oversight to minimize negative impacts. No major habitat disturbances or damages were detected as a result of these activities.

### Scuba Diving

GRNMS is a unique destination for recreational divers, but it is isolated from populated areas, has a short dive season (limited to summer months), has challenging oceanographic conditions (strong currents, low visibility), and anchoring is prohibited. One dive charter, Latitude 31 Dive Company, currently operates at GRNMS (2018–present), making approximately 20 trips annually, with six divers per trip. One to two other dive charter boats operated in GRNMS from 2008 to 2018, and though no data were available on the number of divers or trip frequency, anecdotal observations by GRNMS staff suggest that activity levels were likely equal to or less than levels from 2018 to present.

Although recreational diving within the sanctuary is considered non-consumptive, incidental habitat damage can occur through unintentional contact with benthic organisms (e.g., fin kicks, buoyancy issues; Barker & Roberts, 2004). However, dive professionals are present on each chartered dive to monitor diver behavior and intervene when necessary, which has been shown to be effective in reducing contact (Barker & Roberts, 2004). When contact does occur at GRNMS, the impacts are generally minimal (K. Hunnicutt/Latitude 31 Dive Company, personal communication, March 23, 2023). While some additional diving takes place from private boats, the number and frequency are limited by the challenging environmental conditions and federal regulations prohibiting anchoring.

### **Conclusion**

Some human activities that may adversely influence habitats occur in GRNMS; these include recreational fishing, research activities, and recreational scuba diving. However, the limited data available suggest that these activities generally remained stable and had minimal impacts on GRNMS habitats during the study period. The most apparent impacts to habitat were from fishing gear entanglement; however, substantial data gaps exist regarding the level and impact of recreational fishing activity on GRNMS habitats, and there is a need for updated quantitative assessments and consistent monitoring of fishing activity, patterns, and marine debris in the sanctuary.

## What are the levels of human activities that may adversely influence living resources and how are they changing?



**Status Description:** Some potentially harmful activities exist, but they have not been shown to degrade living resource quality.

**Rationale:** Vessel registrations and activity increased during the study period, but vessel activity was generally seasonal, peaking in summer. The majority of vessels visiting the sanctuary engaged in fishing. The number of recreational fishing trips and landings in federal waters offshore of Georgia were higher during the current study period compared to historical levels; trends were stable during the study period, except for an increase in the number of fish caught and released. Recreational fishing information and fishery-independent data specific to GRNMS were lacking, but experts agreed that although fishing pressure should be further examined in the sanctuary, it likely occurred at sustainable levels during the study period.<sup>9</sup>

### *Findings From the 2012 Condition Report Addendum*

In 2012, the status of human activities that may influence living resources was fair and the trend was improving. Recreational bottom fishing shifted the size-frequency distribution for black sea bass toward a higher abundance of smaller individuals, and sessile organisms were observed entangled by fishing line. Other activities of some concern were diving (for recreational and research purposes), anchoring, and coastal development. However, changes in sanctuary management, including a prohibition on anchoring in 2006, as well as external influences, such as economic trends, increased fuel costs, and new fishing regulations, minimized the impacts of some human activities.

### *New Information in the 2008–2022 Condition Report*

Indicators considered in the present report include vessel activity (including vessel registrations, AIS records, and acoustic vessel detections) and recreational fishing (including fishing trips, landings, and enforcement detections).

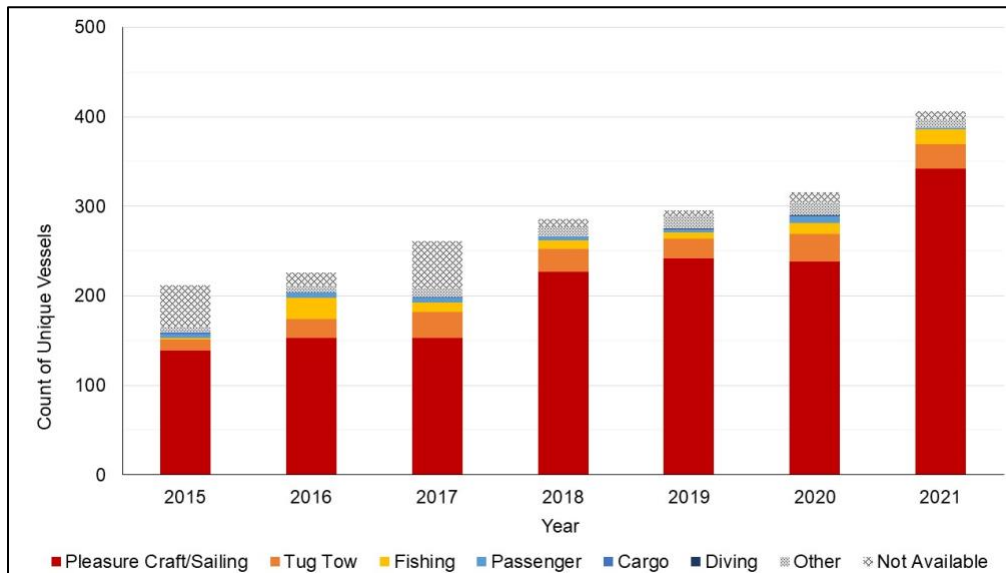
### **Vessel Activity**

Common vessel activities can harm living marine resources in GRNMS via wildlife strikes, interruption of animal behavior, or noise disturbance (e.g., sound masking); discharge of hazardous substances (e.g., bilge water, petroleum products, sewage); introduction of invasive species via ballast water discharges or hull fouling; and leaching of anti-fouling paint. Large vessel operations pose additional potential threats, such as loss of cargo; discharge of chlorinated water; discharge of metals and high-salinity plumes from high-volume water-

<sup>9</sup> Due to time constraints, a status rating for this question was not determined during the expert workshop. This status rating was determined later by GRNMS staff, who reevaluated the indicators, data sets, and expert input provided during the workshop.

making systems;<sup>10</sup> and discharge of exhaust gas cleaning system effluents.<sup>11</sup> While none of these impacts have been directly documented at GRNMS, the level of vessel activity in the sanctuary is an indicator of risk.

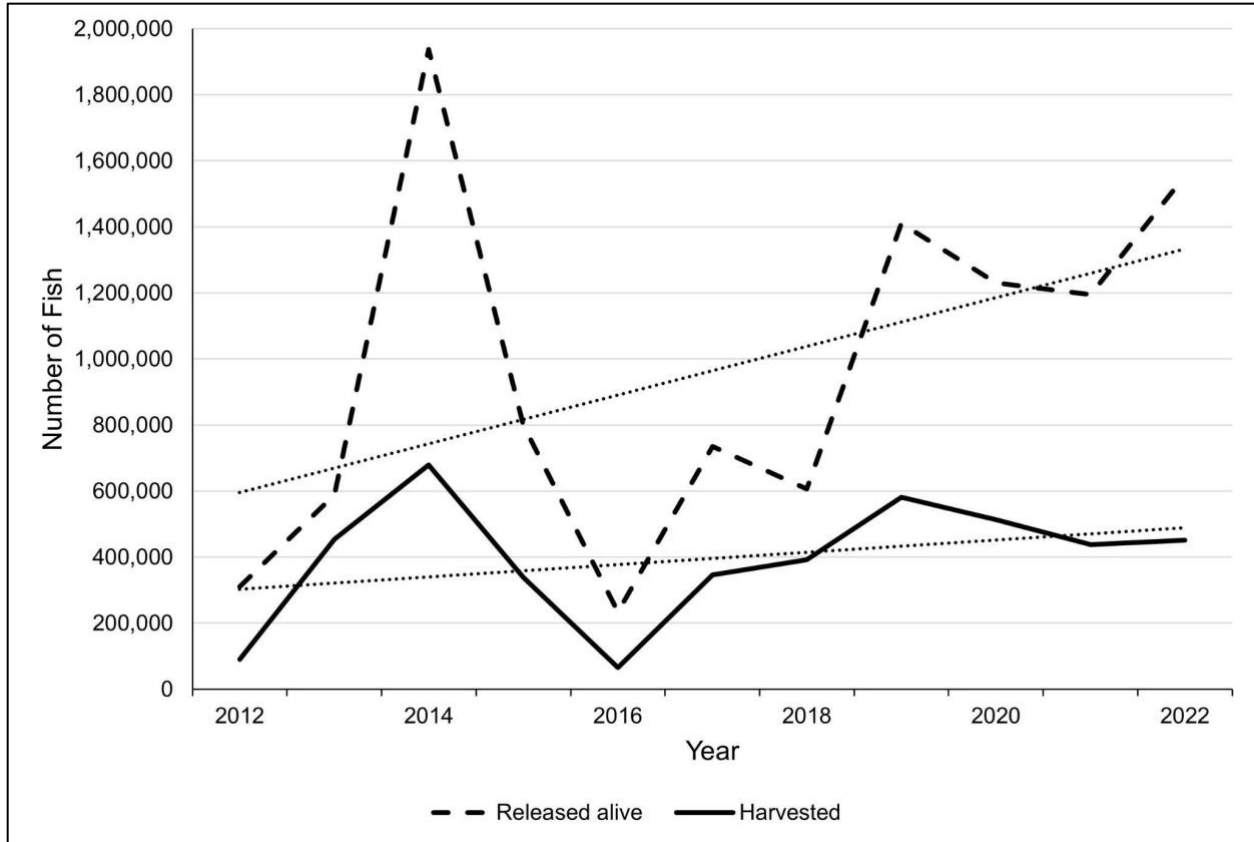
A number of metrics were used to estimate vessel activity in GRNMS. The findings of Kendall et al. (2020), summarized in the previous two sections, are also relevant indicators of human activities that affect living resources. Briefly, Kendall et al. (2020) found that most vessels at GRNMS were Class 1 or Class 2 vessels, and the majority of operators engaged in some type of fishing. As noted in previous sections, Georgia registrations of these types of vessels increased during the study period (GADNR, 2022; Figure S.HA.1). AIS data also indicated frequent vessel transits through the sanctuary (for more information, see the earlier section on human activities that may adversely influence water quality); however, these data are likely an underestimate, as most vessels used at GRNMS are not typically equipped with AIS transmitters. Although there was an apparent increase in the number of unique vessels equipped with AIS in GRNMS from 2015 to 2021 (Figure S.HA.6), this likely reflects an increase in installation of AIS units on vessels rather than a true increase in vessel activity.



**Figure S.HA.6.** Number of unique vessels transiting the sanctuary, by type, 2015–2021. Counts were derived from AIS data, and thus only reflect the number of vessels carrying AIS units. The apparent increase in the number of unique vessels transiting GRNMS may thus reflect changes in AIS usage rather than actual changes in vessel traffic within the sanctuary. Source: U.S. Coast Guard Navigation Center, 2022

<sup>10</sup> Water-making systems, including distilling and reverse osmosis plants, generate freshwater from seawater for multiple types of shipboard activities, including potable water and feedwater for boilers. These systems release brine that may include chemicals used for water treatment as well as heavy metals from corrosion of system constituents. Contaminants of concern include copper, zinc, nitrogen, phosphorus, iron, lead, and nickel (U.S. Environmental Protection Agency, 1999).

<sup>11</sup> Exhaust gas cleaning systems, also known as “scrubbers,” are used aboard large oceangoing vessels to clean marine engine exhaust in order to comply with sulfur oxide emissions regulations. These systems discharge washwater into the ocean. The washwater contains compounds of concern, including the sulfur oxide and nitrogen oxides removed from exhaust emissions, and may also include traces of oil, polycyclic aromatic hydrocarbons, heavy metals, and nitrate (U.S. Environmental Protection Agency, 2011).

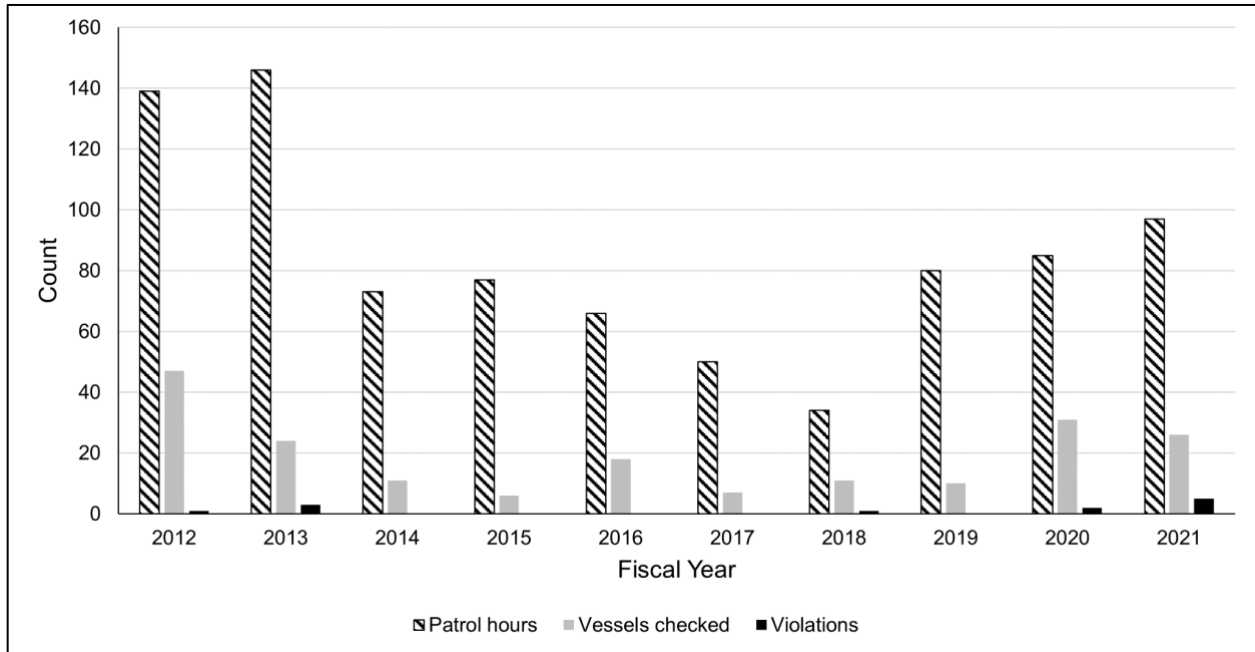


**Figure S.HA.7.** Recreational catch in federal waters off Georgia (which include GRNMS), 2008–2022). Source: NOAA Marine Recreational Information Program, 2022

Although these data provide a broad estimate of regional trends in federal waters off Georgia, the methodology used to collect recreational fishing and landings data does not allow for an analysis of activity or catch levels specifically in GRNMS, and both data and analysis gaps exist for fishery-independent surveys of GRNMS. The lack of long-term data on recreational fishing metrics within the sanctuary specifically was noted by experts at the March 2023 status and trend workshop as a critical gap. In general, expert opinion was that fishing pressure within the boundaries of GRNMS was likely sustainable. However, both experts at the workshop and Kendall et al. (2020) noted that the GRNMS data buoy is one of the only visible structures in the area, serving as a visual landmark that aids fishers in locating and targeting hard bottom habitat, and thus may concentrate fishing activities in some areas of the sanctuary and result in excessive pressure. This is a key area for future study ahead of the next condition report.

Another metric used to understand recreational fishing pressure at GRNMS was GADNR enforcement records. From 2012–2021, GADNR annual patrol hours at GRNMS ranged from 34 to 146 (average:  $84.7 \pm 11.2$  hours per year; GADNR, 2022; Figure S.HA.8). During patrols, an annual average of  $19.1 \pm 4.1$  vessels were checked, and an average of  $1.2 \pm 0.5$  violations were detected each year. Of the 12 total violations detected from 2012–2021, four were for undersized fish, three were for unlawful anchoring, one was for exceeding catch limit, and another was for unlawful fishing in the Research Area (where all fishing is prohibited). The other three violations were not specified, but likely also included detections of undersized fish, catch limit

exceedances, and fishing in the Research Area (M. Carson/GADNR, personal communication, August 12, 2022). AIS data also revealed the presence of fishing vessels on high-relief areas within the Research Area between 2015 and 2021 (U.S. Coast Guard Navigation Center, 2022); however, there are several analysis gaps associated with these data, including the number, sizes, and speeds of the vessels detected. This finding thus warrants further investigation, but may indicate additional instances of unlawful fishing.



**Figure S.HA.8.** GADNR law enforcement information for federal fiscal year 2012 to 2021. The federal fiscal year runs from October 1 to September 30 (thus, 2012 data, for example, were from October 1, 2011 to September 30, 2012). No violations were detected in fiscal years 2014–2017 or 2019. Source: GADNR, 2022

Coastal development was also considered as a potential indicator of human activities that may affect the sanctuary’s living resources. Specifically, there are concerns that species that use GRNMS in adulthood may use nursery habitats along the coast as juveniles, and these nursery habitats may be at risk of disturbance from development. The connection between inshore nursery habitat availability and adult fish populations on reefs further offshore has been explored elsewhere (Swadling et al., 2022), and coastal development has been linked to population impacts (Rees et al., 2021). While these connections have not yet been directly demonstrated for GRNMS, species known to inhabit the sanctuary, including gag grouper (Weisberg et al., 2014), as well as pinfish (*Lagodon rhomboides*), Gulf flounder, summer flounder, southern flounder, and Atlantic menhaden (Thaxton et al., 2020), are known to recruit to nearshore shallow areas before making ontogenetic migrations to offshore reefs. However, the nature and extent of any impacts of coastal development on living resources in GRNMS is considered a data gap. Additional information on the status and trends of coastal development in Georgia is available in the section of this report on human activities influencing water quality.

### ***Conclusion***

While vessel access to GRNMS is somewhat limited by its distance from shore, vessels were regularly present in the sanctuary during the study period, particularly in the summer. Registrations of the vessel types most likely to visit GRNMS increased since 2015, and AIS data suggested a possible increase in vessel traffic in the sanctuary during the same time period. The majority of vessels that visited the sanctuary engaged in fishing. Recreational fishing trips and landings in federal waters offshore of Georgia were greater during the study period compared to previous years. The number of recreational fishing trips in offshore waters, fish harvested in offshore waters, and enforcement violations in the sanctuary remained stable, while the number of fish harvested and caught and released alive in offshore waters increased. A key data gap exists for recreational fishing metrics and fishery-independent data within the sanctuary boundaries specifically; however, experts generally agreed that the level of fishing within the sanctuary has likely been sustainable over the study period.

## Status and Trends of Sanctuary Resources

This section summarizes resource status and trends within three areas: water quality, habitat, and living resources. Virtual and hybrid expert workshops were convened by GRNMS staff on various dates from March–April, 2023 (see Appendices A and C) to discuss the series of questions about each resource topic. In general, the assessments of the status and trends of key indicators in GRNMS rely on information from 2008–2022. During the workshops, indicators for each topic were presented, accompanied by datasets ONMS compiled before the meeting. Attendees were asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest additional data sets that may be relevant. Once all data sets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the quantity and quality of information they used to make judgments; and (2) the group’s agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence rating. Appendix C provides a detailed description of the methods used to develop this report.

The following responses for each question summarize the key indicators, supporting data sets, and rationale for each status and trend rating. Where published or additional information exists, the reader is provided with appropriate references. Workshop discussions and ratings were based on data available at the time (e.g., through 2022). However, in some instances, sanctuary staff later reevaluated and/or incorporated newly available data to more accurately describe the current status and trends of resources. Situations where post-workshop rating decisions were made and/or data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

For the purposes of this report, the term “study period” refers to the period from 2008–2022. The data sets presented in this report may or may not span the entirety of the study period, depending on data availability. When necessary, data from a subset of years may have been used to support status and trend determinations for the entirety of the study period. Additionally, some questions were most recently assessed in the 2008 comprehensive condition report (ONMS, 2008) while others were most recently assessed in the 2012 condition report addendum (ONMS, 2012). For this reason, data from either 2008–2022 or 2012–2022 may be presented to illustrate changes since the most recent assessment. The year and summary of the findings from the most recent assessment are provided at the start of each section, and additional information on previous assessments and ratings is also provided in Appendix D.

Two resource questions from the condition report rating scheme (see Appendix A) were not rated for GRNMS. The first is “What is the condition of known maritime heritage resources and how is it changing?” This question was not rated as there are no known tangible maritime heritage resources within GRNMS.

The second question that was not rated is “What is the status of keystone and foundation species and how is it changing?” Keystone species are those upon which the persistence of many other species in the ecosystem depends (Paine, 1966); these species typically play a role in ecosystem

function that is disproportionate to their abundance or biomass. Foundation species define community structure by creating stable conditions for other species or by stabilizing ecosystem processes (Dayton, 1972). During indicator selection (see Appendix C), experts were consulted to provide input on initial indicator lists developed by ONMS staff. During these discussions, the consensus opinion was that, based on current knowledge, no species at GRNMS serve as either keystone or foundation species. Instead, the ecosystem of GRNMS is believed to be characterized by and dependent on relatively high species richness compared to temperate Atlantic reefs, as well as a diversity of habitat types that support different species assemblages. A hallmark of GRNMS is its functional redundancy; if a given species is removed from the ecosystem, others might fill its functional role (Rosenfeld, 2002). However, many species are considered important within the sanctuary for other reasons. The status and trend of these species are assessed as part of the question “What is the status of other focal species and how is it changing?”

### ***Status and Trends of Water Quality***

The following is an assessment of the status and trends of key water quality indicators in GRNMS for the period from 2008–2022.

The first question in this section focuses on eutrophic conditions and their influence on primary production in sanctuary waters. Eutrophication is the accelerated production of organic matter, particularly algae, usually caused by an increase in the amount of nutrients (primarily nitrogen and phosphorus) from human sources in surface waters (Khan & Mohammad, 2014).

Eutrophication can impact the condition of sanctuary resources, for example, by promoting nuisance and toxic algal blooms or impacting dissolved oxygen levels.





The second question focuses on parameters affecting public health. Human health concerns can arise from water or seafood contamination (bacteria, chemicals, and biotoxins). Indicators of health impacts may include fishery closures and shellfish consumption advisories. Such impacts can be devastating, both ecologically and economically, in affected coastal communities.

The next question focuses on shifts in water quality due to climate drivers. Climate indicators include indices of large-scale climate patterns, upwelling intensity, water and air temperature, dissolved oxygen, and pH. Shifts in water temperature can affect species growth rates, phenology, distribution, and susceptibility to disease; acidification can affect organism survival, growth, and reproduction; and upwelling influences oxygen content and nutrient cycling (Doney et al., 2012).

The final question in this section assesses biotic and abiotic stressors not addressed in other questions that, individually or in combination, may influence sanctuary water quality. Examples include nonpoint source contaminants and hard-to-quantify stressors that influence the condition of habitats and living resources. Such inputs may include industrial discharges and emissions.

## Status and Trends of Sanctuary Resources

**Table S.WQ.1.** Status, trend, and confidence ratings (where applicable) from previous (2008 or 2012) and present (2008–2022) condition report questions focused on water quality.

Previous Condition Report Questions	Year of Previous Rating	Previous Rating	2008–2022 Condition Report Questions	2008–2022 Condition Report Rating
Eutrophic condition	2008	Good ?	Eutrophic condition	
Human health risks	2008	Good/Fair —	Human health risks	
Multiple stressors (including climate)	2012	Good —	Climate drivers	
			Other stressors	

## What is the eutrophic condition of sanctuary waters and how is it changing?



**Status Description:** Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

**Rationale:** Chlorophyll concentration and anomalies varied seasonally but were stable overall, nutrient levels were low, evidence of short-term hypoxia events was limited, and seasonal trends in turbidity and riverine input were consistent.

### ***Findings From the 2008 Condition Report***

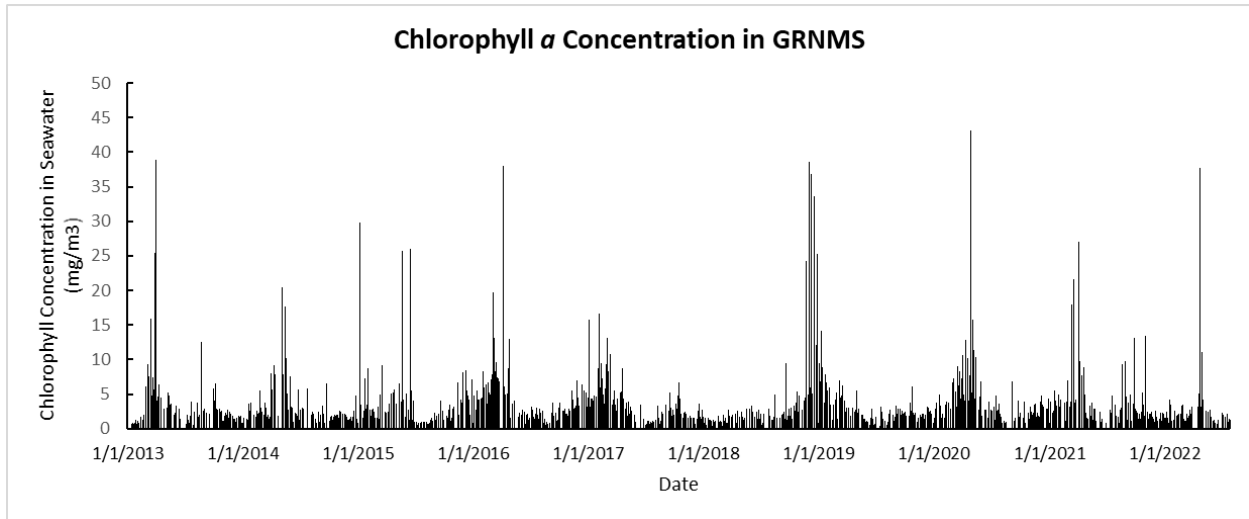
In 2008, the status of eutrophication was good and the trend was undetermined. Chlorophyll and nutrient levels were low and stable, and harmful algal blooms (HABs) were absent. Conditions did not appear to have the potential to negatively affect living resources or habitat quality.

### ***New Information in the 2008–2022 Condition Report***

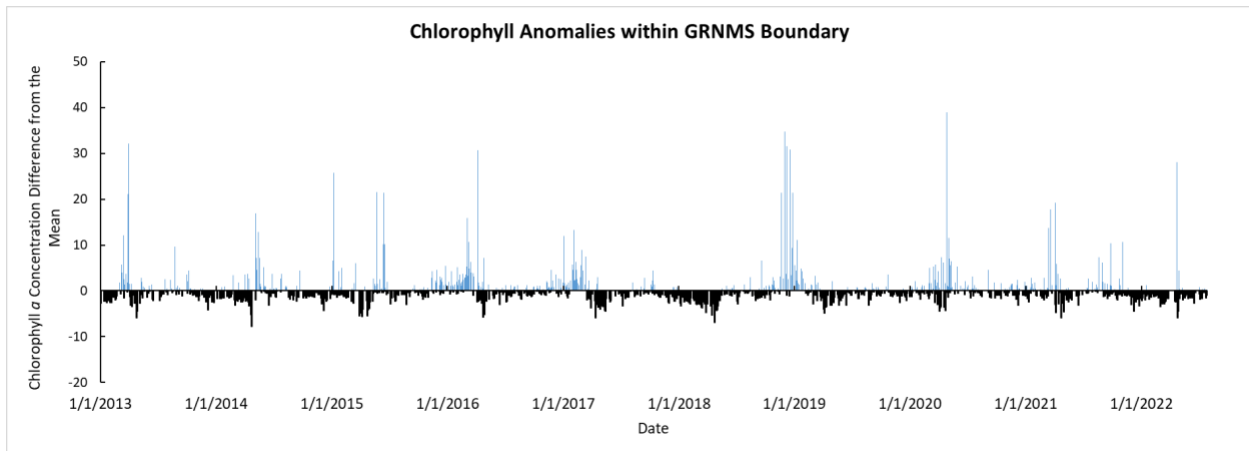
Indicators considered in the present report include turbidity, chlorophyll concentration and anomalies, riverine input via daily discharge, and nutrients and dissolved oxygen at the surface and the seafloor.

### **Chlorophyll *a***

Chlorophyll *a* concentrations and anomalies were investigated as a proxy for changes in primary productivity related to eutrophication. These data were extracted for the area of the sanctuary using the CoastWatch Data Portal (NOAA CoastWatch, 2023). Annual patterns of chlorophyll *a* concentrations remained fairly consistent, with spring peaks that were particularly apparent in 2013, 2016, 2019, 2020, and 2022 (Figure S.WQ.1). These peaks coincided with periods of peak turbidity and riverine input (see Figures S.WQ.6 and S.WQ.7). Daily chlorophyll *a* anomalies were calculated using data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the NASA Earth Observing System Aqua satellite and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi National Polar-Orbiting Partnership spacecraft. Chlorophyll anomalies are determined by comparing daily chlorophyll concentration to the bi-monthly mean. A positive anomaly indicates new algal growth. There were positive anomaly peaks in 2013, 2016, 2019, and 2020, but no significant trend was detected (Figure S.WQ.2).



**Figure S.WQ.1.** Chlorophyll a concentration within GRNMS, 2013–2023. Source: NOAA CoastWatch, 2023



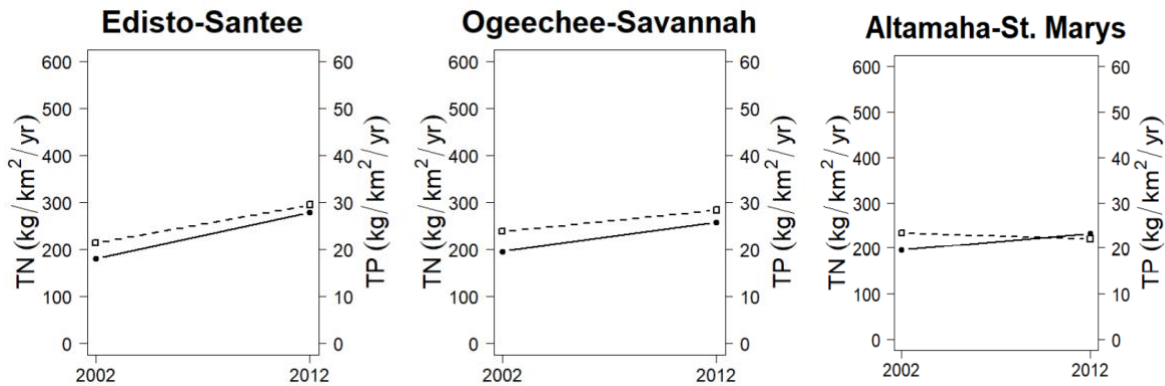
**Figure S.WQ.2.** Chlorophyll anomalies within GRNMS, 2013–2023. Source: NOAA CoastWatch, 2023. Blue lines indicate positive anomalies while black lines indicate negative anomalies.

### Inorganic Nutrients

Assessment of inorganic nutrient loading is considered essential for understanding accelerated growth of algae (Ferreira et al., 2011); however, measurements of inorganic nutrients are lacking in the region and within the sanctuary. The only in situ data available on nutrients within the sanctuary came from NOAA East Coast Ocean Acidification cruises in 2015 and 2018. These cruises sampled nitrite plus nitrate at a station near the GRNMS data buoy. Nitrite plus nitrate was higher in bottom samples, likely due to sediment residence. Values in 2018 ( $2.34 \mu\text{mol kg}^{-1}$ ) were higher than in 2015 ( $0.49 \mu\text{mol kg}^{-1}$ ), but a trend could not be verified given the limited data points.

The *Ecosystem Status Report for the U.S. South Atlantic Region* (Craig et al., 2021) reported increases in total nitrogen and total phosphorus in three coastal Georgia river mouths between 2002 and 2012, with the exception of total phosphorus in the Altamaha river mouth (Figure S.WQ.3). Loading estimates were developed from National Water Quality Assessment Program

data and the Spatially Referenced Regression On Watershed model, which estimates total nitrogen and total phosphorus loads based on constituent sources as well as watershed and stream characteristics (Craig et al., 2021).

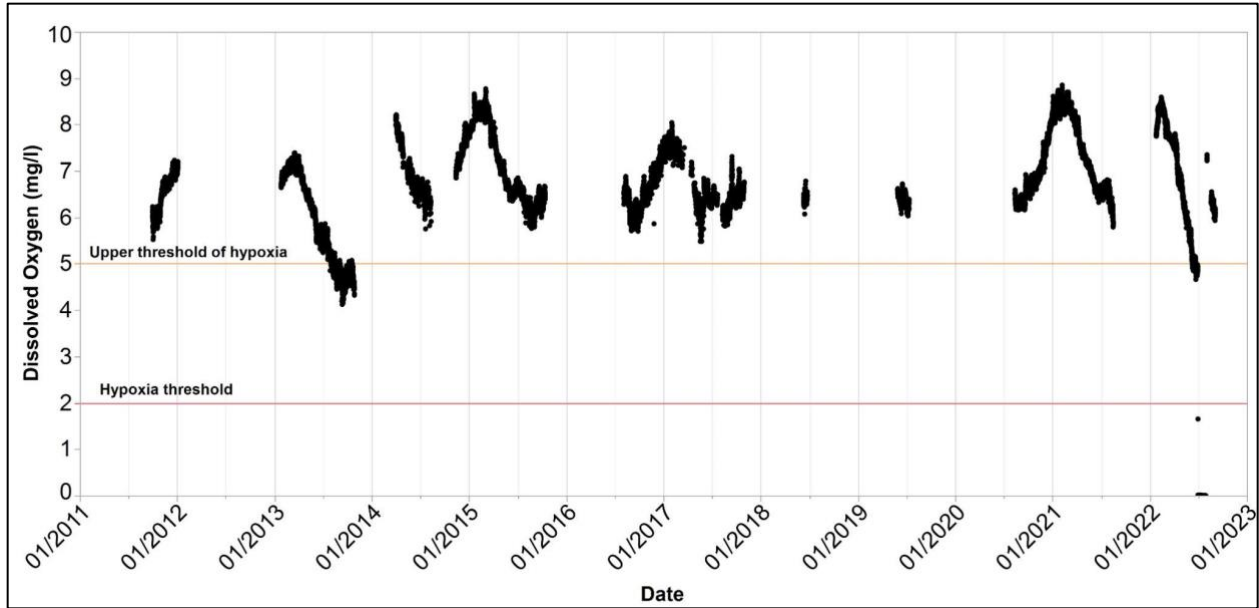


**Figure S.WQ.3.** Total nitrogen (TN, solid line) and total phosphorus (TP, dotted line) loading from river mouths to coastal waters in Georgia, 2002 and 2012. Image: Craig et al., 2021

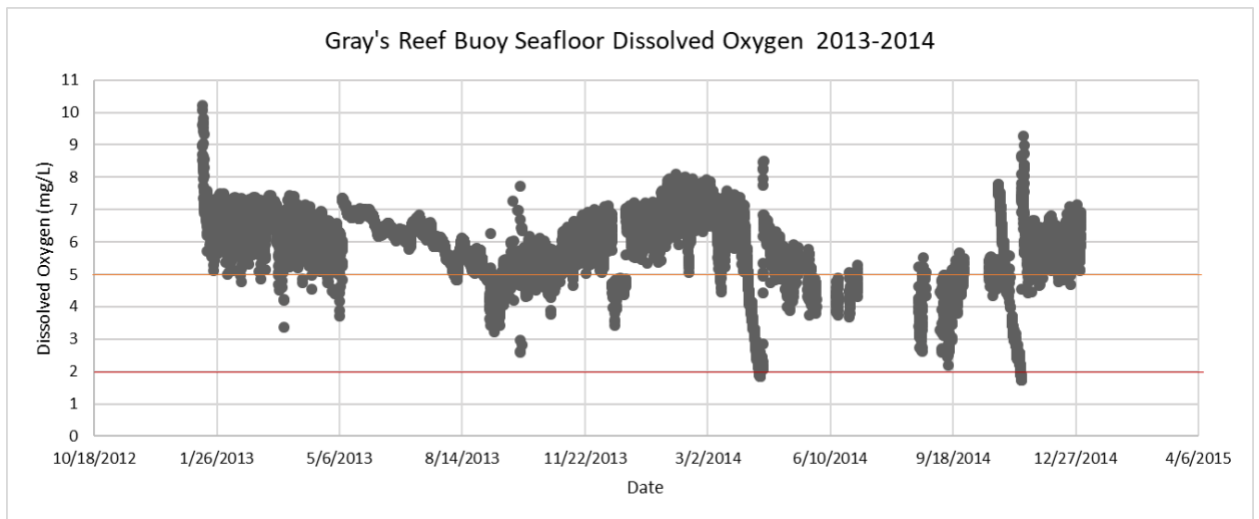
### Dissolved Oxygen

Surface dissolved oxygen followed a seasonal pattern, peaking in winter and spring and declining in summer (Figure S.WQ.4). In the summers of 2013 and 2022, surface dissolved oxygen decreased to the upper hypoxia threshold of 2–5 mg/L, which is sublethal for fish and crustacea (Gray et al., 2002). Data gaps precluded the assessment of trends or any definite causality in surface dissolved oxygen levels.

Seafloor dissolved oxygen was not continuously measured, but data were available for the period from December 2012 to February 2015 (Figure S.WQ.5). In April and November 2014, seafloor dissolved oxygen dipped to  $\leq 2$  mg/L, meeting the definition of hypoxia (Gray et al., 2002). Seafloor dissolved oxygen also fell within the defined range for near hypoxia (2–5 mg/L) in spring 2013, spring 2014, and fall 2014, but data gaps precluded the assessment of trends in seafloor dissolved oxygen.



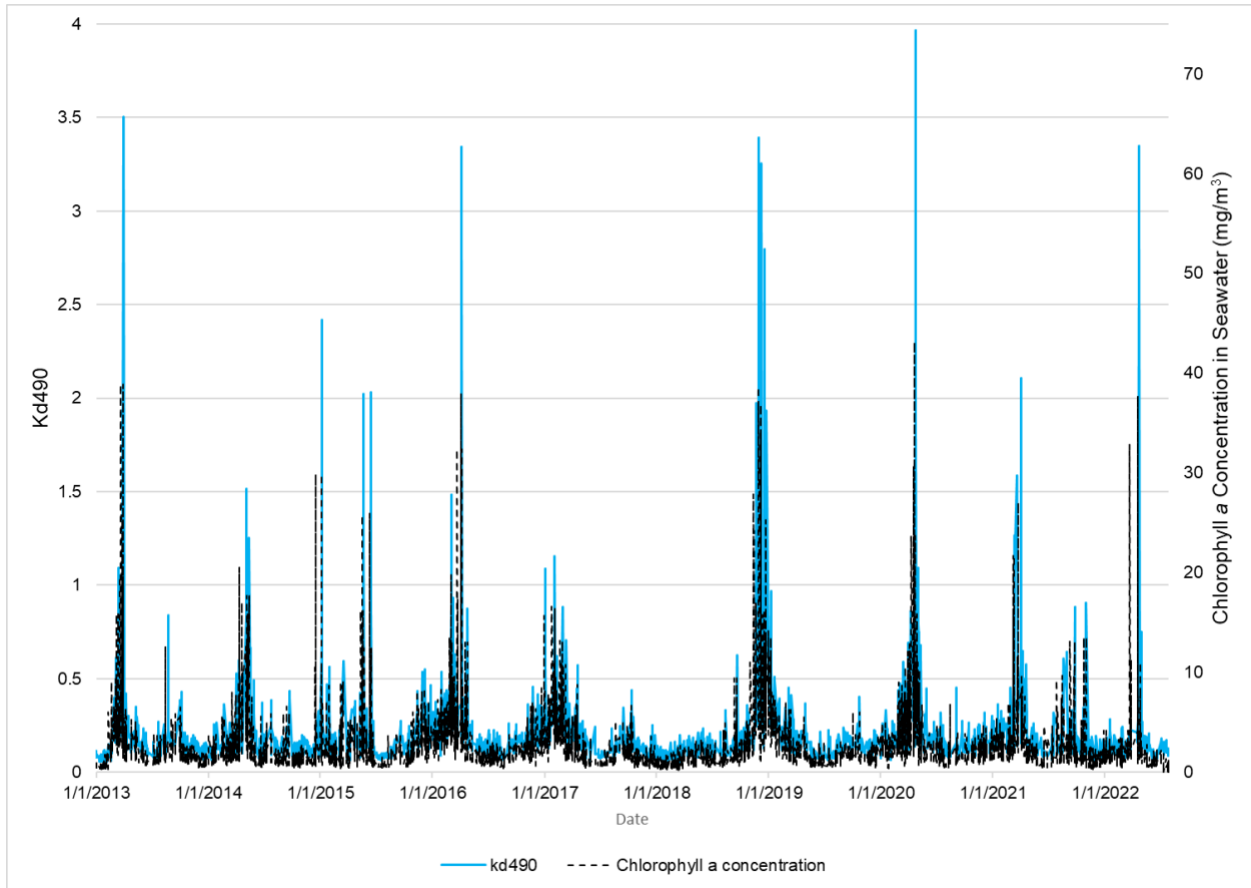
**Figure S.WQ.4.** Surface dissolved oxygen at the GRNMS data buoy, 2011–2023. Horizontal lines indicate the upper thresholds for near-hypoxic (5 mg/L) and hypoxic (2 mg/L) conditions. Source: Noakes, 2023; Image: A. Mabrouk/CSS, Inc. and NOAA



**Figure S.WQ.5.** Seafloor dissolved oxygen at the GRNMS data buoy, 2012–2015. Horizontal lines indicate the upper thresholds for near-hypoxic (5 mg/L) and hypoxic (2 mg/L) conditions. Source: Noakes, 2023

## Turbidity

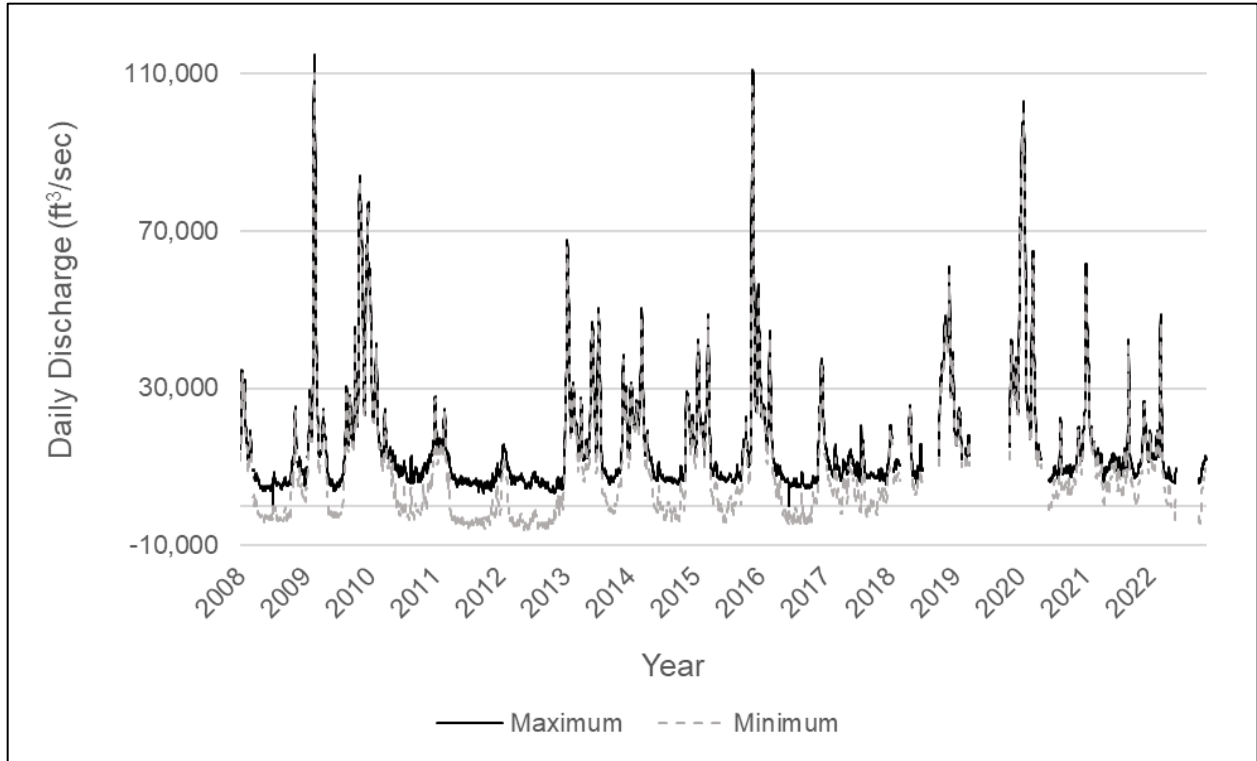
Turbidity is often used as an indicator for algal blooms and stormwater discharge. The diffuse attenuation coefficient ( $K_d490$ ) indicates the rate at which light of a given wavelength (490 nm) is attenuated through the water column. This metric indicates water clarity; higher values correspond to lower water clarity.  $K_d490$  values, derived from MODIS, indicated a seasonal pattern in turbidity at GRNMS, with periodic spikes in 2013, 2016, 2019, 2020, and 2022 (Figure S.WQ.6). These spikes corresponded to chlorophyll *a* concentration patterns, although an overall trend was not apparent.



**Figure S.WQ.6.** Kd490 diffuse attenuation coefficient (turbidity) and chlorophyll a concentration in seawater for GRNMS, 2013–2022. Source: NOAA CoastWatch, 2023

### River Input

Daily discharge levels from the Altamaha River were examined because stormwater transports nutrients from land to offshore waters. Peaks in discharge occurred in 2009, 2016, and 2020 (Figure S.WQ.7). Discharge was highest in 2020, likely due to the above-average number of tropical storms. A corresponding pattern in peak years was found for salinity. More information on tropical storm and salinity patterns is available in the climate section of this report.



**Figure S.WQ.7.** Altamaha River discharge from February 22, 2008 to December 31, 2022. Data are from the U.S. Geological Survey gauging station 02226160 near Everett City, Georgia. Values for 14 days from February to July 2017 were estimated. Data from May 18, 2022 to December 31, 2022 are provisional and subject to revision. Source: U.S. Geological Survey, 2023

### **Conclusion**

Overall, the indicator suite did not show evidence of eutrophication or changes in interannual trends. Seasonal spring peaks in chlorophyll *a*, turbidity, and riverine input were observed; although some years were notably higher than others, interannual variability was limited, and no overall trend was apparent. Although hypoxic conditions were observed at the seafloor on two occasions, conditions improved quickly; however, more consistent monitoring of this metric, augmented by in situ samples, is required. Inorganic nutrient data were limited, and the lack of frequent, in situ inorganic nutrient sampling is considered a data gap for this report. However, no algal blooms were observed within the sanctuary. Together, available data suggest an absence of eutrophic conditions within GRNMS from 2008–2022.

## Do sanctuary waters pose risks to human health and how are they changing?



**Status Description:** One or more water quality indicators suggest the potential for human health impacts, but human health impacts have not been reported.

**Rationale:** Mercury contamination advisories were issued for one targeted fish species, and one study found heavy metals in biota that exceeded some consumption advisories. No ciguatera fish poisoning cases were reported, and only one day of favorable conditions for *Vibrio* spp. was observed during the study period for this report. No offshore phytoplankton data were available to assess harmful algal blooms. Many available human health metrics rely on data from outside the sanctuary.

### ***Findings From the 2008 Condition Report***

In 2008, the status of human health risks in sanctuary waters was good/fair and the trend was not changing. Fecal indicators were below detection limits in eight samples collected throughout 2005. In 2000, chemical contaminants in tissues of sampled benthic species within the sanctuary were below U.S. Environmental Protection Agency thresholds for human consumption. In 2005, chemical contaminants were found at low but detectable levels in tissues of the same species. King mackerel, which are regularly fished in sanctuary waters, were under mercury contaminant advisory levels at the time of report publication.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include mercury advisories for fish consumption, ciguatera cases, HABs, conditions suitable for *Vibrio* spp. growth, and heavy metal levels in biota.

## **Fish Consumption Concerns**

### ***Bioaccumulation of Mercury***

Like other contaminants, mercury enters seawater via stormwater runoff, industrial discharges, and other sources. Mercury is converted to methylmercury by bacteria and other processes, then absorbed by fish via consumption of contaminated food and passage of contaminated water over their gills. Larger, older fish tend to build up more methylmercury over time as they eat smaller, contaminated fish, a process known as bioaccumulation. Thus, eating certain types of seafood, particularly large, long-lived species, can expose humans to excessive levels of mercury (GADNR, 2021). In coastal Georgia, recommendations have been set to limit consumption of sheepshead, blue crab, southern kingfish, spotted seatrout, bluefish, summer flounder, and king mackerel due to concerns regarding bioaccumulation of mercury (Table S.WQ.2). However, many of these species are estuarine; the only recommendation specifically encompassing GRNMS waters is for king mackerel. As a fast-growing, long-lived top predator, king mackerel can accumulate high levels of mercury, and GADNR recommends against consuming any individual over 39 inches.

**Table S.WQ.2.** Consumption guidelines for select fish species from Georgia waters in 2022 based on mercury levels. Each of the locations listed is within 20 nautical miles of GRNMS. Source: GADNR, 2021

Species	Location	Recommendation
Sheepshead	Savannah River Estuary	1 meal per week
Blue crab	St. Catherines Sound	1 meal per week
Southern kingfish	Lower Turtle River system: St. Simons Estuary	1 meal per week
Spotted seatrout	Lower Turtle River System: St. Simons Estuary	1 meal per week
Sheepshead	Lower Turtle River System: St. Simons Estuary	1 meal per week
Bluefish	Terry and Dupree Creeks to St. Simons Estuary	1 meal per week
Summer flounder	DRH Artificial Reef (Atlantic Ocean)	1 meal per week
King mackerel	Atlantic offshore Georgia coast	Different restrictions per size range

### ***Ciguatera***

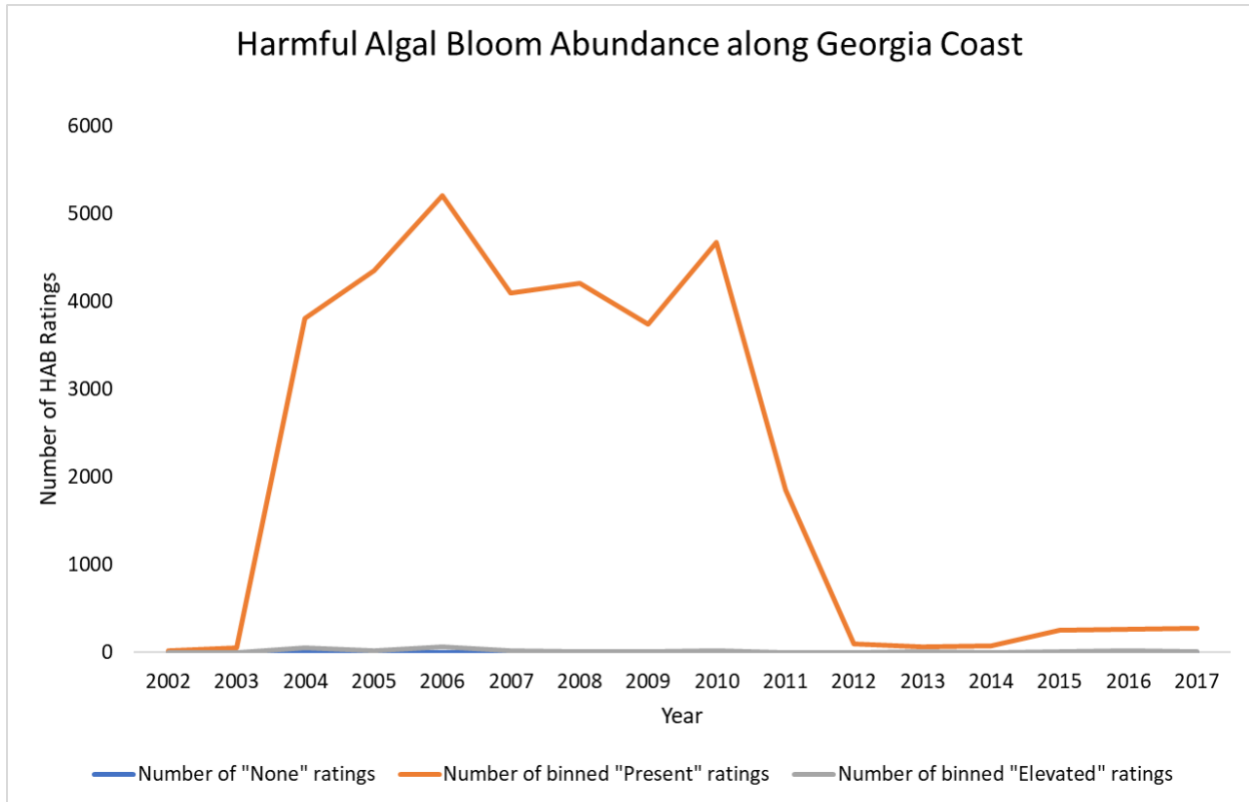
Ciguatera fish poisoning is the most common, non-bacterial, seafood illness. The condition is caused by toxins from microalgae of the genus *Gambierdiscus*, and can lead to diarrhea, paralysis, and, in the worst cases, death (National Centers for Coastal Ocean Science [NCCOS], 2015). There were no ciguatera fish poisoning cases reported from fish caught in Georgia waters during this study period, and no cases have been documented from fish caught in GRNMS waters (U.S. Centers for Disease Control and Prevention, 2022).

### **Harmful Algal Blooms**

HABs within the coastal and intercoastal regions of Georgia are largely undocumented; however, this does not suggest that HABs have not occurred or will not occur in the future. It has been hypothesized that increases in nutrient runoff could increase the number of HAB dinoflagellates in coastal Georgia waters (Verity & Borkman, 2010). At present, continuous HAB monitoring data are only available for coastal waters via a volunteer-based sampling program. No offshore monitoring data are available.

Few coastal HABs have been reported in the state of Georgia. In 2017, an *Akashiwo sanguinea* bloom occurred in the Skidaway River, resulting in an oyster die-off (Pfeiler, 2020). Figure S.WQ.8 illustrates the abundance of HAB-producing phytoplankton species in water samples from nine sampling stations in coastal Georgia. These stations were sampled at least twice per month, and more if HABs were detected (Georgia Department of Public Health, 2014; NCCOS, 2023). Though there was high variability in the number of total samples taken and ratings issued per year, the yearly number of samples containing “Elevated” (i.e., more than 60% of the

sampling grid had HAB cells present) was a very small percentage of the total. Of the available monitoring data that fell within the study period (2012–2018), HAB species were most abundant in samples collected in 2016.



**Figure S.WQ.8.** HAB abundance ratings from sampling of the Georgia coastline. Rating categories are defined by the percent of total phytoplankton biomass represented by HAB species: “None” (0%), “Present” (<60% of sampling grid has HAB cells present), and “Elevated” (>60% of sampling grid has HAB cells present). Source: NCCOS, 2023

### Conditions Suitable for *Vibrio*

*Vibrio* spp. are bacteria that occur naturally in coastal waters, but certain species and strains can be harmful to human health. *Vibrio* infections in humans typically result from eating raw or undercooked seafood, particularly shellfish, but skin infections can also occur following exposure to seawater containing *Vibrio* spp. (NOAA CoastWatch, 2023). From 2011–2022, the only observations of conditions suitable for the growth of *Vibrio* spp. (based on the established *Vibrio* habitat suitability index using temperature and salinity as primary inputs within GRNMS) occurred on just one day, April 20, 2017, at two different locations within the sanctuary (NOAA CoastWatch, 2023).

### Contaminant Levels in Biota

In 2012–2013, Balthis et al. (2015) tested black sea bass and turkey wing ark clams for heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides (see also the report section on contaminants). Most compounds were not detected, and no contaminant levels exceeded U.S. Food and Drug Administration human health guidelines. However, organic arsenic was detected in black sea bass at levels for which the U.S. Environmental Protection

Agency recommends limiting consumption to fewer than four meals per month. Cadmium was detected in turkey wing ark clams in 2012–2013 at levels that either exceeded the U.S. Environmental Protection Agency’s threshold for human consumption, or fell within a range for which consumption should be limited to fewer than four meals per month. Black sea bass from GRNMS and surrounding waters are commonly consumed; though edible, turkey wing ark clams are not commonly consumed in the region.

### **Conclusion**

The key indicators used to assess human health risks posed by sanctuary waters included mercury advisories, ciguatera fish poisoning incidence, HABs, conditions suitable for *Vibrio* spp., and contaminants in biota. Consumption advisories were issued for king mackerel in offshore Georgia, including the sanctuary. Within the study period, no cases of ciguatera poisoning were reported from fish caught within sanctuary waters, and conditions favorable for *Vibrio* growth only occurred on one day. In situ sampling to calibrate satellite characterizations of *Vibrio*-favorable conditions, as well as reports of wounds from fishers regularly visiting sanctuary waters, would aid in corroborating these data. No HAB events are known to have occurred within the sanctuary; however, there was a data gap for phytoplankton monitoring within the sanctuary to assess the abundance of HAB-producing species. Emerging issues include a potential increase in nutrient runoff from agriculture, lawn fertilizer, and developed coastal land, which contributes to algal blooms. However, based on the data available for this condition report, there was very little evidence to suggest risks to human health from GRNMS waters.

## Have recent, accelerated changes in climate-altered water conditions and how are they changing?



**Status Description:** Climate-related changes are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** Changes in a number of key climate parameters (e.g., increasing temperature, increasing storm frequency, increasing CO<sub>2</sub>) were detected, but no large impacts on or measurable degradation of resources were observed from 2012–2022.

### ***Findings From the 2012 Condition Report Addendum***

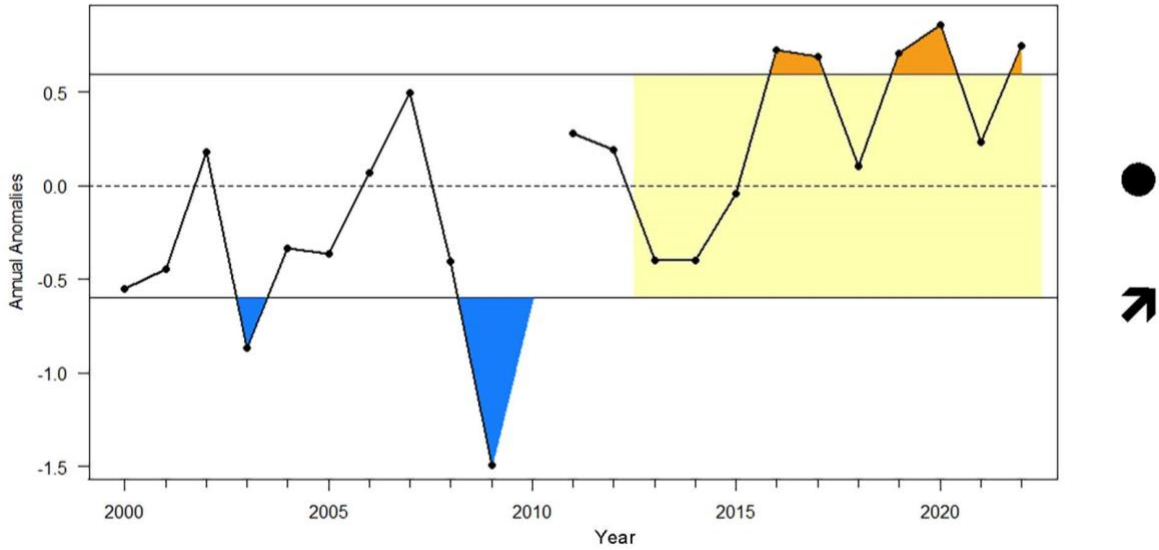
This new question was not assessed in the 2008 condition report or the 2012 addendum. However, the topic of climate change was included in the 2012 addendum in response to Question 1: “Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?” In 2012, the status rating for this question was good and the trend was not changing. A subset of the information considered in the rating of this question included oceanographic indicators related to climate change. Dissolved oxygen was noted to be high in the sanctuary, and available data on temperature and salinity suggested unaltered conditions. However, the potential for future climate-related changes in oceanographic and atmospheric conditions were of concern.

### ***New Information in the 2008–2022 Condition Report***

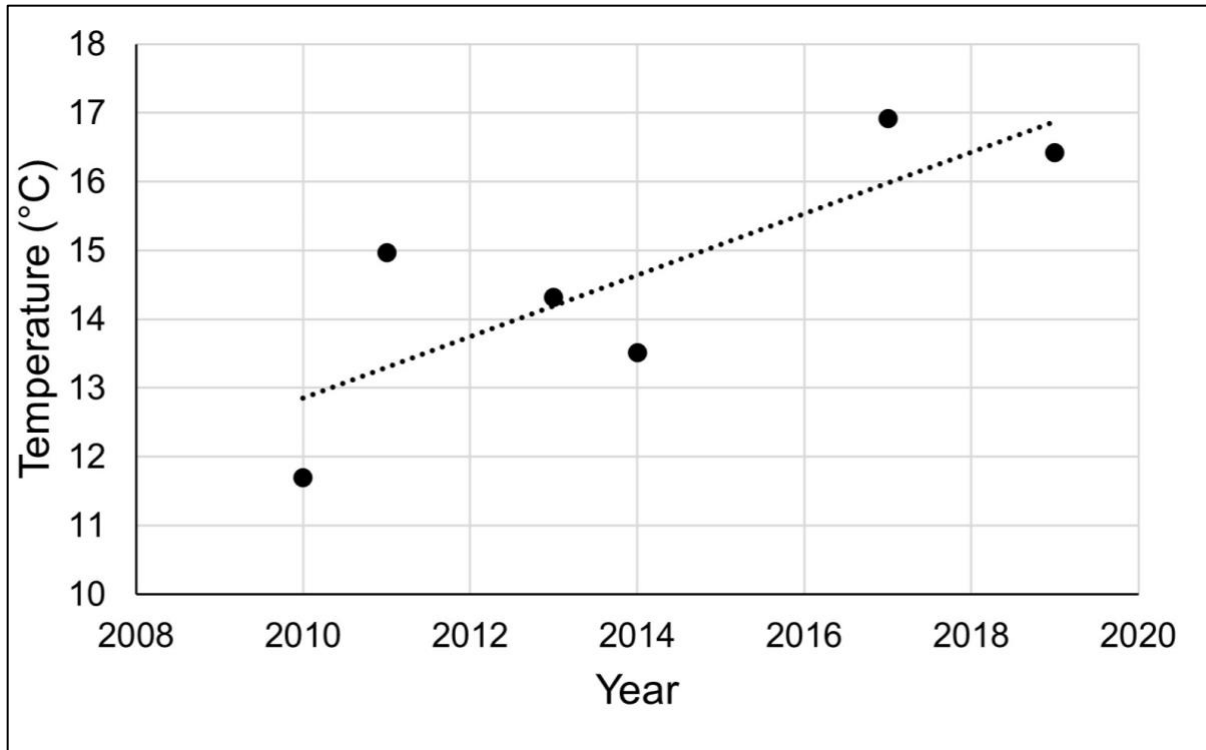
Indicators considered in the present report included sea surface temperature (SST), marine heatwaves, storms and hurricanes, ocean acidification, salinity, and ocean mixing.

### **Water Temperature and Marine Heatwaves**

SST data were obtained from the GRNMS data buoy and from satellite images using the Spatiotemporal Data and Time Series Toolkit (NOAA Fisheries, 2022; O’Brien & Oakes, 2020). Both buoy (Figure S.WQ.9) and satellite data showed an increase in SST over the past 10 years. Temperature data were also collected at the GRNMS seafloor in 2010, 2011, 2013, 2014, 2017, and 2019 during the winter months (February and March, historically two of the three coldest months of the year in the region; see Whitfield et al. [2014]). There was a marginally significant increase in winter seafloor temperature over the years measured ( $R^2 = 0.65$ ,  $p = 0.053$ ; Figure S.WQ.10).

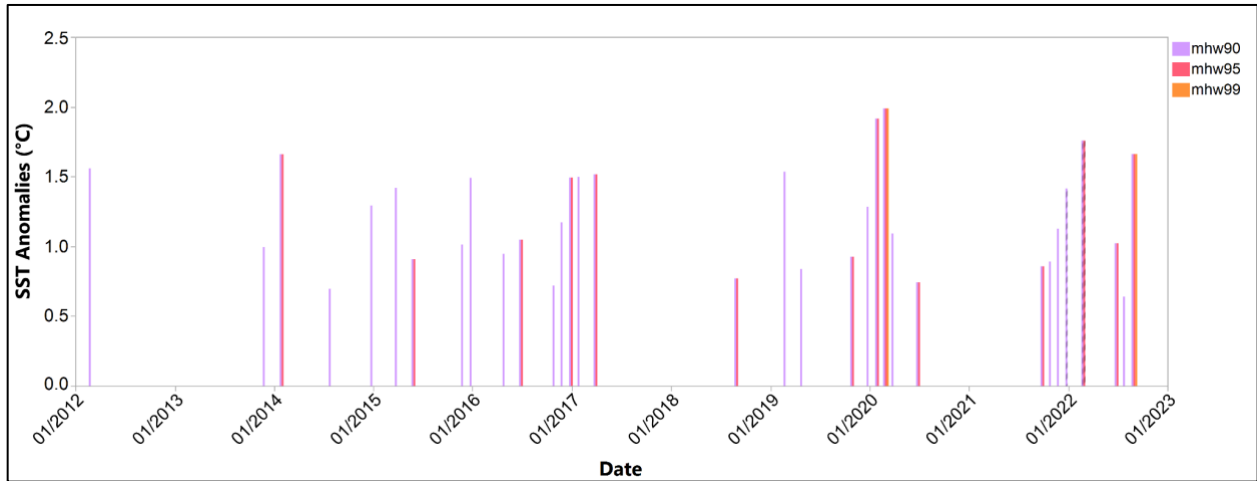


**Figure S.WQ.9.** SST annual anomalies based on measurements from the GRNMS data buoy. The shaded area in yellow represents the years used for the trend analysis (2012–2022). During this time period, the mean was within one standard deviation (●) of the long-term mean, and the trend was increasing (↗). Blue and orange shaded areas show years when the indicator value was below or above one standard deviation from the mean. Source: National Data Buoy Center & Southwest Fisheries Science Center, 2023; Image: M. Karnauskas/NOAA & A. Mabrouk/CSS, Inc. and NOAA



**Figure S.WQ.10.** Mean winter (February 21–March 31) water temperatures at the GRNMS seafloor, 2010–2019. Source: Noakes, 2022a; Muñoz et al., 2021

Marine heatwaves are defined as warm event anomalies that last for five or more days, with temperatures warmer than the 90th percentile over a 30-year climatology (Hobday et al., 2016). NOAA’s Physical Sciences Laboratory categorizes marine heatwaves using three thresholds: the 90th, 95th, and 99th percentiles of SST anomalies in a three-month window. Data from the GRNMS buoy show that marine heatwaves in all three categories were more frequent in recent years, but there was no significant trend from 2012–2022 (Figure S.WQ.11).

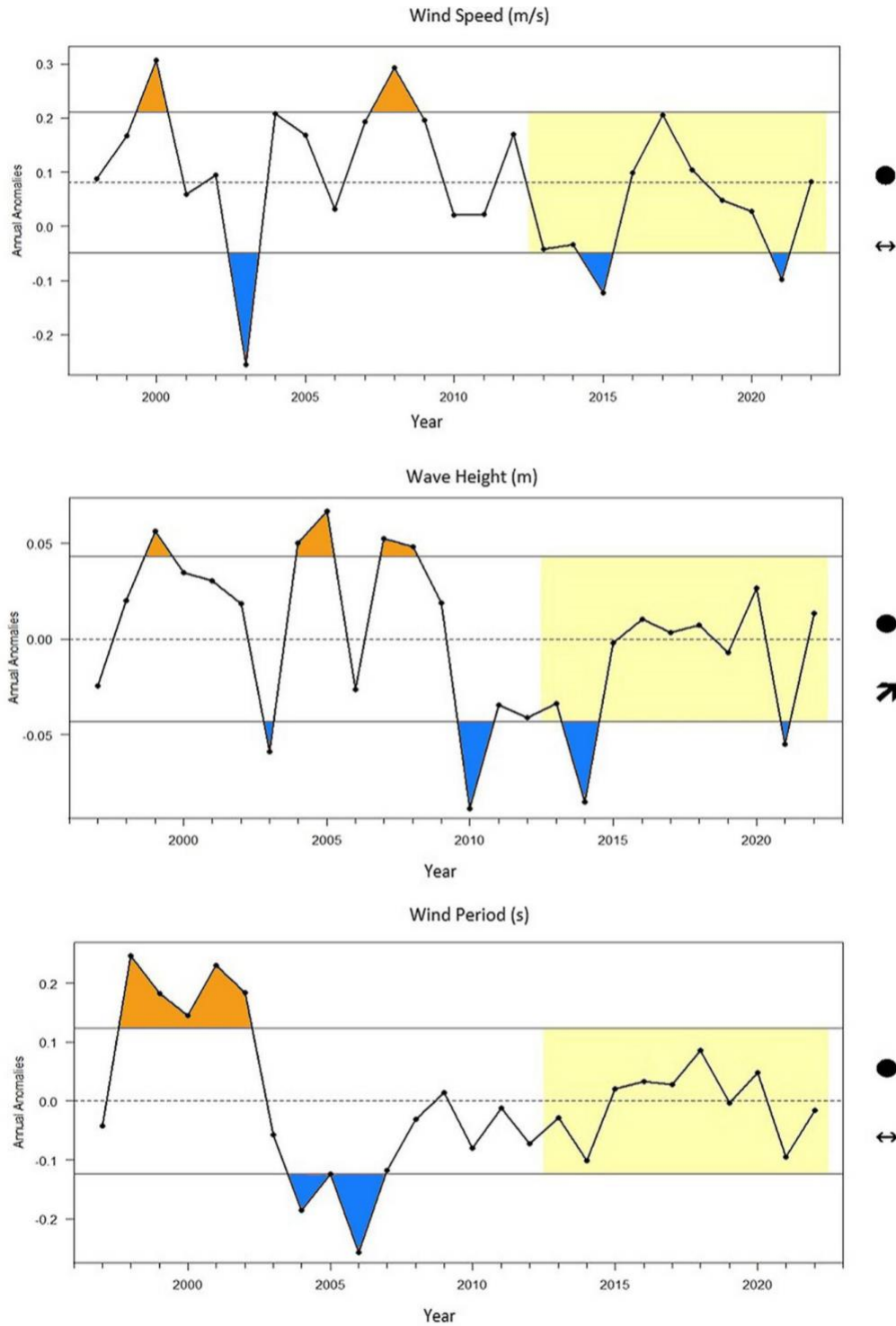


**Figure S.WQ.11.** Monthly SST anomalies (2012–2022) in GRNMS that exceeded the 90th (mhw90), 95th (mhw95), or 99th (mhw99) percentile over a 30-year climatology, and are thus considered marine heatwaves. Source: Physical Sciences Laboratory, 2022; Image: A. Mabrouk/CSS, Inc. and NOAA

### Wind and Waves

Wind speed, wave height, and dominant wave period (the period with the maximum wave energy) are continuously monitored by the GRNMS data buoy. Annual anomalies for these three parameters were assessed, and the recent mean (2012–2022) was within one standard deviation of the long-term mean. For the same time period, wind speed and wave period remained stable, while wave height increased over time (Figure S.WQ.12).

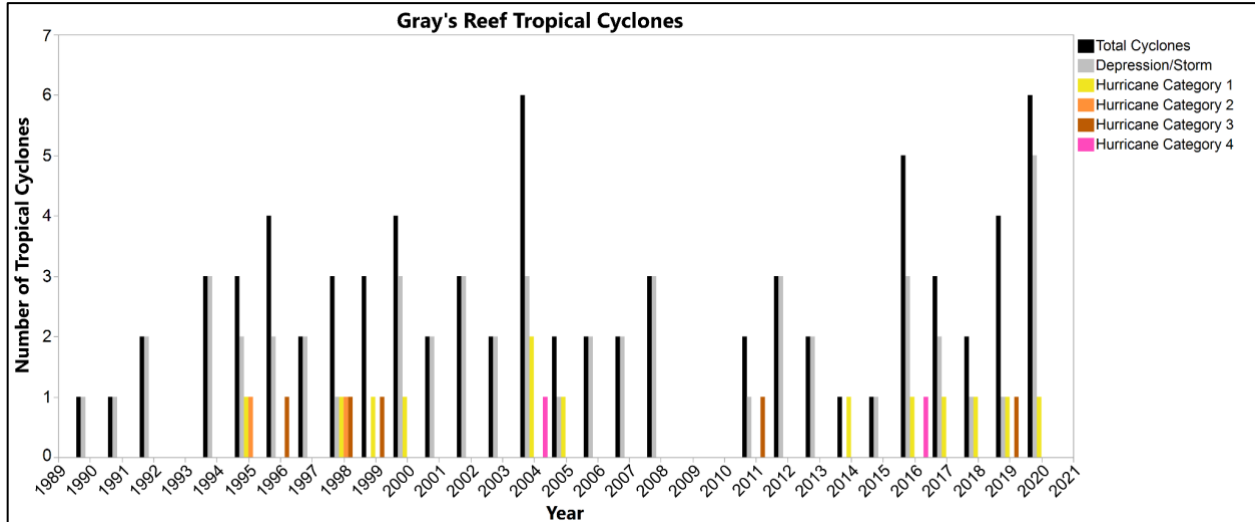
## Status and Trends of Sanctuary Resources



**Figure S.WQ.12.** Annual wind speed (top), wave height (center), and wave period (bottom) anomalies in GRNMS. The shaded area in yellow represents the years used for the trend analysis (2012–2022). The mean was within the one standard deviation (●) of the long-term mean for all three indicators. The trend was increasing (↗) for wave height and not changing (↔) for wind speed and wave period. Blue and orange shaded areas show years when the indicator value was below or above one standard deviation from the mean. Source: National Data Buoy Center & Southwest Fisheries Science Center, 2023; Image: M. Karnauskas/NOAA & A. Mabrouk/CSS, Inc. and NOAA

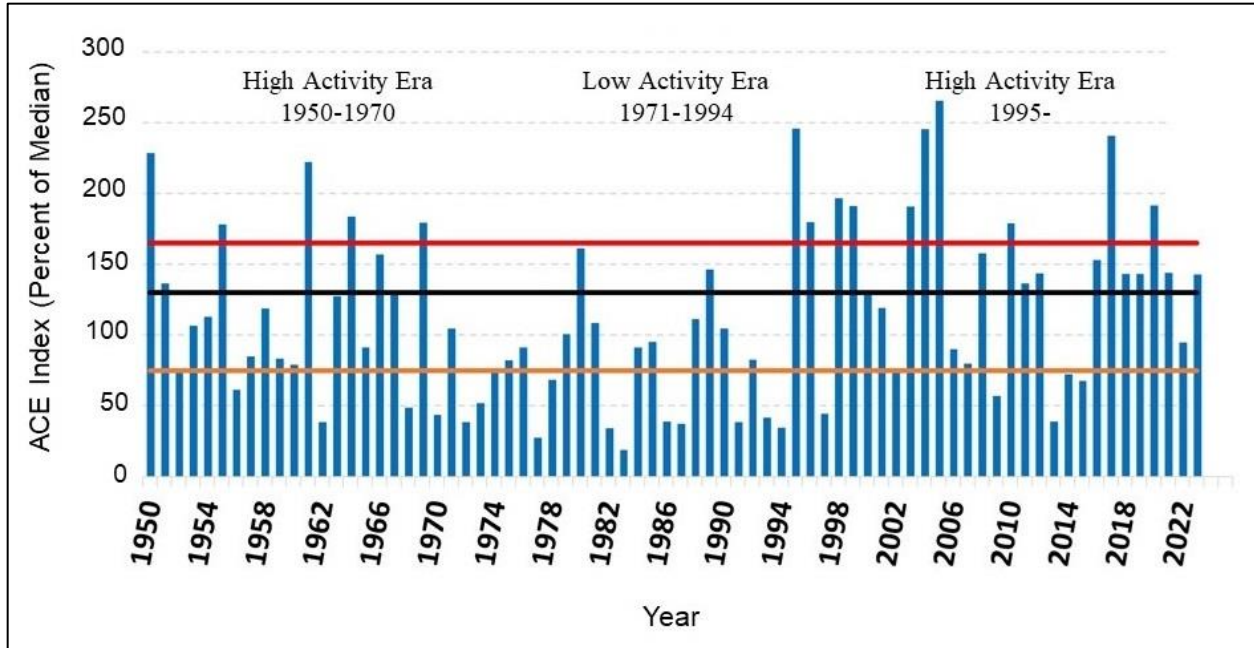
## Storms and Hurricane Intensity and Frequency

The number and intensity of tropical depressions, tropical storms, and hurricanes within 100 miles of GRNMS were assessed. In the period from 2012 to 2022, storm frequency was highest in 2020, and the total annual number of storms increased (Figure S.WQ.13).



**Figure S.WQ.13.** Number of tropical cyclones within 100 miles of GRNMS by category. Source: Noakes, 2022b; Image: A. Mabrouk/CSS, Inc. and NOAA

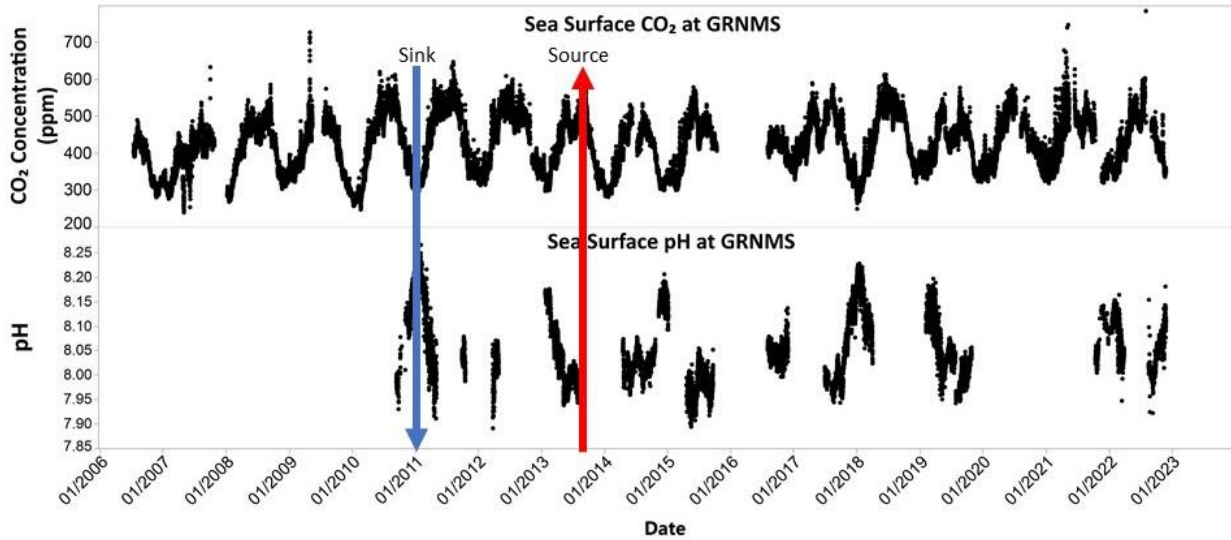
The Accumulated Cyclone Energy (ACE) index is a wind energy index used by NOAA to measure the combined intensity and duration of Atlantic named storms and hurricanes that occur during a given hurricane season. NOAA uses this index to classify hurricane season strength into high- and low-activity eras based on the 1950–2020 ACE index median. The period from 2012–2022 fell within a high-activity era (Figure S.WQ.14).



**Figure S.WQ.14.** ACE index, 1950–2023. Atlantic hurricane season strength is classified into high- and low-activity eras; the period from 2012–2022 fell within a high-activity era. The horizontal lines indicate classification thresholds for individual hurricane seasons. The yellow, black, and red lines correspond to 75%, 130%, and 165% of the 1951–2020 median, respectively. Hurricane seasons with ACE indices <75% are classified as below-normal, those between 75–130% are classified as near-normal, those between 130–165% are classified as above-normal, and those >165% are classified as extremely active. Image: Modified from National Weather Service, 2023

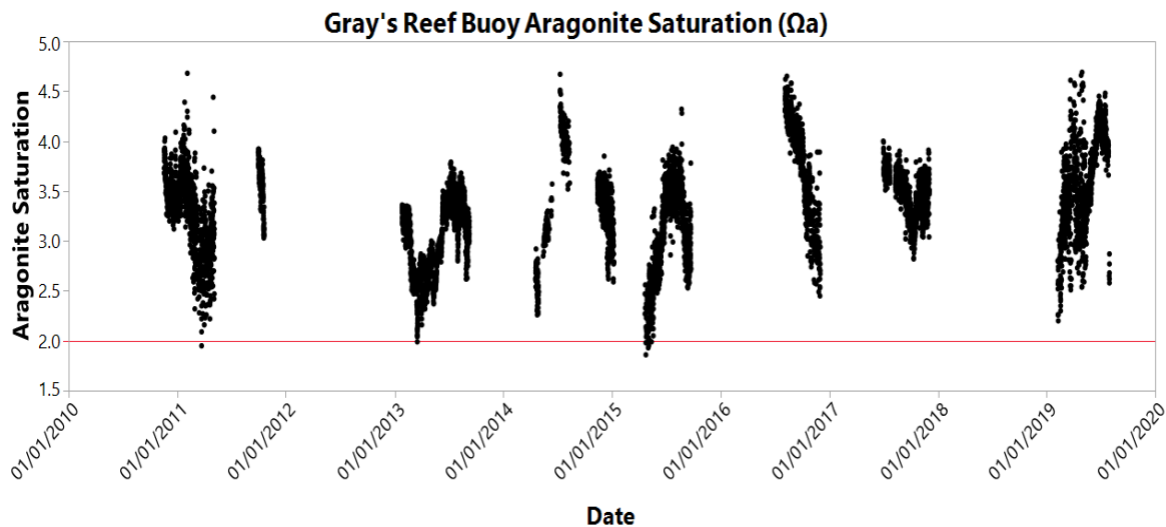
## Ocean Acidification

In 2006, NOAA’s Ocean Acidification Program began to continuously monitor air and surface water CO<sub>2</sub> concentrations at the GRNMS data buoy; however, pH monitoring did not begin until 2010 and has been intermittent due to biofouling and sensor failures. The data show that surface water CO<sub>2</sub> increased in summer, making the sanctuary’s warm water a CO<sub>2</sub> source and decreasing the pH, while in winter, the sanctuary’s water worked as a CO<sub>2</sub> sink, with a lower concentration of CO<sub>2</sub> and higher pH (Figure S.WQ.15). The mean of sea surface CO<sub>2</sub> annual anomalies from 2012–2022 was within one standard deviation of the long-term mean (2006–2022), and the trend was stable. Atmospheric CO<sub>2</sub> has also increased steadily from 2006–2022, which, through physics and chemical reactions, causes more CO<sub>2</sub> to transfer into the water column (Noakes, 2022a).



**Figure S.WQ.15.** Surface water CO<sub>2</sub> (top) and pH (bottom), as measured at the GRNMS data buoy. Both panels show that GRNMS acts as a CO<sub>2</sub> sink in winter (i.e., lower CO<sub>2</sub> and higher pH; blue arrow indicates winter 2011 as an example) and CO<sub>2</sub> source in summer (i.e., higher CO<sub>2</sub> and lower pH; red arrow indicates summer 2013 as an example). Source: Noakes, 2022a; Image: A. Mabrouk/CSS, Inc. and NOAA

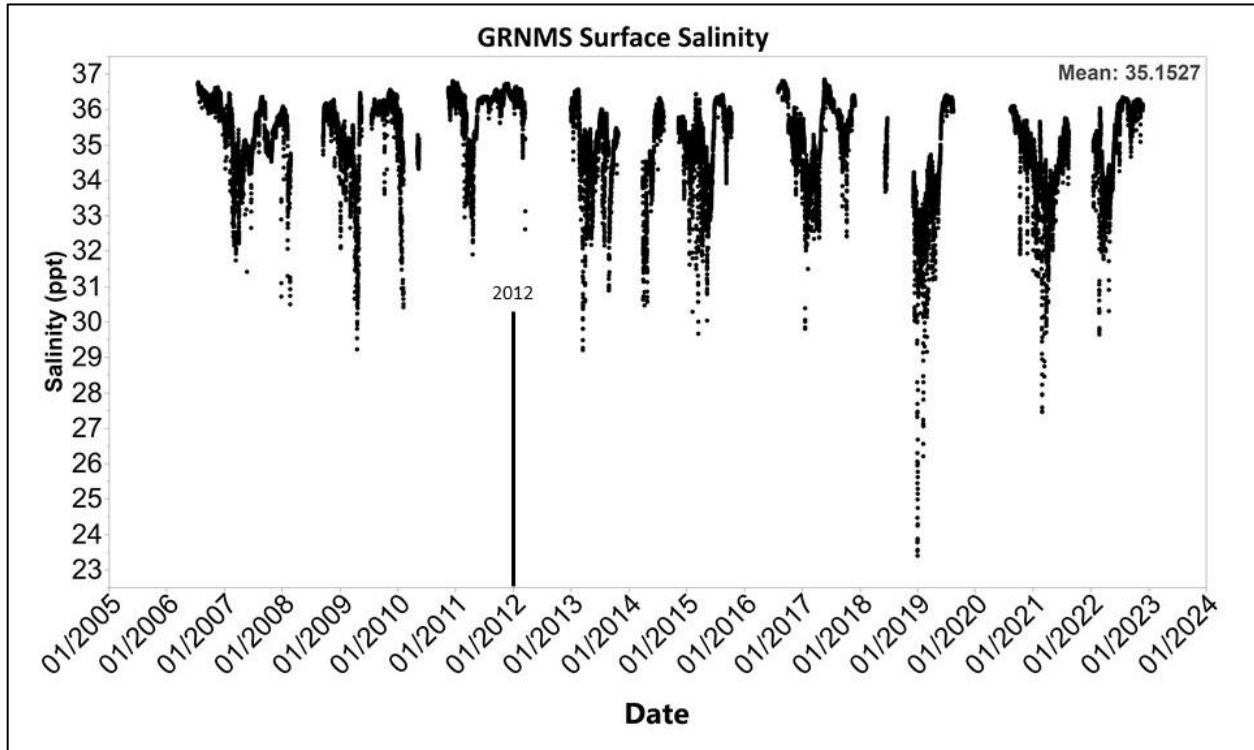
Another key ocean acidification indicator is aragonite saturation, which affects marine organisms. Aragonite saturation was calculated from carbonate ion concentration in seawater from 2010–2019 using CO<sub>2</sub>SYS software. During this time period, calculated aragonite saturation remained above the threshold of 2 Ω, except in the spring of 2011, 2013, and 2015 (Figure S.WQ.16). Sub-lethal effects have been shown to occur in some marine organisms when aragonite saturation falls below 2 Ω (Pacific Marine Environmental Laboratory, 2022). A trend in aragonite saturation could not be determined due to data gaps.



**Figure S.WQ.16.** Aragonite saturation, calculated from GRNMS data buoy measurements. Source: Noakes, 2022a; Image: A. Mabrouk/CSS, Inc. and NOAA

## Salinity

Low salinity can cause stress in many marine organisms, including corals, which can bleach (a stress response involving the loss of intracellular symbiotic algae; Ding et al., 2022). Surface salinity has been monitored at the GRNMS data buoy since 2006. During the study period, salinity ranged from 23 to 36 ppt (with an average of 35.15 ppt), and followed a seasonal pattern in which it was higher in summer and lower in winter. Salinity was lowest in the winter of 2019 (Figure S.WQ.17). Although it appears that salinity has decreased in recent years (particularly 2019 and 2020), a statistical trend analysis could not be performed due to data gaps.



**Figure S.WQ.17.** Surface water salinity as measured at the GRNMS buoy. The vertical line indicates the start of the time period of interest for the assessment of this metric (i.e., 2012–2022). Source: Noakes, 2022a; Image: A. Mabrouk/CSS, Inc. and NOAA

## River Discharge and Mixed Layer Depth

Changes in freshwater discharge can be a key indicator associated with climate change and can affect living resources in the sanctuary, especially habitat-building organisms like sponges and corals. GRNMS may be affected by discharge from the Altamaha River, although more so in the spring than the fall (Gleason & Cohen, 2012). The Altamaha drainage is one of the three largest river basins and the largest free-flowing river on the U.S. East Coast (Georgia River Network, 2023). Altamaha River discharge data were downloaded from the USGS National Water Information System as daily maximum and minimum discharge in cubic feet per second. A seasonal pattern was found, with higher discharge in winter/spring and lower discharge in summer. The highest discharge years during the study period were 2009, 2016, and 2020, but no clear trend was observed (Figure S.WQ.7).

## **Dissolved Oxygen**

Dissolved oxygen is an important indicator for tracking changes in water quality at GRNMS due to climate change. Warmer water holds less dissolved oxygen and contributes to increased water stratification, which can also result in reduced levels of dissolved oxygen; dissolved oxygen levels are projected to decline by 1% within the sanctuary by 2050 (ONMS, 2020). Although low oxygen can stress and kill bottom-dwelling invertebrates, dissolved oxygen is unlikely to drop to harmful levels in the sanctuary (ONMS, 2020). Data on dissolved oxygen are presented in the earlier section addressing the eutrophic condition of sanctuary waters. Briefly, although dissolved oxygen was not measured continuously at the sanctuary's surface, available data showed a seasonal pattern in which dissolved oxygen was highest in winter and spring and lowest in summer. Surface dissolved oxygen levels reached near-hypoxic levels (<5 mg/L) in 2013 and 2022 (Figure S.WQ.4). Seafloor data from December 2012 to February 2015 showed that dissolved oxygen reached near-hypoxic levels more frequently compared to the surface and reached hypoxic levels ( $\leq 2$ mg/L) in April and November 2014 (Figure S.WQ.5).

## **Conclusion**

A number of indicators, including increasing SST, increased tropical storm frequency, and suspected decreases in pH and salinity, point to the growing effects of climate change on GRNMS. However, the attribution of these changes directly to climate change was not assessed in this analysis. Despite these changes, experts agreed that these changes have not yet resulted in measurable effects on GRNMS habitats or living resources. However, experts also agreed that, when considered together, these indicators pointed to a worsening trend for the effects of climate change on GRNMS water quality. This analysis was complicated by critical data and analysis gaps for a number of indicators, particularly seafloor temperature, pH, CO<sub>2</sub>, and dissolved oxygen, which are likely more reflective of effects on GRNMS habitats compared to sea surface metrics. Consistent monitoring and analysis will be important for future assessment of climate impacts on the sanctuary.

## Are other stressors, individually or in combination, affecting water quality, and how are they changing?



**Status Description:** Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** No contaminant discharges from vessels were reported within the boundaries of GRNMS during the study period. Discharge of contaminants (primarily petroleum) did occur within 100 kilometers of the sanctuary, although there was no trend in the number of incidents or volume of material released during the study period. No direct sampling of GRNMS waters for contaminants associated with these regional events has occurred, representing an important knowledge gap.

### ***Findings From the 2012 Condition Report Addendum***

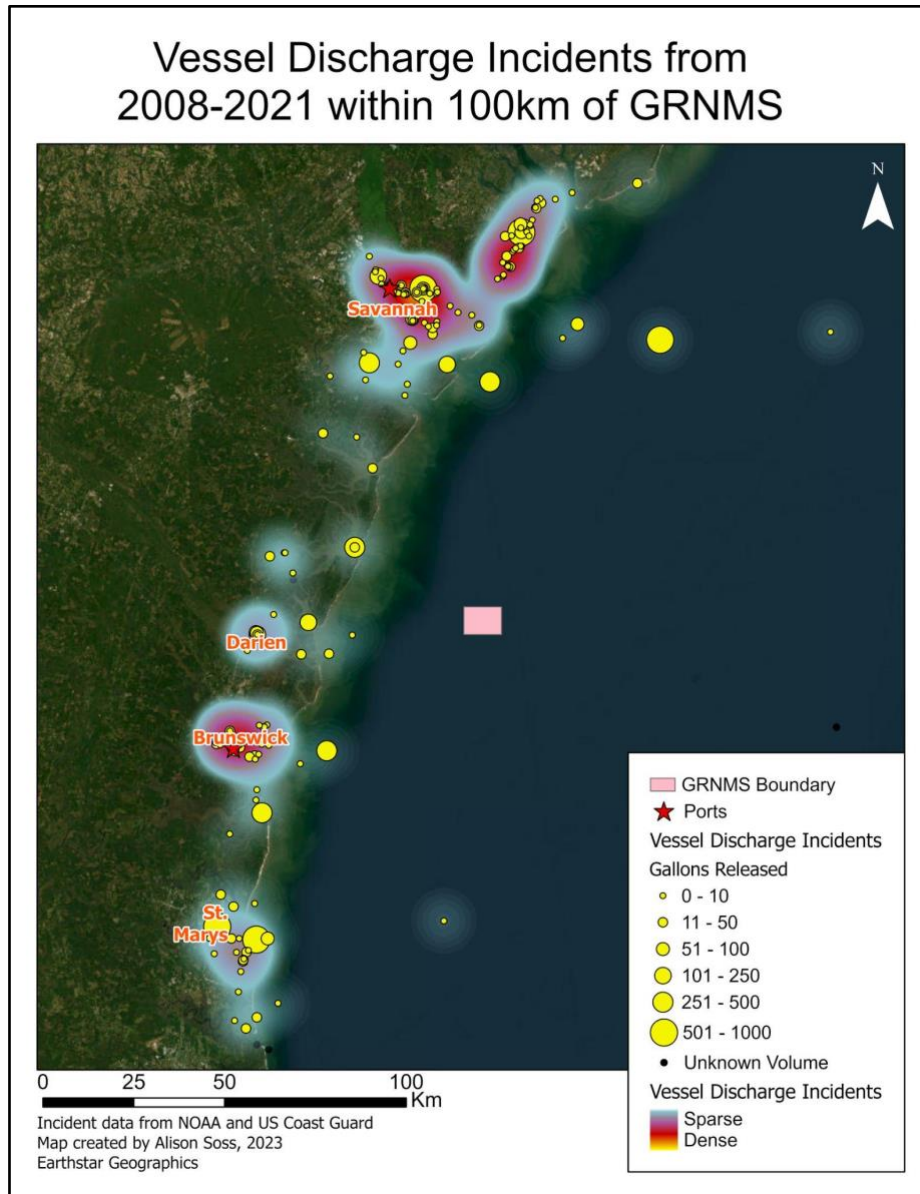
This new question was not assessed in the 2008 condition report or the 2012 addendum. However, the topic of other stressors related to water quality was included in the 2012 addendum in response to Question 1: “Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?” In 2012, the status rating for this question was good and the trend was not changing. This rating was attributed in part to a lack of chemical contaminants in sanctuary waters.

### ***New Information in the 2008–2022 Condition Report***

The sole indicator considered in the present report is contaminant releases from vessels.

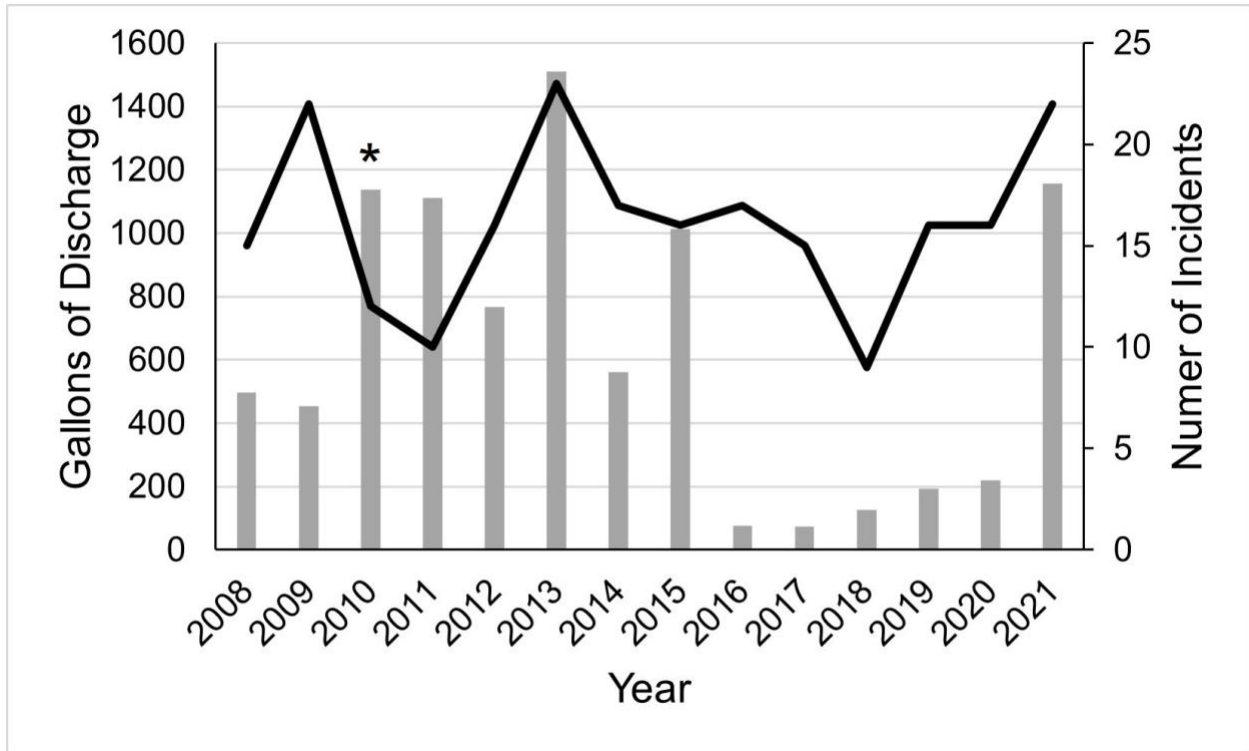
### **Contaminant Releases From Vessels**

Data on contaminant releases from vessels were obtained from NOAA’s Office of Response and Restoration (2022) and the U.S. Coast Guard (2022). For the purposes of this report, only incidents that occurred within 100 km of the GRNMS boundary were considered. From 2008 to 2021, there were 227 reported discharge incidents. The majority of the incidents occurred along the coastline, and few occurred offshore. Incidents were concentrated in highly populated areas with seaports (Savannah and Brunswick) and commercial fishing ports, such as Bluffton, Darien, and St. Mary’s (Figure S.WQ.18). Although GRNMS is an offshore site and not directly adjacent to these ports, coastal discharge from the Altamaha River was shown to reach the sanctuary within three days during high-flow periods (Gleason & Cohen, 2012). Experts at the status and trends workshop noted that low salinity in the sanctuary may indicate increased riverine input, and, in turn, times when coastal contaminants may be more likely to reach the sanctuary (see the condition report section on climate change for more information on salinity patterns at GRNMS).



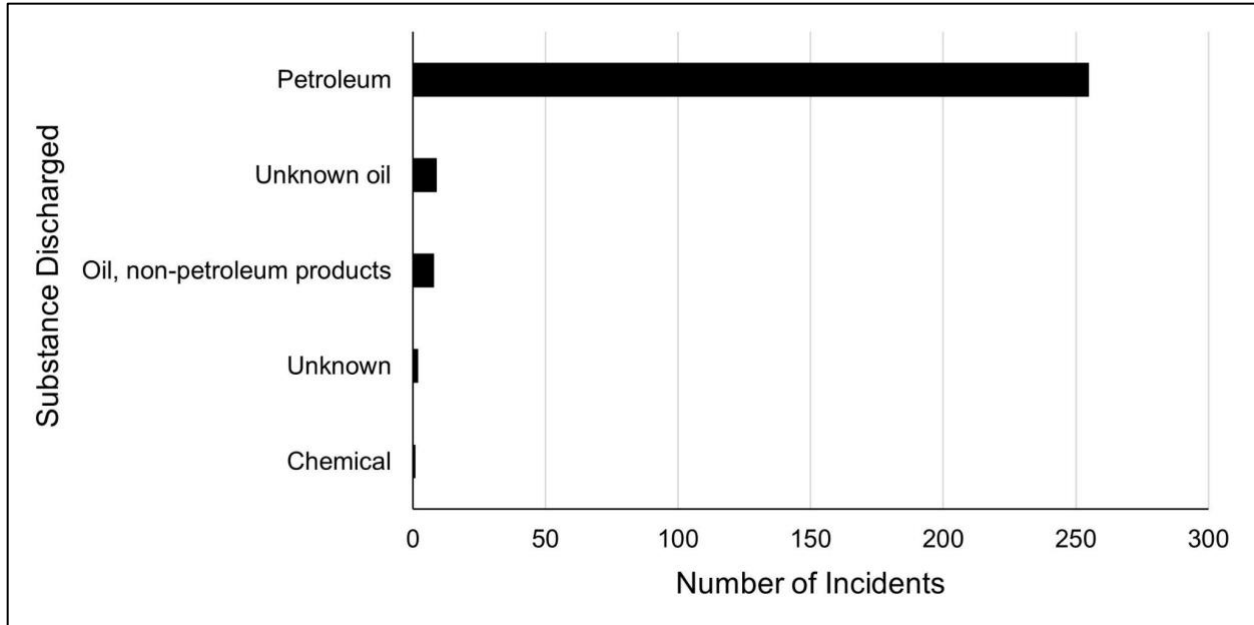
**Figure S.WQ.18.** The geographic distribution and magnitude of vessel discharge incidents within 100 km of GRNMS. Source: Office of Response and Restoration, 2022; U.S. Coast Guard, 2022

The number of discharge incidents and volume of material discharged within 100 kilometers of GRNMS varied without apparent trend from 2008 to 2021 (Figure S.WQ.19). An outlier not depicted in Figure S.WQ.19 is a 2010 incident in which a fuel tank ruptured aboard the roll-on/roll-off cargo vessel *Liberty*, releasing 7,000 gallons of diesel fuel into the Savannah River (Mayle, 2010).



**Figure S.WQ.19.** Known volumes of discharge (bars) and the number of incidents that resulted in these discharges (line) within 100 km of GRNMS, 2008–2021. An additional one to six incidents were reported in all years except 2016, 2018, and 2020, but these are not shown as they resulted in an unknown volume of discharge. The asterisk (\*) denotes that the release of 7,000 gallons of diesel fuel from the vessel *Liberty* in 2010 was excluded from this figure. Source: Office of Response and Restoration, 2022; U.S. Coast Guard, 2022

Petroleum was the most common type of discharge released within 100 kilometers of GRNMS (Figure S.WQ.20). Chemicals, including bilge oil, bilge waste, and automotive gasoline, were the least commonly reported discharge.



**Figure S.WQ.20.** Number of discharge incidents (with known and unknown volumes of discharge) by substance category, 2008–2021. Source: Office of Response and Restoration, 2022; U.S. Coast Guard, 2022

Water sampling for the presence of contaminants associated with vessel discharge incidents in GRNMS has not occurred. However, water samples were recently collected to assess the presence of microplastics in GRNMS waters (Geiger, 2021). Although microplastics were less abundant in GRNMS compared to nearshore sites, they were detected in 100% of water samples. No trend data for microplastic presence at GRNMS were available.

### **Conclusion**

Although no contaminant discharge incidents occurred in GRNMS, numerous releases of contaminants, primarily petroleum, occurred within 100 kilometers of the sanctuary during the study period. There was no apparent trend in the number of discharge incidents or volume of material discharged. A major data gap is a lack of direct sampling for associated contaminants (or indicators thereof) in sanctuary waters during the study period. Future monitoring should include such sampling to better understand the impacts of coastal incidents on GRNMS. In addition to contaminant levels in the sanctuary, the potential impacts to vulnerable communities should be assessed (e.g., zooplankton). Further, although microplastics were detected in GRNMS, long-term data are required to assess changes and associated impacts on water quality over time. Additionally, emerging contaminants, such as pharmaceutical contaminants and per- and polyfluoroalkyl substances (PFAS), warrant future investigation.

## Status and Trends of Habitat



The following sections assess the status and trends of key habitat indicators in GRNMS from 2008–2022.

The most common live-bottom habitat in GRNMS is composed of low-relief sandstone ledges and adjacent flat, bedrock areas. These ledges and frequently sand-covered bedrock surfaces provide attachment points for many species, including sponges, soft corals, algae, and tunicates. The cover provided by this attached marine life hosts mobile invertebrates and fishes.

The first question in this section focuses on the integrity of major habitats within the sanctuary, including biogenic and abiotic habitats. Sandstone ledges, sand, and the water column are abiotic habitats, formed through various geological and physical processes. Biogenic habitats are created by organisms whose structure and/or remains become habitat that can be used by other living marine resources. Biogenic habitats are layered on top of, and are often associated with, specific physical habitat types. Changes to both biotic and abiotic habitat can significantly alter the diversity of living marine resources and ecosystem services.

The second question in this section examines the types and amounts of contaminants found in major habitats within the sanctuary.

**Table S.H.1.** Status, trend, and confidence ratings (where applicable) from previous (2008 or 2012) and present (2008–2022) condition report questions focused on habitat.

Previous Condition Report Questions	Year of Previous Rating	Previous Rating	2008–2022 Condition Report Questions	2008–2022 Condition Report Rating
Habitat abundance/distribution	2012	Good ?	Integrity of major habitats	
Condition of biologically structured habitat	2012	Good ?		
Contaminants	2008	Good —	Contaminants	

## What is the integrity of major habitat types and how are they changing?



**Status Description:** Habitats are in near-pristine condition.

**Rationale:** Available data suggest no changes to habitat at GRNMS other than those likely from natural processes (e.g., storm activity, sand movement). New and ongoing monitoring is required to increase understanding of the dynamics of sanctuary habitat integrity.

### ***Findings From the 2012 Condition Report Addendum***

In 2012, habitat integrity was addressed in two separate questions: “What are the abundance and distribution of major habitat types and how are they changing?” and “What is the condition of biologically structured habitats and how is it changing?” The status and trend ratings for these two questions were good and undetermined, respectively. Habitat was assessed in 2001 using multibeam and side-scan sonar surveys combined with diver observations, remotely operated vehicle video, and still photographs. Newer multibeam surveys were conducted in 2011, but the data were not usable due to incomplete metadata collection and could not be fully analyzed for the 2012 report; however, none of the information available at that time suggested alterations to habitat in the sanctuary. Additionally, the 2006 prohibition of anchoring in GRNMS reduced the potential for habitat damage throughout the sanctuary, and the 2011 establishment of a Research Area added additional habitat protections to the southern third of the sanctuary (see the Response chapter of this report).

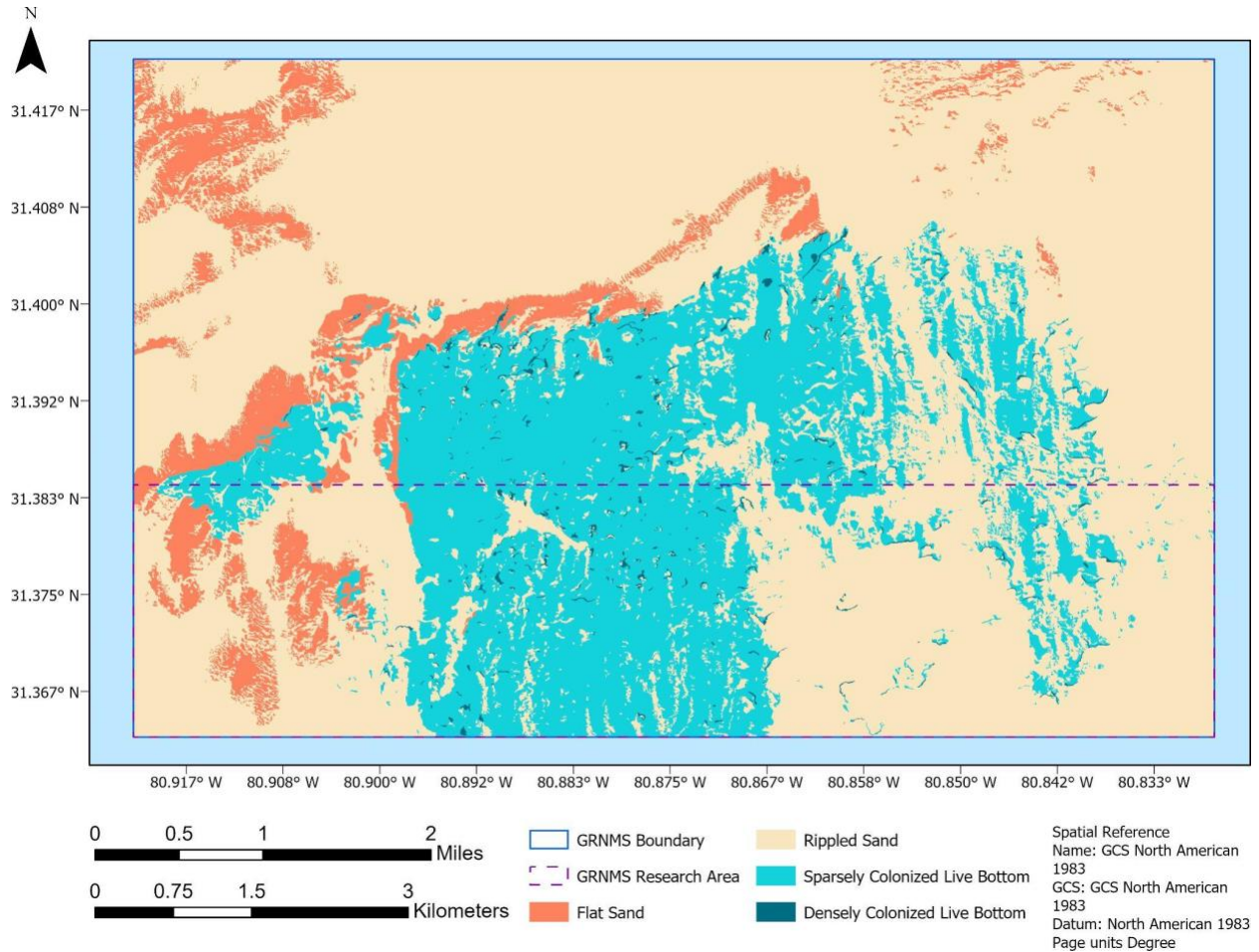
### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include benthic habitat distribution, unconsolidated sediment, ledge height and undercut depth, sessile benthic invertebrate cover, macroalgal cover, and soundscape/acoustic environment.

### **Benthic Habitat Distribution**

The habitats of GRNMS support a diverse and abundant wildlife population, and include ledges and bedrock densely colonized by sponges, tunicates, macroalgae, and other organisms. These ledges are surrounded by sandy substrates teeming with infaunal invertebrates such as worms, clams, and anemones. These biogenic and abiotic habitats provide food and shelter for many invertebrates and fishes (Gleason et al., 2020). GRNMS is a dynamic area, influenced by daily tidal patterns and seasonal north-south currents. These physical characteristics result in changes over multiple time scales and weathering events, including scouring by storms, the collapse of ledges, ledges becoming exposed and colonized, and burial of ledges by shifting sand. The ledges of GRNMS have been described as “ribbons of life in a sea of sand;” however, the sand is also abundant with life, most of it living hidden below the subsurface (Kendall et al., 2005; 2007).

Kendall et al. (2005) reported that GRNMS was primarily composed of unconsolidated sediment (67% rippled sand and 8% flat sand<sup>12</sup>), followed by sparsely colonized live bottom (25%) and densely colonized live bottom (0.6%; Figure S.H.1; Figure S.H.2). This assessment was based on side-scan sonar, multibeam sonar, scuba surveys, and video transects. New bathymetry and ground truthing data have been collected in GRNMS more recently (2019–2021); however, these data have not yet been analyzed, preventing assessments of temporal changes in habitat distribution. This is considered an analysis gap for the present report.



**Figure S.H.1.** Habitat distribution within GRNMS. Source: Kendall et al., 2005; Image: A. Soss/NOAA

<sup>12</sup> Flat sand (sand plain) was defined as a stable, flat area of coarse sediment with variable thickness, characterized by bioturbation from fish and invertebrates; rippled sand was defined as sediment occurring in sufficient thickness to form 6–10 cm ridges (see Kendall et al. [2003] for detailed definitions and additional information on these habitats).



**Figure S.H.2.** Representative photos illustrating benthic habitat types within GRNMS. Clockwise from bottom left: flat sand, densely colonized live bottom, sparsely colonized live bottom, and rippled sand. Photos (clockwise from bottom left): Justin Miyano/NOAA, Kimberly Roberson/NOAA, Justin Miyano/NOAA, NOAA/NCCOS

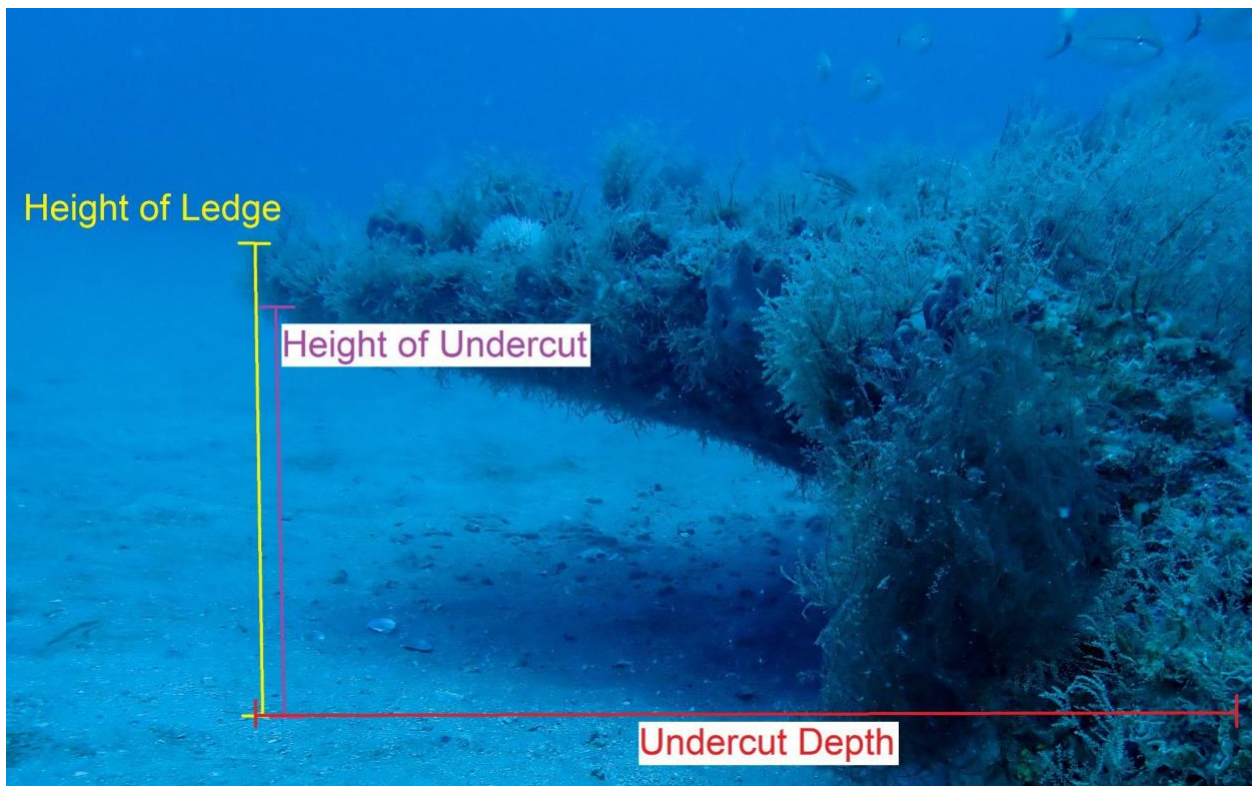
### Unconsolidated Sediment

Unconsolidated sediment (flat and rippled sand) comprises the majority of habitat in GRNMS by area. Alexander et al. (2020) assessed sediment composition off the Georgia coast and found that sediments at GRNMS were coarser than those on the open shelf, likely due to local erosion of rocky outcrops. Sediment grain size can affect contaminant sequestration; coarser grain sizes are typically correlated with lower contaminant concentrations (Grant & Middleton, 1998; Lakhan et al., 2003). Although the specific relationship between sediment size and contaminant concentration has not yet been explored at GRNMS, contaminants in sediments within the sanctuary were found to be low (Balthis et al., 2015; this topic is also discussed in the subsequent question on contaminants). Sediment size also affects the distribution, composition, and species abundance of infaunal and microalgal communities (e.g., Sandulli & Pinckney, 1999; Anderson et al., 2004). The most recent studies of unconsolidated sediment habitats in the sanctuary (2012–2013) suggested they support a healthy infaunal community with species richness and diversity that exceed that of comparable sites in the South Atlantic Bight (Balthis et al., 2015).

Although unconsolidated sediment is the most common habitat type in GRNMS and supports vast biological communities, it is understudied compared to live-bottom habitats. Updated information on the areal extent of unconsolidated sediment, as well as biological community structure, contaminant concentrations, and sediment organic content, which can also affect contaminant concentrations (Eggleton & Thomas, 2004), in these habitats, represent key data gaps. Given these gaps in data, the remaining indicators in this section focus on live-bottom habitat.

### Ledge Height/Undercut Depth

Although live bottom represents just a quarter of GRNMS habitat, it supports a variety of marine species. Ridges of hard substrate (known as scarps) provide vertical relief and form ledges where sessile invertebrates settle and grow, as well as overhangs (undercuts) that attract a variety of fishes and other species (Figure S.H.3; Ruzicka & Gleason, 2009; Roberson et al., 2020). The sizes of ledges and undercuts change over time or seasonally as natural sand transport occurs, variously exposing and burying hard bottom substrate (Renaud et al., 1996; Muñoz et al., 2020). Nevertheless, ledge height and undercut size are positively associated with species richness, diversity, and abundance (Kendall et al., 2008, 2009; Muñoz et al., 2020; Figure S.H.3). As one moves away from the ledge and over the scarp, the hard bottom transitions to a flat area of soft substrata known as the plateau, which generally supports a different species assemblage (Kendall et al., 2008, 2009; Muñoz et al., 2020; Ruzicka & Gleason, 2009).

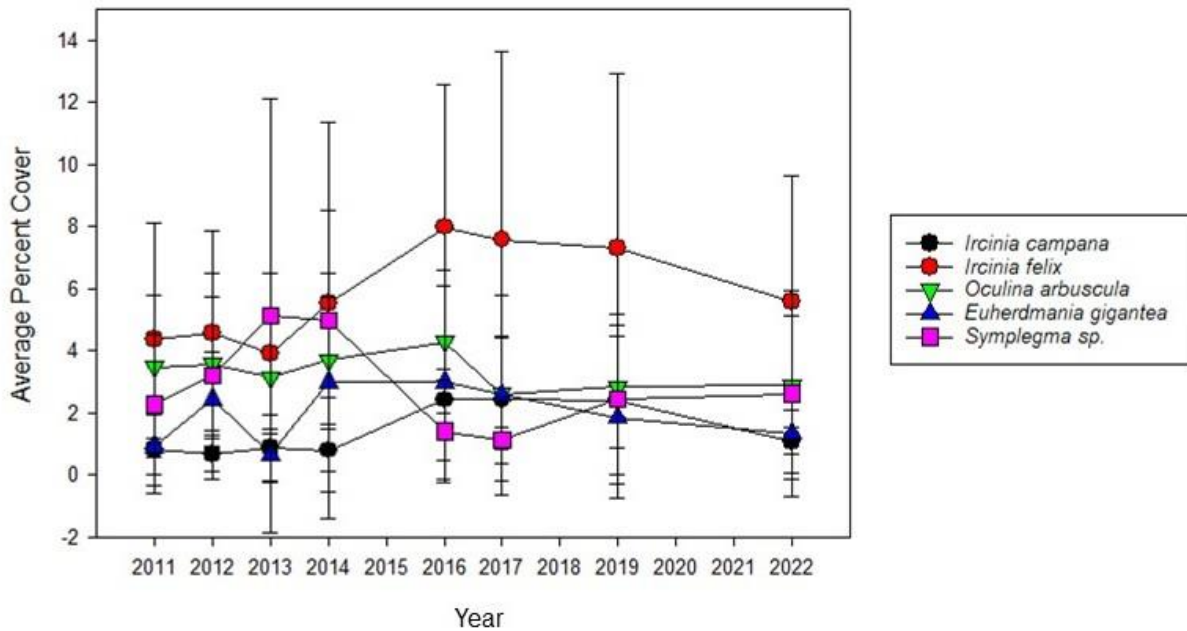


**Figure S.H.3.** A live-bottom ledge with an undercut. Labels indicate the structural attributes that are measured during habitat surveys in GRNMS. Photo: Alison Soss/NOAA

Although fish communities associated with these features varied from year to year, certain species consistently associated with tall (>25 cm) ledges, including gag, scamp, red snapper, sheepshead, Atlantic spadefish, great barracuda, greater amberjack, Almaco jack, scad, longspine porgy, tomtate, and loggerhead sea turtles (Kendall et al., 2008, 2009; Muñoz et al., 2020). These species are also occasionally observed on short ( $\leq 25$  cm) ledges, particularly as juveniles (Muñoz et al., 2020). Additionally, juvenile fish communities associated with ledges in GRNMS are distinct from those communities present on adjacent plateaus, where the ledge community quickly transitions into a mixed soft substratum community (Muñoz, 2019).

### Sessile Benthic Invertebrate Cover

Sessile benthic invertebrates, such as tunicates, sponges, and corals, dominate the live bottom of the sanctuary and are integral components in providing habitat complexity and essential habitat for a variety of fish and invertebrate communities (Gleason et al., 2020; Greene, 2008). Key benthic species include the sponges *Ircinia campana* and *I. felix*, which create habitat structure in ledge habitats and cycle organic nutrients; the coral *Oculina arbuscula*, which is the dominant coral species in GRNMS hard-bottom habitats and the only structurally complex shallow water scleractinian coral in the South Atlantic Bight; and *Euherdmania gigantea* and *Symplegma* sp., two of the most common tunicate taxa in the sanctuary. Percent cover of these taxa was stable from 2011 to 2022 (Figure S.H.4; Gleason et al., 2022).



**Figure S.H.4.** Mean percent cover ( $\pm$  standard deviation) of key benthic invertebrate species, 2011–2022. Source: Gleason et al., 2022

Additionally, Daniel and Gleason (2021) found that invertebrate communities in the sanctuary were resilient to disturbance (e.g., tropical cyclones). Invertebrate mean percent cover, species richness, and taxonomic diversity remained stable at study sites within GRNMS from 2010–2019, despite impacts from the passage of seven tropical cyclones during that period.

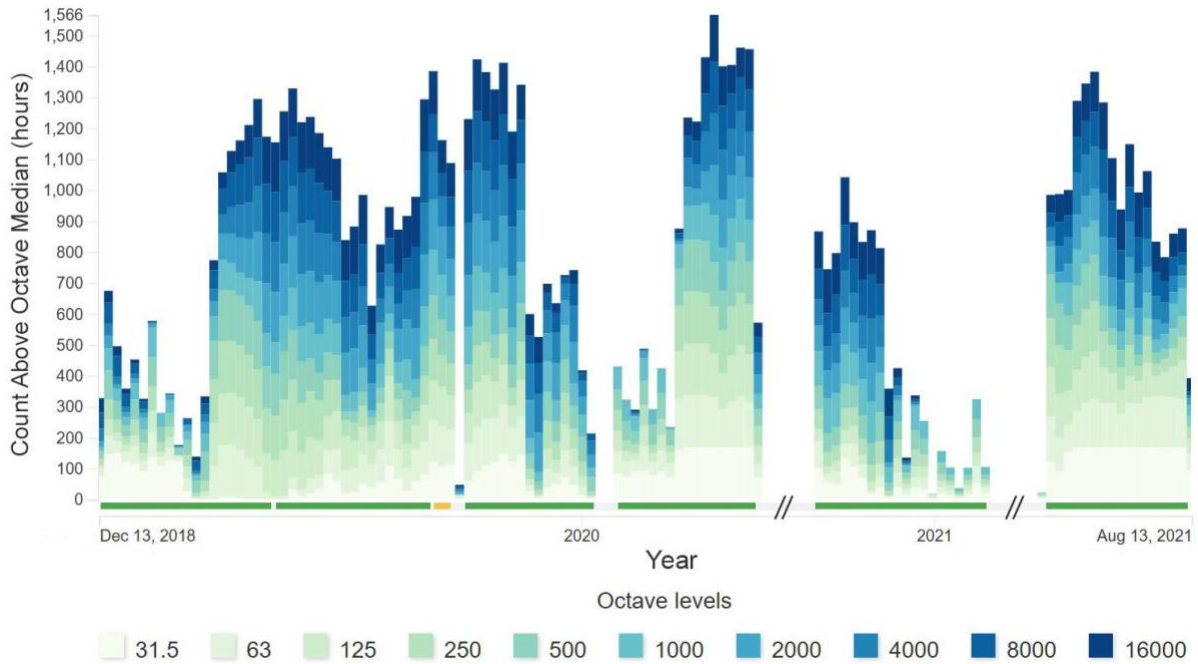
Despite overall stability within the GRNMS benthic invertebrate community, some emerging concerns may affect the contributions of some species to habitat integrity in GRNMS. Disease was recently observed among *I. campana* and *I. felix*, but prevalence has not been quantified (D. Gleason/Georgia Southern University, personal communication, March 22, 2023). In addition, although *O. arbuscula* is resistant to moderate ocean acidification (Ries et al., 2010; Varnerin et al., 2020; Wang et al., 2021), the combined effects of acidification and warming, which are both occurring at GRNMS (see the section on climate change in this report), cause significant reductions in calcification rates (Rogers, 2019). Continued monitoring will allow for the detection of shifts in the benthic community as a result of these processes.

### **Macroalgae**

Macroalgae contribute to the habitat integrity of the sanctuary's unconsolidated and live-bottom habitats, acting not just as primary producers, but also providing structure and refuge for a variety of organisms. Gaps in long-term assessments of macroalgal cover, height, richness, and other ecological metrics were identified in the previous report, and these data remain limited. Macrophyte composition in the sanctuary was assessed in the 1980s (Searles, 1987) and 2010s (Goldberg & Heine, 2012). In 2018, 2019, and 2021, samples of over 55 macroalgae species were collected at GRNMS (Aumack & Cohen, 2021). Monitoring of macroalgae spatial distribution and species richness data began in 2021. Although long-term data on these metrics are not yet available, they will be valuable for future sanctuary condition reports.

### **Soundscape/Acoustic Environment**

In 2018, NOAA and the U.S. Navy launched the SanctSound project, which monitors the biotic (living), abiotic (non-living), and anthropogenic (human made) soundscape within GRNMS and seven other national marine sanctuaries (Integrated Ocean Observing System, 2023). The data show intra- and interannual variability in the GRNMS soundscape, with maximum overall sound levels dictated by increases at medium and lower pitches (Figure S.H.5). The lowest overall sound levels were recorded in winter, and temporary increases in winter months were associated with storms (Integrated Ocean Observing System, 2023). Medium and higher pitch sounds were substantial contributors to the soundscape in the spring and fall; this was attributed to the increased activity of snapping shrimp and fish chorusing in those seasons (Stanley et al., 2021; Integrated Ocean Observing System, 2023). Anthropogenic noise (e.g., from vessels) was relatively low compared to other national marine sanctuaries that were analyzed (Stanley et al., 2021). Vessel noise was detected most frequently in the summer months (June–August; Kendall et al., 2020). Of the vessel events detected, 78% appeared to result from transits through the sanctuary and about half occurred for less than 10 minutes (Kendall et al., 2020). Although soundscape data were not available for the entirety of the condition report study period, the available data provide a baseline from which further studies can explore anomalies or long-term temporal changes.



**Figure S.H.5.** A stacked histogram of the number of hours of above-median sound levels for different frequencies recorded at GRNMS from December 2018 to August 2021. Shading indicates the octave levels recorded and the stacked histogram displays the contribution of these frequencies to the overall soundscape (hours detected). Lighter colors indicate lower pitches and darker colors indicate higher pitches. Note changes in scale on the x-axis to collapse times for which no data were unavailable (denoted by hash marks). The green bar below the histogram indicates data used was of good quality; the orange line indicates a period in which the instrument came into contact with the seafloor, potentially resulting in reduced sound levels at some frequencies. Image: ONMS & U.S. Navy, 2021

## Conclusion

Existing assessments of GRNMS provide baseline information on the distribution of key habitat types. New bathymetry data have been collected since 2012 but have not yet been analyzed, precluding the assessment of any large-scale changes in habitat distribution over the past two decades. These subsequent surveys will reveal the extent to which sand is moving within the boundaries of GRNMS and potentially changing the location and extent of live-bottom and unconsolidated sandy habitats. The most recent available data showed that unconsolidated sediment, the most common habitat type in the sanctuary by area, was characterized by healthy infaunal communities, however there is a data gap for unconsolidated sediment metrics over the past decade. Ledge and undercut features of colonized substrate habitats in the sanctuary continued to provide habitat for numerous fish and invertebrates. Benthic invertebrate cover has not changed over time, and these communities display high resilience in GRNMS, although recent observations of disease and impacts of climate change warrant continued investigation. Recent studies of macroalgae in the sanctuary have built on past assessments; however, further monitoring is required to understand long-term patterns in spatial distribution and species richness, as well as the role of macroalgae in terms of habitat provision within the sanctuary. Baseline soundscape data illustrated patterns in biotic, abiotic, and anthropogenic noise in the sanctuary; anthropogenic noise was relatively low. Continued or new monitoring of all indicators is necessary to fully assess habitat within the sanctuary. In particular, seasonal

assessments are required to fully understand the range of changes that may occur in GRNMS habitats annually. Additionally, there is a need for analysis of existing bathymetry data to better understand major changes in habitat availability over time. Despite some data and analysis gaps, available information suggests sanctuary habitats remained in near-pristine condition during the study period.

## What are contaminant concentrations in sanctuary habitats and how are they changing?



**Status Description:** Selected contaminants are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

**Rationale:** Some contaminants were present in GRNMS sediments and biota, but they were detected at low levels that would not be expected to significantly degrade ecological integrity. However, data on contaminants were limited to one or few time points.

### **Findings From the 2008 Condition Report**

In 2008, the status of contaminant concentrations in sanctuary habitats was good and the trend was not changing. Sediment samples taken in 2000 and 2005 indicated low background concentrations of contaminants (including pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and metals) that were below thresholds at which biological effects would be expected. These low levels were attributed to the sanctuary’s offshore location and sandy substrate. However, the presence of these compounds in GRNMS sediments showed that contaminants can reach the sanctuary despite its distance from shore.

### **New Information in the 2008–2022 Condition Report**

Indicators considered in the present report include contaminant levels in sediment and biota.

#### **Contaminant Levels in Sediment**

Sediment samples were collected and tested for contaminants at 20 sites throughout GRNMS in 2012–2013 (Balthis et al., 2015). The contaminants assessed included 23 metals, 29 polycyclic aromatic hydrocarbons, 30 pesticides, and one polychlorinated biphenyl. Concentrations were either undetectable or below Effects Range Low thresholds within NOAA’s Sediment Quality Guidelines, indicating that contaminants were not likely to adversely affect marine-sediment-dwelling organisms. These findings were consistent with the low levels of contaminants measured during previous sampling efforts in 2000 (Hyland et al., 2006; Cooksey et al., 2004) and 2005 (Balthis et al., 2007), suggesting little change in the status of contaminants in sediment.

The first sampling for the presence of microplastics in GRNMS sediments occurred in 2021 (Geiger, 2021). Microplastics were present in every sample collected, although their abundance was lower in GRNMS than at coastal sites in the lower Wassaw Sound estuary. Additional data are required to determine trends in the presence of microplastics and to assess potential impacts on GRNMS habitat and biota.

#### **Contaminant Levels in Biota**

Balthis et al. (2015) assessed contaminants in tissues of black sea bass (*Centropristis striata*) and turkey wing ark clams (*Arca zebra*) within GRNMS in 2012–2013. A total of 10 black sea bass tissue samples were collected from five sites, and a total of 91 turkey wing ark clam tissue samples were collected from 10 sites. Tissue samples were tested for the same contaminants as

sediment samples (described above). Most contaminants were undetectable or at low background levels, and none exceeded U.S. Food and Drug Administration human health guideline values. However, arsenic levels in one black sea bass sample fell within a range for which the U.S. Environmental Protection Agency recommends limiting consumption to four meals per month. Additionally, six of ten turkey wing ark clam samples had cadmium levels within the range for limited human consumption (four meals per month), and two more samples had cadmium levels that exceeded the U.S. Environmental Protection Agency's threshold for human consumption. Although these results do not directly illustrate the presence of contaminants in GRNMS habitats, they do indicate the presence of contaminants within the local environment. However, there was insufficient information to understand the sources of these contaminants.

### ***Conclusion***

Although some contaminants were detected in GRNMS habitats and biota, they were generally present at low levels, and there was no evidence to suggest measurable degradation due to their presence. Additionally, the samples collected during the study period in 2012–2013 suggested little change compared to previous sampling efforts in 2000 and 2005. However, substantial data gaps exist; contaminants and microplastics were each only measured at one time point during the study period, precluding the assessment of a trend.

## Status and Trends of Living Marine Resources

The following is an assessment of the status and trends of living marine resources in GRNMS from 2008–2022. The term “living marine resources” encompasses a range of organisms, including focal and non-indigenous species.

The first question in this section is about focal species, including loggerhead sea turtles, North Atlantic right whale, red snapper, and black seabass, which may not be abundant or highly influential to the sanctuary’s ecosystem function, but their presence and health is important for the provision of economic, cultural, spiritual, recreational, ecological, or conservation-related values and services. Some focal species discussed here (e.g., turtles and whales) are also threatened or endangered and protected under state and/or federal laws.

The next question focuses on the impacts of non-indigenous species (e.g., lionfish), which are not native to the region. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their endemic geographical range. Often having arrived in the sanctuary as a result of human activity, either deliberately or accidentally, their abundance in sanctuary habitats, along with any known ecological impacts, will be discussed. These species are of concern because they have the potential to impact ecosystem structure and function (e.g., through rapid spread, effective competition for resources, displacement of native species), at which point they are considered invasive species.

The final question in this section addresses the status of biodiversity, defined as variation of life at all levels of biological organization. Assessment often employs measures of diversity within species (genetic diversity), among species (species diversity), and comparative diversity among ecosystems (ecosystem diversity). Biodiversity can be measured in many ways. The simplest measure is to count the number of species found in a certain habitat or ecosystem, termed species richness. Other indices of biodiversity couple species richness with relative abundance to provide a measure of evenness and heterogeneity. Aspects of community structure not well captured by diversity indices alone are often also considered as part of this assessment. These may include community and food web structure, as well as indicators of ecosystem integrity (e.g., levels of recruitment and rates of recovery following disturbance).

**Table S.LR.1.** Status, trend, and confidence ratings (where applicable) from previous (2008 or 2012) and present (2008–2022) condition report questions focused on living marine resources.

Previous Condition Report Questions	Year of Previous Rating	Previous Rating	2008–2022 Condition Report Questions	2008–2022 Condition Report Rating
Status of key species	2012	Good/Fair ▲	Other focal species	Mixed
Non-indigenous species	2008	Good/Fair ▼	Non-indigenous species	Good/Fair
Biodiversity	2012	Good —	Biodiversity	Good/Fair

## What is the status of other focal species and how is it changing?



**Status Description:** Conflicting signals from indicators prevent the selection of a singular status rating.

**Rationale:** Select focal fish (red snapper, tomtate, black sea bass, king mackerel) and coral (*Oculina arbuscula*) species remained stable or improved within GRNMS during the study period. Conversely, North Atlantic right whales are endangered and experienced an unusual mortality event during the study period. For other species, including loggerhead sea turtles, sand tiger sharks, and *Halymenia* spp. algae, data were too limited to determine status or trends.<sup>13</sup>

### Findings From the 2012 Condition Report Addendum

In 2012, focal species were addressed in the question “What is the status of key species and how is it changing?” The status for that question was good/fair and the trend was improving, based on 1) stock assessments that indicated the status of some species had improved (e.g., black sea bass) or had not changed (e.g., red snapper) since 2008; 2) a 2009 spawning season closure for groupers that was expected to reduce overfishing; 3) a possible reduction in fishing tournament pressure on king mackerel; and 4) long-term monitoring that indicated stable cover and good condition of benthic species.

### New Information in the 2008–2022 Condition Report

Indicator focal species considered in the present report include wide-ranging species that are known to use the sanctuary (loggerhead sea turtles, North Atlantic right whales, and sand tiger sharks) and resident species (red snapper, tomtate, black sea bass, king mackerel, *Oculina arbuscula*, and *Halymenia* spp.).

### Loggerhead Sea Turtle

Sea turtles, primarily loggerheads (*Caretta caretta*), are dispersed throughout the sanctuary. GRNMS is part of a migration pathway for loggerheads between the Archie Carr National Wildlife Refuge in Florida and northern foraging regions along the South Atlantic Bight and the Mid-Atlantic Bight (Evans et al., 2019). Loggerhead sea turtles are important focal species for GRNMS because they are charismatic, iconic megafauna. They are also listed as threatened within the region under the Endangered Species Act (Conant et al., 2009).

Loggerhead sea turtles are distributed throughout GRNMS and have been spotted primarily at the surface of the sanctuary in the vicinity of tall ledges and on the seafloor resting under overhanging ledges (Muñoz et al., 2020; Auster et al., 2020a). From 2010 to 2021, sea turtles were observed in the sanctuary almost every year, and 150 sightings were made in total (Gray’s Reef National Marine Sanctuary [GRNMS], 2021a). However, sightings were sporadic, making

<sup>13</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

the detection of temporal trends difficult. Long-term and directed monitoring would be required to fully assess the status and trend of loggerhead sea turtles at GRNMS.

### **North Atlantic Right Whale**

North Atlantic right whales (*Eubalaena glacialis*) are present in the South Atlantic Bight and at GRNMS from November–April, when they give birth and raise their calves. The area off of the southeast U.S. coast from Cape Fear, North Carolina to the south of Cape Canaveral, Florida has been designated as an area of critical habitat for North Atlantic right whales (NOAA Fisheries, 2023a), which have been listed as endangered under the U.S. Endangered Species Act and Canadian Species at Risk Act since 1970 and 2005, respectively (Borggaard et al., 2020). The last preliminary estimate suggests that there were approximately 360 remaining whales throughout their range (NOAA Fisheries, 2024), including fewer than 70 breeding females (Borggaard et al., 2020). In 2017, the species began experiencing an unusual mortality event that continued into 2020 (NOAA Fisheries, 2023a).

According to NOAA Fisheries (2024), the most common causes of mortality of North Atlantic right whales are entanglement in fishing gear and vessel strikes. Ocean noise is also a concern for right whale health, as it can increase stress and interfere with communication.

Underwater sound was monitored from 2018–2021 as part of the sanctuary system-wide SanctSound project (Integrated Ocean Observing System, 2023). North Atlantic right whale vocalizations were detected on underwater microphones (hydrophones) in GRNMS during winter months (GRNMS, 2021b). When vocalizations were detected, there were typically one to three vocalizations per week, indicating that GRNMS may be an important habitat for visiting whales. These vocalizations were not paired with sighting data to confirm that they occurred within the sanctuary boundary, although there has been one confirmed sighting. Further, it has been hypothesized that pregnant and lactating females exhibit a form of “acoustic crypsis,” where vocalizations are low in amplitude to avoid attracting possible predators (Matthews & Parks, 2021); females exhibiting this behavior may thus not be detected using hydrophones. There is a critical need to obtain better data on population trends, distribution, and health, as well as habitat needs and uses, for North Atlantic right whales in GRNMS.<sup>14</sup>

### **Sand Tiger Shark**

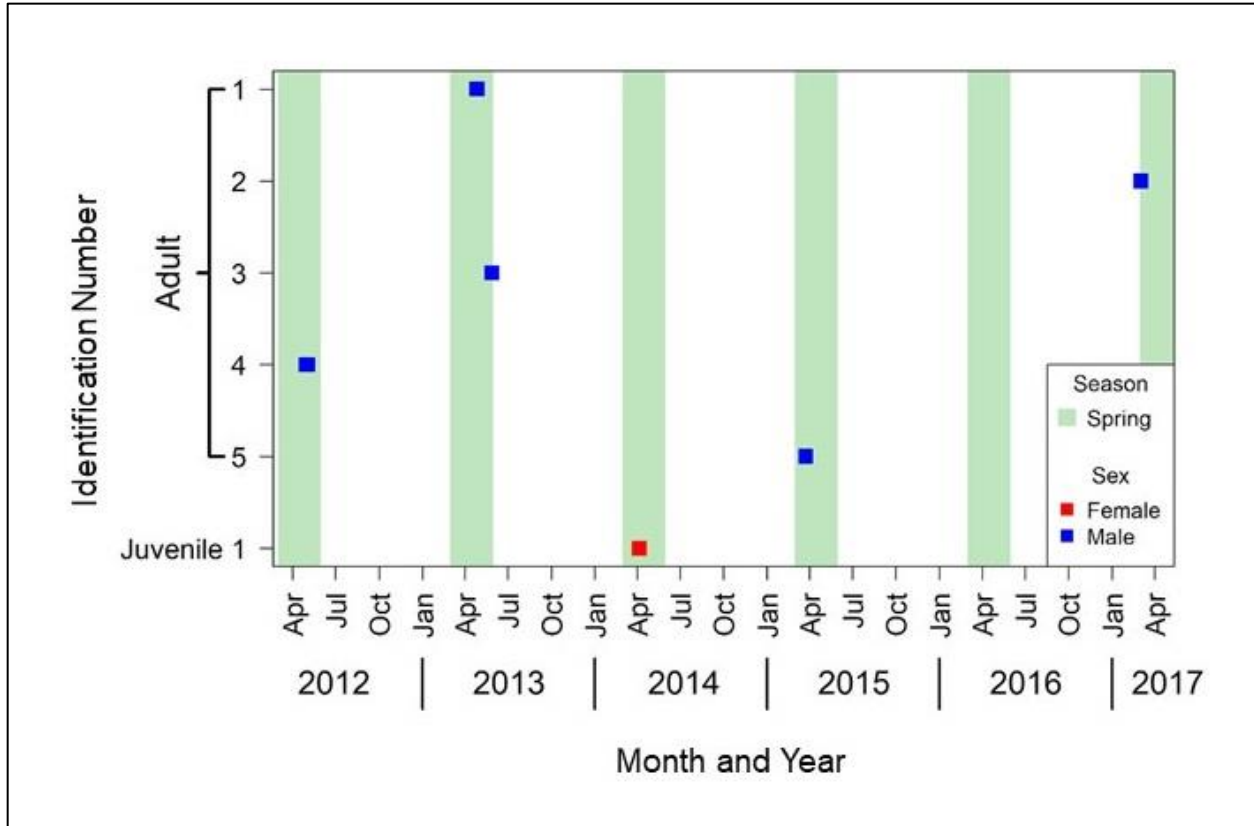
Sand tiger sharks (*Carcharias taurus*) occur widely around the world in coastal tropical and temperate waters, with their western Atlantic range extending from the Gulf of Maine to Argentina. In addition, they undertake extensive coastal migrations (Compagno, 1984; Williams et al., 2019). Although now protected, sand tiger sharks are listed as critically endangered on the International Union for Conservation of Nature Red List (Rigby et al., 2021) and as a species of concern by NOAA due to decades of exploitation, slow growth, and low reproductive rates (Musick et al., 1993; Carlson et al., 2009; Williams et al., 2019).

From April 2012 to April 2017, six different tagged sand tiger sharks were detected in the sanctuary by the acoustic array maintained by GRNMS (Figure S.LR.1). Five were adult males

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<sup>14</sup> Following the study period for this condition report, 29 passive acoustic moorings were deployed by NOAA in coastal waters from Cape Canaveral, Florida to north of Cape Hatteras, North Carolina to monitor North Atlantic right whales. Results will be reported in future GRNMS condition reports.

and one was a juvenile female (Williams et al., 2019). All sand tiger sharks detected were tagged in Delaware Bay, ~995 kilometers northeast of GRNMS, and all detections at GRNMS were in spring, suggesting they transit the sanctuary during seasonal migrations. Most individuals spent less than one day at the sanctuary, indicating they pass through GRNMS quickly. The number of detections was insufficient to determine a status or trend for the species.



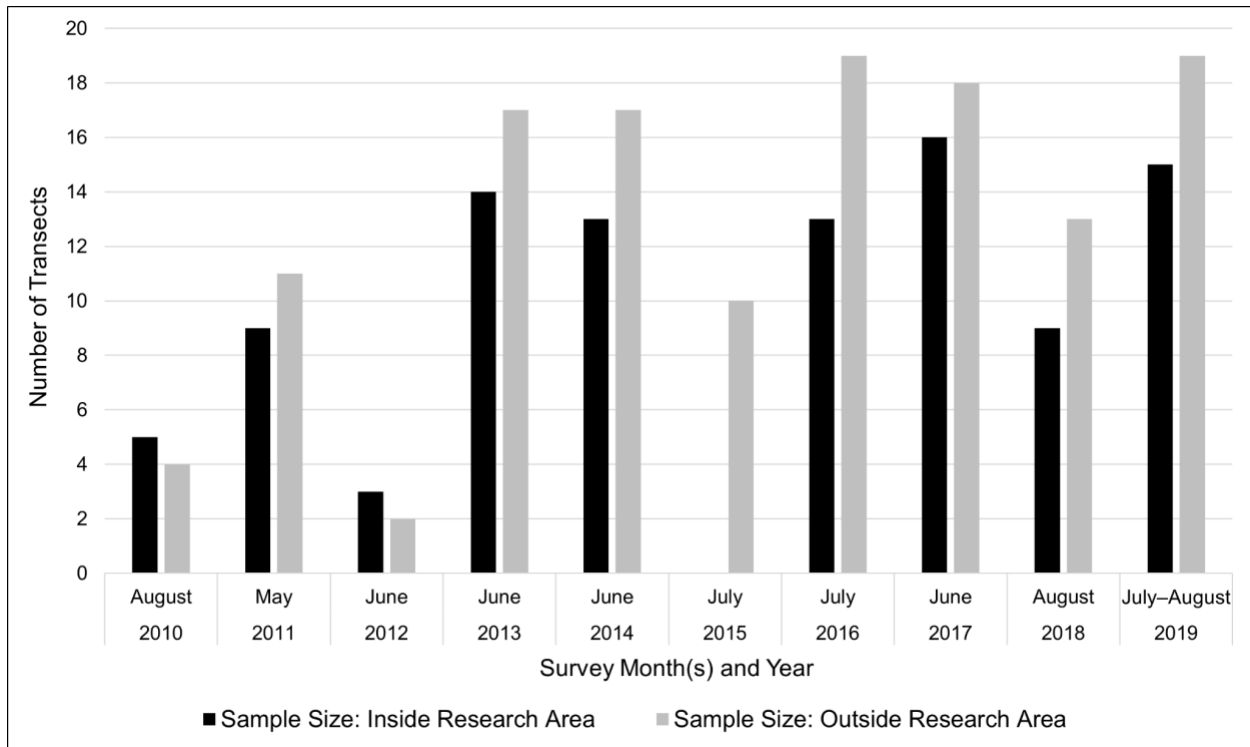
**Figure S.LR.1** Sand tiger sharks detected at GRNMS using acoustic monitoring surveys. Numbers on the y-axis indicate individual tagged sharks. Image: Williams et al., 2019

### Red Snapper

Red snapper (*Lutjanus campechanus*) have both social and ecological value throughout the South Atlantic Bight. In addition to serving an important ecological role as predators, they are a favored food item for residents and an iconic species for both fishers and the general public. Live-bottom reefs are important habitats for red snapper, including small juveniles and the organisms they prey on (Auster et al., 2013; Mitchell et al., 2014; Campanella et al., 2019).

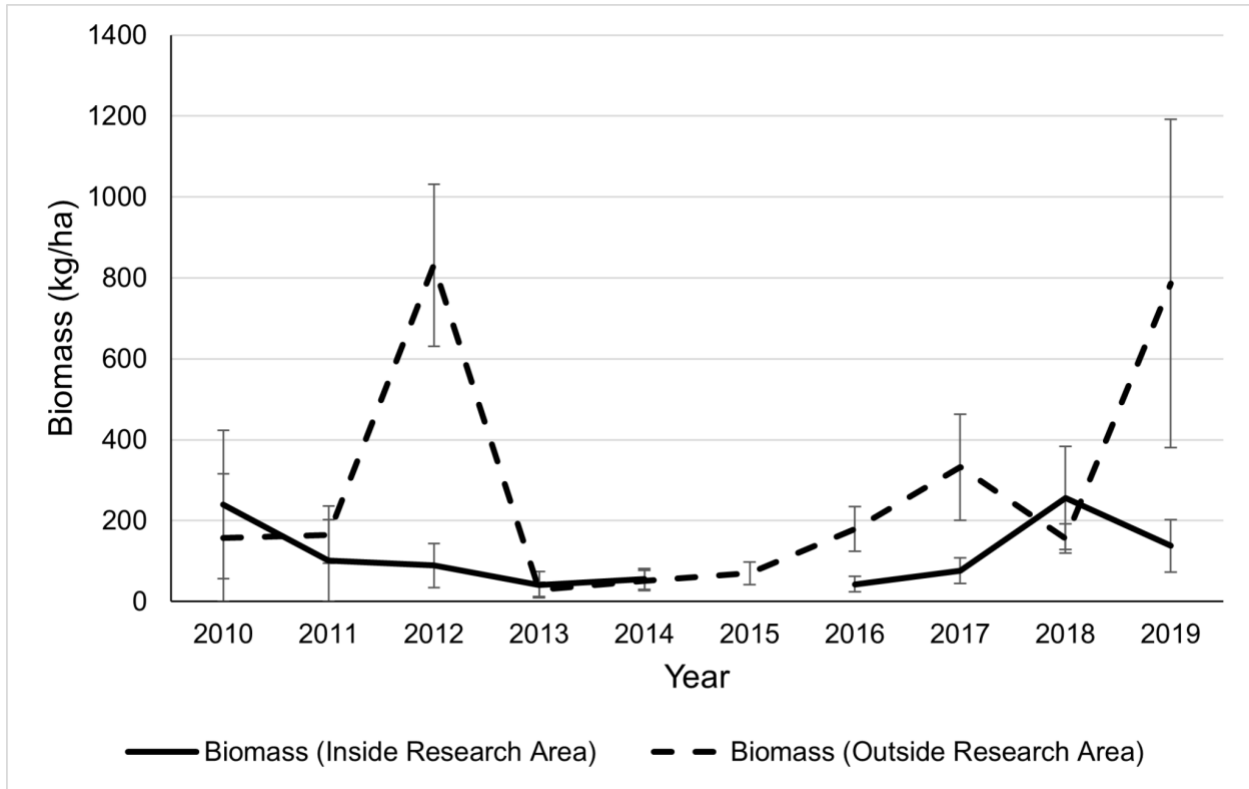
Underwater visual census transect surveys assessed the biomass and density of common predator and prey species in hard-bottom habitats at GRNMS annually between May and August; specific survey dates and survey effort varied among years (Muñoz et al., 2019). Although the same ledges were targeted for sampling each year, permanent transects installed on the seafloor were not used, so there was interannual variation in the specific location of transects on each feature. During these surveys, both tall (maximum ledge height >25 cm) and short (maximum ledge height ≤25 cm) ledges were surveyed. Because fish community composition is known to differ between tall and short ledges (Kendall et al., 2009; Muñoz et al.,

2020), only data from tall ledges were used to compile Figures S.LR.2–S.LR.5 to better control for differences based on the number of tall versus short ledges surveyed each year. Table S.LR.2 indicates the number of tall ledges surveyed each year inside and outside the Research Area. Although this report aims to assess the entirety of GRNMS, summary biomass data were only available by management zone.



**Figure S.LR.2.** Information for underwater visual census transect surveys conducted in GRNMS, including sample size (number of transects on tall ledges [ $>25$  cm] only) by management zone. Data from the surveys described by this figure are displayed in Figures S.LR.3–S.LR.5. Source: Muñoz et al., 2019

Red snapper were consistently present at GRNMS throughout these surveys, and varied with no apparent trend from 2010 to 2019 (Figure S.LR.3; Muñoz et al., 2019). Additionally, acoustic tagging demonstrated that red snapper movement patterns between reefs and rates of immigration and emigration from GRNMS were unclear (Auster et al., 2020b). Regionally, red snapper stocks are not yet considered to be rebuilt following historical declines, and continue to experience overfishing in the South Atlantic; however, the stock has improved and has made progress toward rebuilding since 2014 (Southeast Data, Assessment, and Review [SEDAR], 2021).

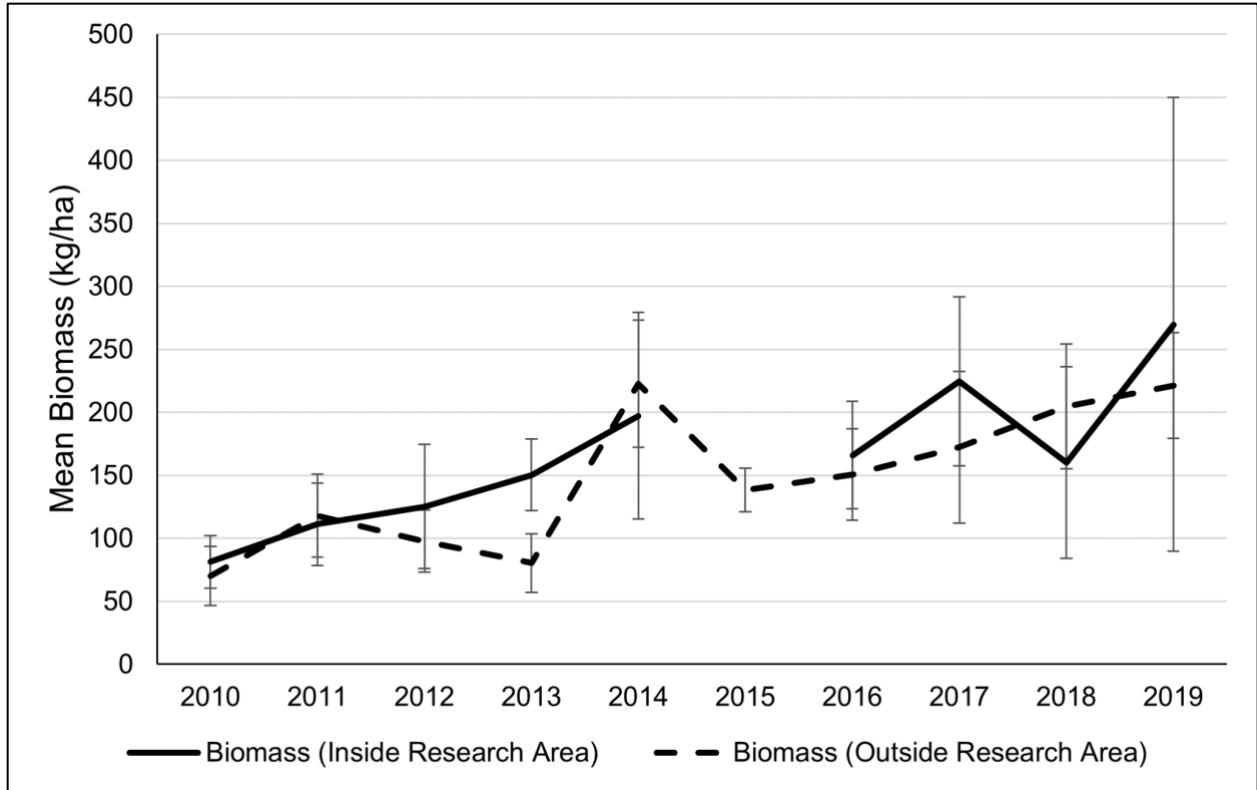


**Figure S.LR.3.** Mean biomass of red snapper ( $\pm$  standard error) observed during surveys of tall ledges (>25 cm) in GRNMS within and outside of the Research Area, 2010–2019. Source: Muñoz et al., 2019

### Black Sea Bass<sup>15</sup>

Black sea bass (*Centropristis striata*) are abundant and ubiquitous at GRNMS (Kendall et al., 2008) and serve an important role as predators in the sanctuary, controlling populations of crustaceans and prey fish (Auster et al., 2013; Campanella et al., 2019). Visual surveys within GRNMS documented the consistent presence of black sea bass in the sanctuary from 2010 to 2019 (Figure S.LR.4; Muñoz et al., 2019). This species is also a popular target species for recreational fishing; abundance of individuals over the minimum size limit for harvest was substantially lower compared to smaller size classes in GRNMS, suggesting recreational fishing has affected the size distribution of this species within the sanctuary (Kendall et al., 2008). Anecdotal field observations by GRNMS staff also supported this finding, as black sea bass captured inside sanctuary boundaries for a tagging effort in 2019 did not meet the minimum recreational size limit of 13 inches (total length). An additional study in 2012–2013 examined movement patterns of black sea bass using acoustic tagging (Auster et al., 2020b). Fourteen black sea bass were tagged at a reef within the GRNMS Research Area, and seven of these remained on the study reef for 26–430 days.

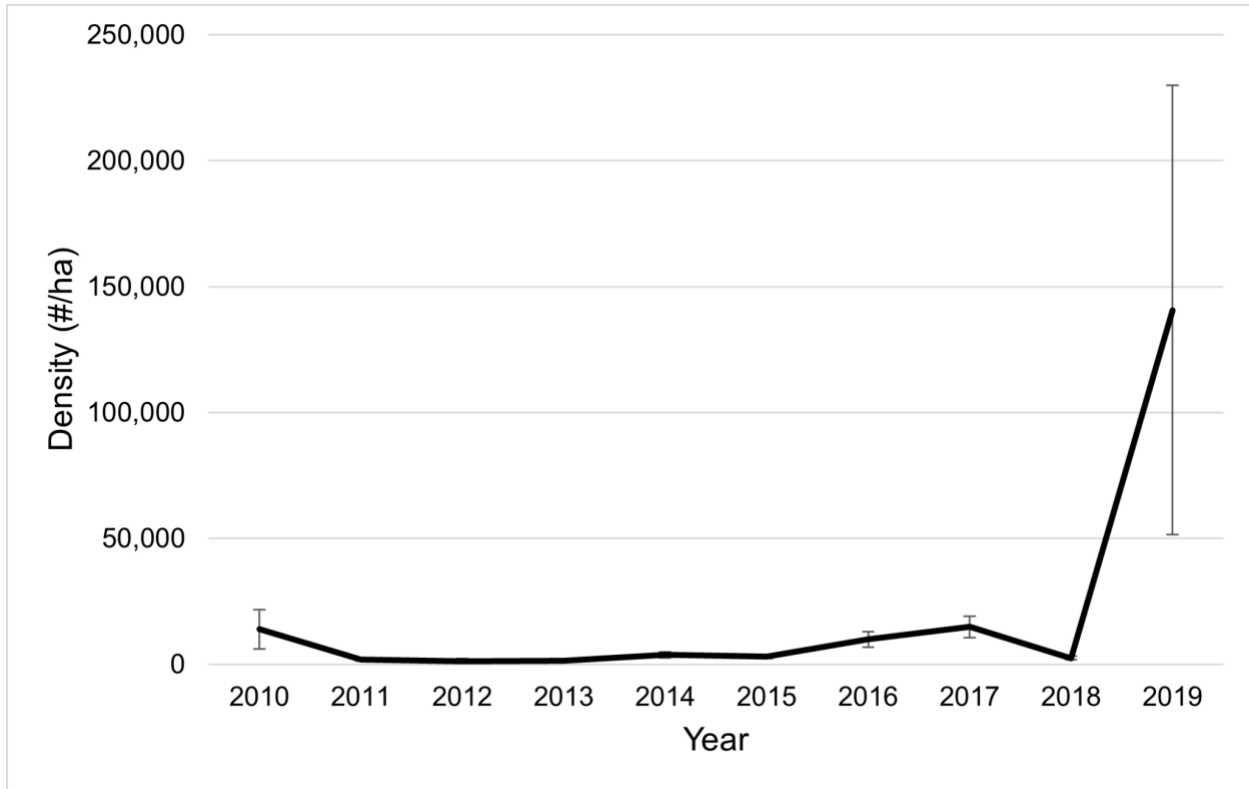
<sup>15</sup> The *SEDAR 76 South Atlantic Black Sea Bass Stock Assessment Report* (SEDAR, 2023) found that the South Atlantic black sea bass stock was overfished and undergoing overfishing, and biomass declined in recent years as a result of below-average recruitment from 2012–2021. Although these regional changes in the stock may have implications for GRNMS, they were not considered in the overall rating for this question, as the report was not available at the time of the condition report status and trends workshop.



**Figure S.LR.4.** Mean biomass ( $\pm$  standard error) of black sea bass observed during surveys of tall ledges (>25 cm) in GRNMS within and outside of the Research Area, 2010–2019. Source: Muñoz et al., 2019

### Tomtate

Tomtate (*Haemulon aurolineatum*) are an important prey species for larger predators in the snapper-grouper complex and are among the most abundant species at GRNMS. Juvenile tomtate aggregate over tall ledges in association with other dominant aggregating species, principally round and mackerel scad (*Decapturus* spp.; Auster et al., 2013). The density and patchiness of these multispecies aggregations can vary substantially among years, based on acoustic surveys (Gabriel et al., 2020). Muñoz et al. (2020) found that the abundance of tomtate was generally stable from 2011 to 2016 but increased in 2019 (Figure S.LR.5; Muñoz et al., 2019).



**Figure S.LR.5.** Mean density of tomstate observed during surveys of tall ledges (>25 cm) at GRNMS, 2010–2019. Source: Muñoz et al., 2019

### King Mackerel

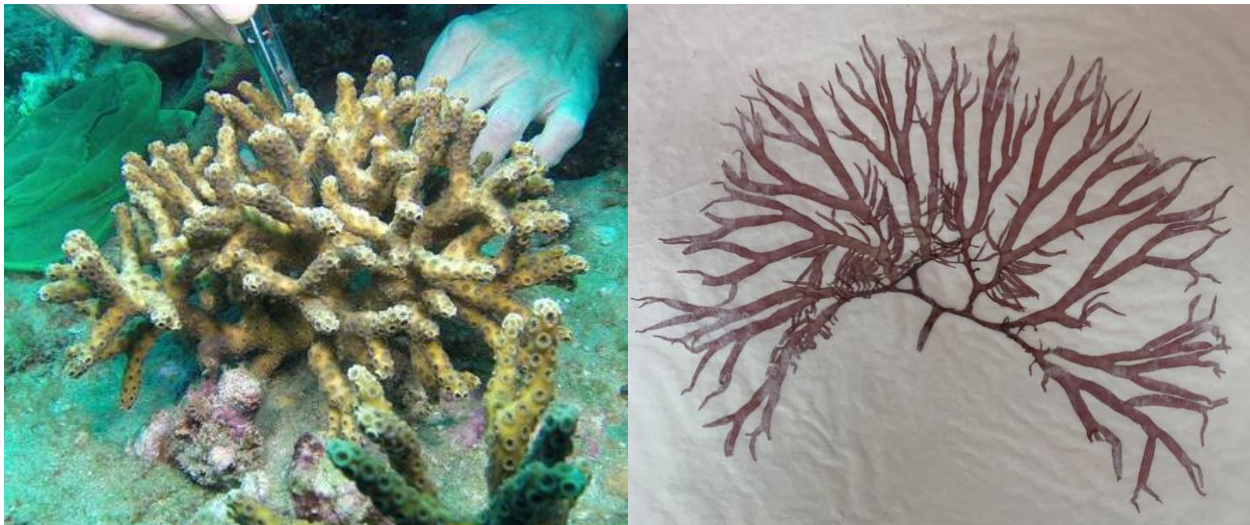
King mackerel (*Scomberomorus cavalla*) is a popular target species for recreational fishers, as it is an aggressive fish that puts up a fight when hooked, making it more challenging to land. In 2022, recreational harvest of king mackerel totaled 5.6 million pounds (NOAA Fisheries, 2023b). King mackerel support valuable tournament and recreational fisheries. Prior to the 1980s, king mackerel fisheries were essentially unregulated and became depleted. Regulations were implemented in 1983 to control harvest and rebuild declining king mackerel stocks, and today these stocks have been restored to target population levels (NOAA Fisheries, 2023b). The standardized index of abundances for the 2019 assessment of king mackerel in the entire South Atlantic region (including, but not limited to, GRNMS) was included in the Southeast Data, Assessment, and Review (SEDAR, 2020). Three king mackerel catch per unit effort indices were calculated for landings by commercial trolling handline, recreational headboats, and the Southeast Area Monitoring and Assessment Program (SEAMAP) trawl fishery independent survey, which assesses juveniles. The use of multiple indices created standardized values across years and gear types, which were used to estimate population abundance. Abundance estimated from commercial handline landings was stable from 2012 to 2017 (the years of the study period for which data were available), and abundance estimated from recreational headboat and SEAMAP trawl fishery independent monitoring increased from 2012 to 2017. Considered together, the data indicated that commercial and recreational fisheries are still supported by the stock. In addition to these indices, estimated total and spawning stock biomass increased from 2013 to 2017.

### ***Oculina arbuscula***

*Oculina arbuscula* (Figure S.LR.6) is the primary scleractinian<sup>16</sup> coral species on GRNMS live-bottom ledges (Gleason et al., 2018, 2023). This species has high recruitment rates, and monitoring at adjacent sites outside the sanctuary suggests that physical factors, such as sedimentation, exert more influence on population sizes of *O. arbuscula* than biotic factors, such as larval supply and competition (Gleason et al., 2018). Gleason et al. (2022) reported relatively stable cover, ranging from about 2% to slightly over 4% from 2011 to 2022.

### ***Halymenia* spp. Algae**

Macroalgae on live-bottom reefs provide structural complexity and serve as food or refuge for many fishes and invertebrates (Levin & Hay, 1996). Algae of the genus *Halymenia* are abundant at GRNMS both on rocky ledges and in sand. *Halymenia* spp. are heavily colonized by invertebrate epifauna. Aumack and Cohen (2021) observed *Halymenia* spp. at each of 21 sites visited within GRNMS during a 2021 survey; *Halymenia elongata* (Figure S.LR.6) was observed at 18 sites, *Halymenia hancockii* was observed at 14 sites, and *Halymenia floridana* was observed at 14 sites. A trend could not be determined due to a lack of long-term monitoring data for these species within the sanctuary.



**Figure S.LR.6.** *Oculina arbuscula* on the seafloor at GRNMS (left) and a sample of *Halymenia elongata* algae collected from GRNMS (right). Photos: (left) S. Fangman/NOAA, (right) C. Aumack/Georgia Southern University

<sup>16</sup> Scleractinian corals, also known as hard or stony corals, are coral species that produce a rigid skeleton made of calcium carbonate (CaCO<sub>3</sub>; Coral Reef Conservation Program, n.d.).

### **Conclusion**

There are few long-term surveys and studies that targeted focal species in GRNMS during the condition report study period. Specifically, information gaps for loggerhead sea turtles, North Atlantic right whales, sand tiger sharks, and *Halymenia* spp. presented challenges in summarizing key metrics such as species composition, trends, and potential threats. Long-term monitoring is needed to assess the status and trends of these species within the sanctuary. Species for which more extensive monitoring data were available, including red snapper, tomtate, black sea bass, king mackerel, and *Oculina arbuscula*, suggest that these species generally remained stable or improved somewhat within the sanctuary during the study period. Monitoring should continue to increase our understanding of population fluctuations and shifts in biomass within the sanctuary.

## What is the status of non-indigenous species and how is it changing?



**Status Description:** Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.

**Rationale:** To date, the abundances of non-indigenous species in GRNMS have been low, and impacts have not been observed nor are they suspected. Limited data suggest high variability and no consistent trends across most indicators.

### **Findings From the 2008 Condition Report**

In 2008, the status of non-indigenous species was good/fair and the trend was worsening. Lionfish were first observed within GRNMS in 2007. Other non-indigenous species (titan acorn barnacle, Asian green mussel, and orange cup coral) were found only on human-made structures in the sanctuary. Although non-indigenous species were present in the sanctuary, available information suggested they were unlikely to cause substantial or persistent degradation of ecosystem integrity. The report also identified the need to continue monitoring efforts and to consider removal of invasive species while abundances were still low.

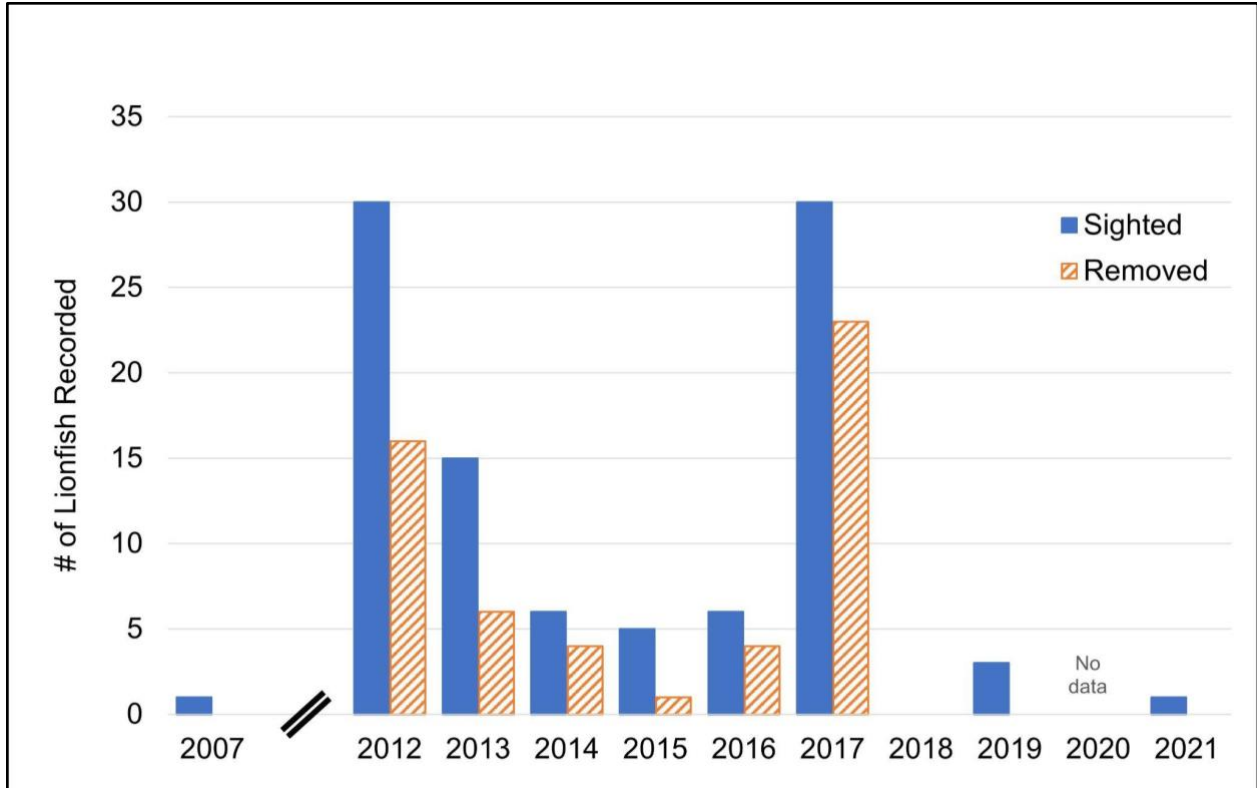
### **New Information in the 2008–2022 Condition Report**

Indicator focal species considered in the present report include three species of concern that were also considered in the 2008 report: lionfish, titan acorn barnacle, and orange cup coral.

Two species not previously observed in GRNMS were also initially considered for inclusion as indicators: the branching vase sponge *Callyspongia aculeata* and the red macroalga *Platoma gelatinosum*. However, these species were ultimately not addressed in the response to the non-indigenous species question, as expert opinion was that both species are likely present as a result of range expansion; for this reason, both species are discussed in response to the following question on biodiversity.

### **Lionfish**

Lionfish (*Pterois volitans* and *P. miles*) are native to the Indo-Pacific and have become invasive in the Caribbean, Gulf of Mexico, and western Atlantic in recent decades. As opportunistic predators with a high reproductive capacity, they pose a potential threat to native fish species in GRNMS, such as grouper and black sea bass (Muñoz et al., 2011; Shein et al., 2019). The lionfish population in GRNMS is considered sparse compared to areas outside of the sanctuary. While the reasons for this are not completely known, studies have suggested that temperature may play an important role in limiting population growth (Kimball et al., 2004; Côté & Smith, 2018; NCCOS, n.d.). Existing data from reported sightings indicate that they are found throughout the sanctuary, but appear primarily in high-relief habitats such as ledges. Two lionfish were first reported in the sanctuary in 2007, and then none were reported until 2012 (Figure S.LR.7; GRNMS, 2023a; Muñoz et al., 2019). From 2012 to 2017, 97 lionfish were sighted in the sanctuary. During this time, 54 lionfish were removed. Fewer than five have been observed in recent years.



**Figure S.LR.7.** Lionfish sightings in the sanctuary, 2007–2021. Lionfish are present in the sanctuary, but in low numbers. No lionfish were observed in 2018, while no surveys took place in 2020. Source: GRNMS, 2023a; Muñoz et al., 2019

### Other Previously Observed Species

Two additional non-indigenous species that have been observed in the sanctuary are the titan acorn barnacle (*Megabalanus coccopoma*) and the orange cup coral (*Tubastraea coccinea*; ONMS, 2012; Figure S.LR.8). Each poses a potential threat through displacement of native benthic invertebrates and, therefore, were assessed for the 2008–2022 time period.



**Figure S.LR.8.** Examples of (a) the titan acorn barnacle and (b) the orange cup coral. Photo: (a) Alicia Reigel/Washington & Lee University; (b) G.P. Schmahl/NOAA

The titan acorn barnacle, a common fouling species on human-made structures, has expanded its non-native range throughout the Gulf of Mexico and along the U.S. Atlantic coast since the early 2000s (Fofonoff, 2023). Three barnacles were first observed attached to the GRNMS data buoy in January 2008. However, none were observed on the sanctuary's live bottom habitats during extensive benthic surveys in the summer of 2011 (ONMS, 2012). Since then, all observations have been isolated to the GRNMS data buoy, including observations made in spring 2014, when an average density of 20 individuals per 400 cm<sup>2</sup> was recorded (Reigel, 2015).

The ahermatypic orange cup coral is native to the Indo-Pacific region and has become established in the Gulf of Mexico, Caribbean, and western Atlantic regions (Fofonoff, 2023). Similar to the titan acorn barnacle, the orange cup coral has only been observed attached to the GRNMS data buoy and not on live bottom habitats in the sanctuary (ONMS, 2012). There has been no documentation of its presence at the GRNMS data buoy or elsewhere within the sanctuary in recent years.

### **Conclusion**

Observations of non-indigenous species in GRNMS are typically made while conducting other short- and long-term studies. The lack of surveys focused specifically on non-indigenous species makes it difficult to quantify key metrics, such as species composition, densities, trends, and potential impacts. The presence of non-indigenous species in GRNMS appeared to be low during the study period, but further monitoring is needed to track both presence and abundance of non-indigenous species. Further, while the non-indigenous species discussed here are known to damage ecosystems, their presence does not necessarily mean that local conditions in GRNMS support their sustained presence or effective reproduction. Tracking changes in these species is important to understand the extent to which their populations may grow within the sanctuary; further, changes in abundance of these species could also be an indicator of changing conditions in the sanctuary. Future monitoring should consider sampling locations (e.g., habitat types) and times that maximize the opportunity for early warning and appropriate response.

## What is the status of biodiversity and how is it changing?



**Status Description:** Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

**Rationale:** Biodiversity data were available for fish and invertebrates, but were limited for infauna and macroalgae, which are particularly important, as they are indicators for climate change. Metrics for observed species appeared to be stable; however, there is lack of information regarding species turnover, as well as for observed increases of tropical fishes.

Assessing biodiversity in marine protected areas can involve measures of community structure (e.g., richness, evenness), as well as measures of functional interactions among species within the community. These interactions may include trophic, competing, or symbiotic relationships.

### ***Findings From the 2012 Condition Report Addendum***

In 2012, the status of biodiversity was good and the trend was not changing. This rating was based on high diversity of sessile invertebrates, benthic infaunal invertebrate diversity and abundance, and algal abundance and diversity. Although some negative effects of fishing pressure on the fish community were suspected, experts considered biodiversity to be good overall.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include fish, benthic invertebrate, and algal biodiversity, as well as shifts in species distribution due to sea surface temperature.

### **Fish Biodiversity**

Long-term data on fish community structure at GRNMS were considered as an indicator of biodiversity. Data were collected by visual surveys during summer months, using two different transect methods to target mobile conspicuous and cryptic prey fishes (Muñoz et al., 2020). General patterns in fish community structure were consistent across years (Table S.LR.2). However, these data were mostly collected during summer months at GRNMS, and experts identified the lack of seasonal information as a data gap.

## Status and Trends of Sanctuary Resources

**Table S.LR.2.** The top five dominant conspicuous and prey fish species in transects at GRNMS. Species were classified as dominant based on a multivariate analysis of abundance and spatial distribution (permutational multivariate analysis of variance with similarity percentages). Source: Muñoz et al., 2019

Year	Category	Species 1	Species 2	Species 3	Species 4	Species 5
2011	Conspicuous	Black sea bass ( <i>Centropristis striata</i> )	Longspine porgy ( <i>Stenotomus caprinus</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )	Cubbyu ( <i>Pareques umbrosus</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Black sea bass ( <i>Centropristis striata</i> )	Painted wrasse ( <i>Halichoeres caudalis</i> )	Longspine porgy ( <i>Stenotomus caprinus</i> )
2013	Conspicuous	Black sea bass ( <i>Centropristis striata</i> )	Cubbyu ( <i>Pareques umbrosus</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Longspine porgy ( <i>Stenotomus caprinus</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Black sea bass ( <i>Centropristis striata</i> )	Seaweed blenny ( <i>Parablennius marmoreus</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )
2014	Conspicuous	Black sea bass ( <i>Centropristis striata</i> )	Longspine porgy ( <i>Stenotomus caprinus</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )	Cubbyu ( <i>Pareques umbrosus</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Black sea bass ( <i>Centropristis striata</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Painted wrasse ( <i>Halichoeres caudalis</i> )	Cubbyu ( <i>Pareques umbrosus</i> )
2016	Conspicuous	Tomtate ( <i>Haemulon aurolineatum</i> )	Black sea bass ( <i>Centropristis striata</i> )	Longspine porgy ( <i>Stenotomus caprinus</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Cubbyu ( <i>Pareques umbrosus</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Painted wrasse ( <i>Halichoeres caudalis</i> )	Black sea bass ( <i>Centropristis striata</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )
2017	Conspicuous	Tomtate ( <i>Haemulon aurolineatum</i> )	Black sea bass ( <i>Centropristis striata</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Scad complex ( <i>Decapturus</i> spp.)	Cubbyu ( <i>Pareques umbrosus</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Black sea bass ( <i>Centropristis striata</i> )	Tomtate ( <i>Haemulon aurolineatum</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Cubbyu ( <i>Pareques umbrosus</i> )

Year	Category	Species 1	Species 2	Species 3	Species 4	Species 5
2019	Conspicuous	Tomtate ( <i>Haemulon aurolineatum</i> )	Black sea bass ( <i>Centropristis striata</i> )	Cubbyu ( <i>Pareques umbrosus</i> )	Slippery dick ( <i>Halichoeres bivittatus</i> )	Painted wrasse ( <i>Halichoeres caudalis</i> )
	Prey	Slippery dick ( <i>Halichoeres bivittatus</i> )	Painted wrasse ( <i>Halichoeres caudalis</i> )	Black sea bass ( <i>Centropristis striata</i> )	Belted sandfish ( <i>Serranus subligarius</i> )	Cocoa damselfish ( <i>Stegastes xanthurus</i> )

Additionally, biomass of common predators at GRNMS fluctuated since 2011. Ledges that harbor large predators may provide suitable habitat for these species, so changes in the availability of habitat space associated with ledges (e.g., through sand movement following major storms or hurricanes) may alter large predator biomass (Muñoz et al., 2020).

While patterns of species abundance and distribution remain the foundation for understanding dynamics of biodiversity, patterns and dynamics of species interactions reveal important elements of community organization and emergent properties of biodiversity (Hagen et al., 2012). Piscivorous fish species at GRNMS exhibited consistent patterns of mixed-species hunting interactions, with the greatest rate of interactions at medium and tall ledges (Auster et al., 2013; Auster, 2020; Auster & Giacalone, 2021; Campanella et al., 2020). Midwater piscivores (e.g., Spanish mackerel, almaco jack) attack aggregations of prey fishes, driving them down to reefs and facilitating predation by demersal piscivores (e.g., black sea bass, red snapper, gag grouper). Such interactions, in general, appeared stable based on observations from 2009–2019 (P. Auster/University of Connecticut, personal communication, February 2, 2024).

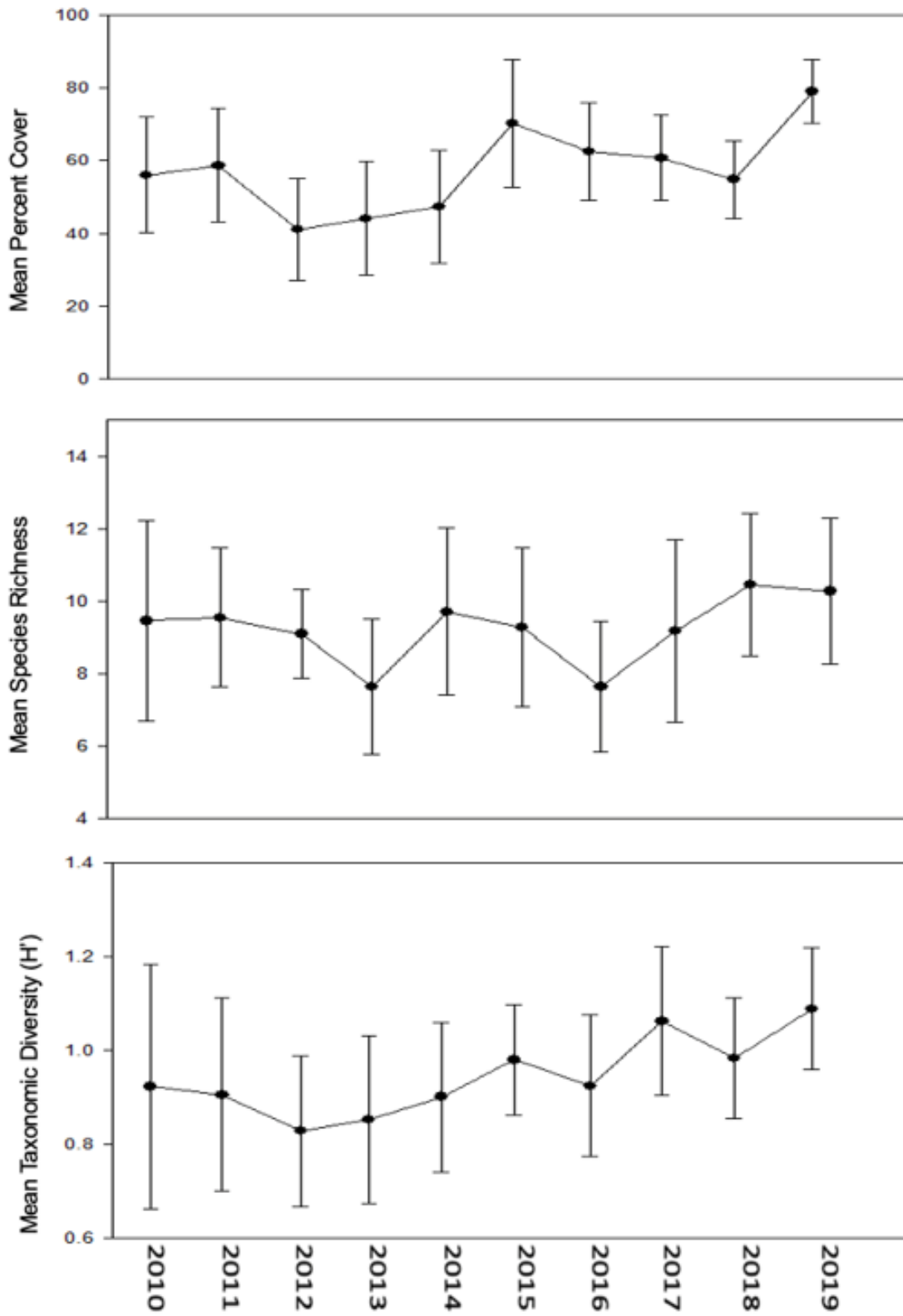


**Figure S.LR.9.** Fishes such as tomtate, slippery dicks and cocoa damselfish as well as sponges, algae and the hard coral *Oculina arbuscula* are just some of the species that make up the biodiversity of GRNMS. Photo: R. Muñoz/NOAA

## **Benthic Invertebrate and Macroalgae Diversity**

Benthic species, including macroalgae and sessile macroinvertebrates (e.g., sponges, corals, tunicates) provide a variety of ecological functions within the sanctuary. As described in the habitat integrity section of this report, macroalgae and macroinvertebrates play an integral role in habitat complexity and provide food resources and refuge for many organisms that inhabit the reefs. Different species serve different functional roles, therefore it is essential to understand diversity within these communities to detect any changes that may affect the overall function and/or health of GRNMS ecosystem.

Benthic invertebrate diversity, richness, and percent cover were monitored from 2010 to 2019 in permanent plots established on a single ledge within GRNMS. Annual monitoring of these plots showed no significant differences in these parameters over time, indicating a stable benthic invertebrate community (Daniel & Gleason, 2021; Figure S.LR.10). Further, recovery of the benthic invertebrate community after a disturbance was assessed from 2010 to 2019 by initially removing all of the organisms and then following their reestablishment over time. Results demonstrated recovery to the levels of taxonomic diversity and percent cover observed in unmanipulated plots within one year, whereas species richness was still lower in cleared versus unmanipulated plots 10 years later. Invertebrate species found to colonize the cleared plots included focal species, such as the sponges *Ircinia campana* and *I. felix*, the hard coral *Oculina arbuscula*, and the tunicates *Euherdmania gigantea* and *Symplegma* spp., which contribute to habitat integrity at GRNMS. Trend data were not available for benthic infaunal diversity for GRNMS in the present study period; however, sampling in 2000, 2005, and 2012–2013 suggested that benthic infaunal diversity was stable during those years (Balthis et al., 2015).



**Figure S.LR.10.** Benthic invertebrate mean percent cover, species richness, and taxonomic diversity (H') at GRNMS during summer monitoring, 2010–2019. Source: Daniel & Gleason, 2021



**Figure S.LR.11.** Diverse assemblages of macroalgae are important for primary production and habitat provision. Photo: K. Roberson/NOAA

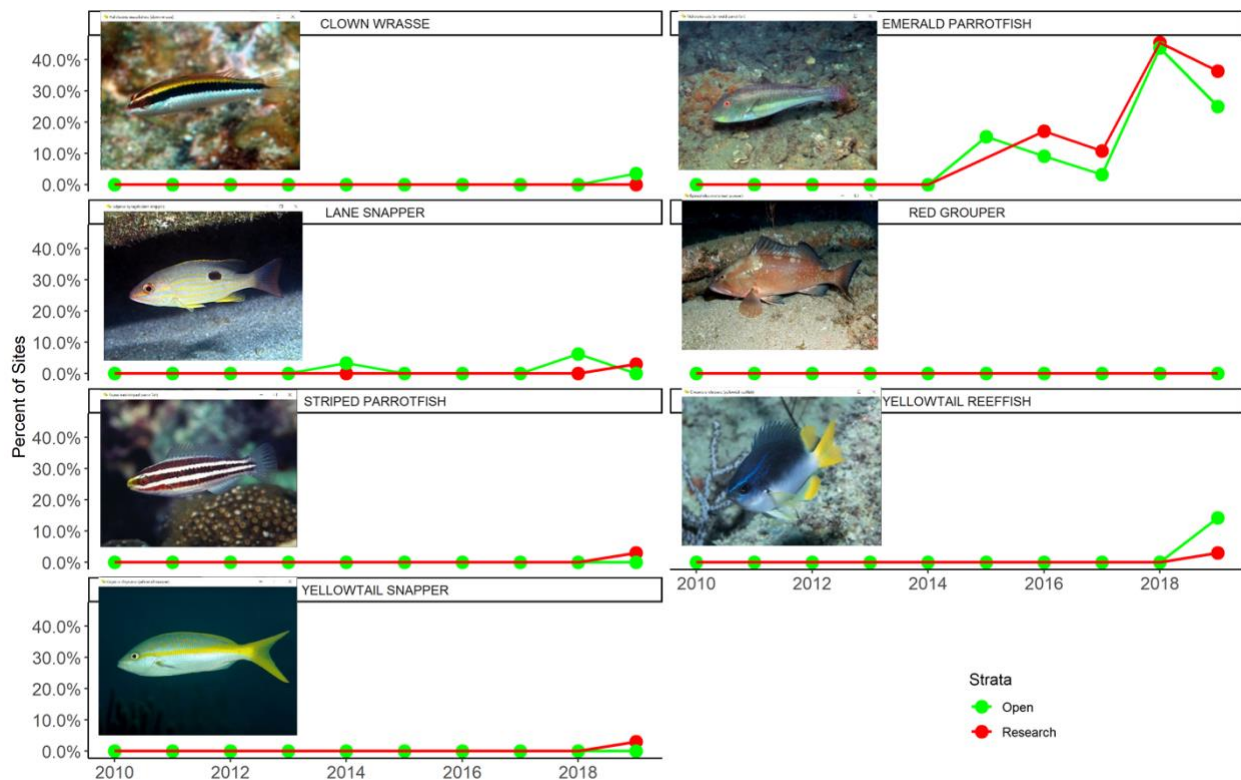
The most recent macroalgae data within the sanctuary boundaries consist of species inventory and collections since 2018 (Aumack & Cohen, 2021). As noted in the habitat integrity chapter, data gaps remain, including long-term assessments of macroalgal cover, height, richness, and other ecological metrics. However, based on available data, there appear to be no substantial changes in species richness between current studies (Aumack & Cohen, 2021) and earlier inventory studies (Goldberg & Heine, 2012; Searles, 1987). Most of the species present in these two earlier studies are still prevalent today; however, it is important to note that earlier studies also sampled both in the summer and winter months, whereas current data are only collected during the summer. Absence of multiple, seasonal data collections within the sanctuary was identified as a data gap by experts. Planning for long-term monitoring of the macrophyte community at GRNMS is currently underway.

Long-term monitoring efforts at various times throughout the year are important to not only understand seasonal variability of organisms but to increase chances of detecting changes in the biodiversity and distribution of those organisms related to stressors such as climate change.

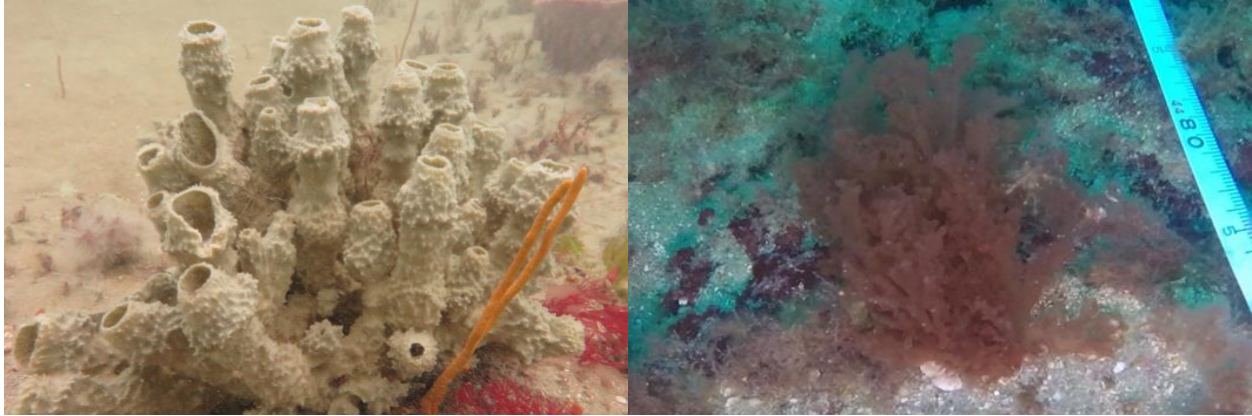
## Shifts in Species Distribution Related to Water Temperature

Surveys at GRNMS from 2010–2019 show that the tropical species may be becoming more abundant in the temperate GRNMS (Muñoz et al., 2021; Figure S.LR.12). These observations are consistent with observations of changes in fish assemblages elsewhere in the region (e.g., Fodrie et al., 2010). At GRNMS, the presence of emerald parrotfish (*Nicholsina usta*) has increased to about 17% of recent sites surveyed (R. Muñoz/NOAA, personal communication, March 22, 2023). Observations of most other species were documented in only 2018–2019, precluding a full understanding of trends for these species. Recent observations of the branching vase sponge *Callyspongia aculeata* and the red macroalgae *Platoma gelatinosum* in GRNMS may also be the result of range expansions (Figure S.LR.13). More information on climate-related changes to water quality can be found in the water quality section of this report.

Occurrence of tropical species may be related to mean winter seafloor temperatures, which show a marginally significant increasing trend from 2010 to 2019 (Noakes, 2022a; Muñoz et al., 2021; Figure S.WQ.10). While range shifts have been observed in tropical and temperate fish, knowledge of the full extent of shifts in species distributions and ranges is limited. Current data are only collected during the summer months; absence of multiple seasonal observations within the sanctuary was identified as a data gap by experts. Planning is currently underway at GRNMS for long-term monitoring of the fish community to include seasonality.



**Figure S.LR.12.** Percent of sites surveyed per year (2010–2019) where seven common tropical species have been documented. Some may be becoming more abundant at the warming, temperate GRNMS. Image: Muñoz et al., 2021



**Figure S.LR.13.** (a) The branching vase sponge *Callyspongia aculeata*, photographed in 2022 and (b) the red algae *Platoma gelatinosum*, photographed during a field survey in 2019. Photos: (a) Ben Prueitt/NOAA; (b) Sean Morton/NOAA

### **Conclusion**

Available data for fish, invertebrates, and algae suggest few apparent changes in biodiversity over time. However, a number of data gaps hindered full understanding of the overall biodiversity of the sanctuary. Data were limited for infauna and macroalgae diversity, and data on species turnover for major taxonomic groups were not available. Additionally, all available data were collected during the summer months only, and thus seasonal variability in these metrics is not understood. The unique location of GRNMS between tropical and temperate environmental oceanographic settings increases the potential for northward movement of tropical species, including fish, algae, invertebrates, and other organisms. While range shifts may be underway for some tropical and temperate fish, the full extent of shifts in species distributions and ranges, as well as their impact on the overall biodiversity of the sanctuary, are yet to be determined. Acoustic monitoring data could provide further insight into biodiversity at GRNMS (i.e., through assessment of the variety of biogenic sounds), but this represents an analysis gap for the present report.

## Status and Trends of Ecosystem Services

This section summarizes the status and trends of ecosystem services. Hybrid expert workshops were convened by GRNMS staff in March, 2023 (see Appendices B and C) to discuss ecosystem services. In general, the assessments of the status and trends of key indicators in GRNMS rely on information from 2008–2022. During the workshops, indicators for each topic were presented, accompanied by datasets ONMS compiled before the meeting. Attendees were asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest additional data sets that may be relevant. Once all data sets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the quantity and quality of information they used to make judgments; and (2) the group's agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence rating. Appendix C provides a detailed description of the methods used to develop this report.

The following responses for each question summarize the key indicators, supporting data sets, and rationale for each status and trend rating. Where published or additional information exists, the reader is provided with appropriate references. Workshop discussions and ratings were based on data available at the time (e.g., through 2022). However, in some instances, sanctuary staff later reevaluated and/or incorporated newly available data to more accurately describe the current status and trends of ecosystem services. Situations where post-workshop rating decisions were made and/or data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

For the purposes of this report, the term “study period” refers to the period from 2008–2022. The data sets presented in this report may or may not span the entirety of the study period, depending on data availability. When necessary, data from a subset of years may have been used to support status and trend determinations for the entirety of the study period.

### ***Ecosystem Services: A Brief Introduction***

Ecosystem services are the benefits that humans receive from natural and cultural resources. Generally, the taxonomy of the Millennium Ecosystem Assessment (2005) is used in ONMS condition reports. That assessment was an initiative of the United Nations to assess ecosystem services, including cultural, provisioning, regulating, and supporting services. The categories of ecosystem services in the United Nations report include “final” services, which are directly valued by people, and “intermediate” services, which are ecological functions that support final services (Boyd & Banzhaf, 2007). In ONMS condition reports, only final ecosystem services are rated, which is consistent with the anthropogenic focus of the reports and highlights priority management successes and challenges in sanctuaries. The complete definitions of ecosystem services considered by ONMS are included in Appendix B.

### Intermediate and Final Ecosystem Services

There are two categories of ecosystem services: intermediate and final. Ecosystem services that are evaluated in condition reports are final ecosystem services. Intermediate services support other ecosystem services, whereas a good/service must be directly enjoyed by a person to be considered a final ecosystem service. For example, nutrient balance leads to clearer water and higher visibility for snorkeling and scuba diving. Nutrient balance is an intermediate service that supports the final ecosystem service of non-consumptive recreation via snorkeling and scuba diving.

### Ecosystem Services That May Be Considered in ONMS Condition Reports

#### *Provisioning* (material benefits)

1. Commercial harvest — The capacity to support commercial market demand for seafood products
2. Subsistence harvest — The capacity to support non-commercial demand for food and utilitarian products
3. Drinking water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash
4. Ornaments — Resources collected for decorative, aesthetic, or ceremonial purposes
5. Biotechnology — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use
6. Renewable energy — Use of ecosystem-derived materials or processes for the production of energy

#### *Cultural* (non-material benefits)

7. Consumptive recreation — Recreational activities that result in the removal of or harm to natural or cultural resources
8. Non-consumptive recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources
9. Science — The capacity to acquire and contribute information and knowledge
10. Education — The capacity to acquire and provide intellectual enrichment
11. Heritage — Recognition of historical and heritage legacy and cultural practices
12. Sense of Place — Aesthetic attraction, spiritual significance, and location identity

#### *Regulating* (buffers to change)

13. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Notably, some consider consumptive recreational fishing as a provisioning service, but it is included here as a cultural ecosystem service. Also, even though biodiversity was listed as an ecosystem service by the Millennium Ecosystem Assessment (2005), ONMS decided to remove it, recognizing that biodiversity is an attribute of the ecosystem on which many final ecosystem services depend (e.g., recreation, harvest); therefore, it is addressed in the Status and Trends of Sanctuary Resources chapter of this report. Lastly, although ONMS listed climate stability as an ecosystem service in 2015, it is no longer considered an ecosystem service in ONMS condition

reports because national marine sanctuaries are not large enough to influence climate stability on a large scale (Fisher & Turner, 2008; Fisher et al., 2009).

For GRNMS, six of the 13 final ecosystem services were considered relevant to the sanctuary and were therefore rated: consumptive recreation, non-consumptive recreation, science, education, heritage, and sense of place. The other seven ecosystem services were evaluated by staff, but were determined to not be applicable to the site.

### ***Ecosystem Services Indicators***

The status and trends of ecosystem services are best evaluated using a combination of three types of indicators: economic, non-economic, and resource. Economic indicators may be quantified through direct measures of use (e.g., person-days of recreation, catch levels) that result in spending, income, jobs, gross regional product, and tax revenues, or by non-market economic valuation (the difference between what people pay to use a good/service and what they would be willing to pay). Non-economic indicators can be used to complement economic indicators and include evaluation of the importance and satisfaction levels of users in relation to natural and cultural resources, facilities and services for recreation uses, limits of acceptable change for resource conditions, social values and preferences (measured by polls), social vulnerability indicators, perceptions of resource conditions in the present and expectations for the future, and access to resources. Finally, resource indicators are considered in determining status and trend ratings for each ecosystem service. Resource indicators are used to determine if current levels of use are sustainable or are causing resource degradation. If resources cannot support current levels of use, it may be necessary to downgrade a rating that may otherwise be higher based on economic and non-economic indicators alone. Together, these three types of indicators are considered when assessing the status and trends of ecosystem services in national marine sanctuaries.

## Science

### The capacity to acquire and contribute information and knowledge



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** GRNMS has supported scientific activities throughout the study period and is a valued site for scientific research in the South Atlantic region. Research activity, publications, and public support for research remained consistent throughout the study period; however, some limitations on vessel availability may have affected the overall capacity for science during the study period.<sup>17</sup>

### *New Information in the 2008–2022 Condition Report*

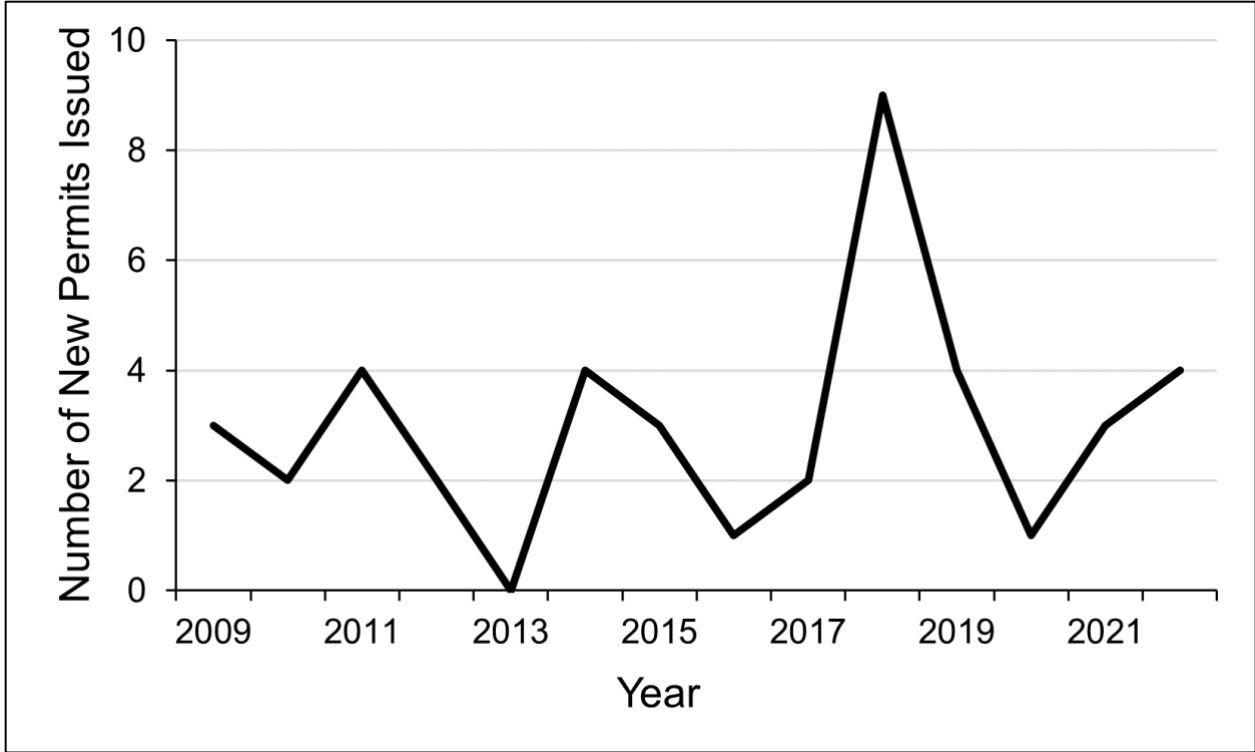
Indicators considered in the present report include research activity (number of permits, number of active projects, and dive hours), vessel time, volunteer hours, science publications, and level of public support for research.

### Research Activity

Given its unique biodiversity, GRNMS is a hub for scientific research. In 2011, a Research Area was designated to enhance scientists' ability to distinguish between natural and human-induced changes to species, communities, and habitats (Roberson et al., 2020). The ability to conduct investigations in a marine environment relatively free from direct human influences is critical for meeting GRNMS research and resource protection goals, and has also made the sanctuary an attractive site for studies by scientific partners. Researchers who have worked at GRNMS were surveyed in 2023 to better understand their reasons for choosing to conduct research in the sanctuary (Botta et al., 2024). Results showed that the top factors for selecting GRNMS as a research site were: (1) its status as a national marine sanctuary, (2) a specific request from GRNMS or another resource management agency, (3) the biodiversity/productivity of the area, (4) dive support, and (5) vessel availability. Subject matter experts at the status and trend workshop noted that GRNMS is an ecosystem well suited for both applied and basic science.

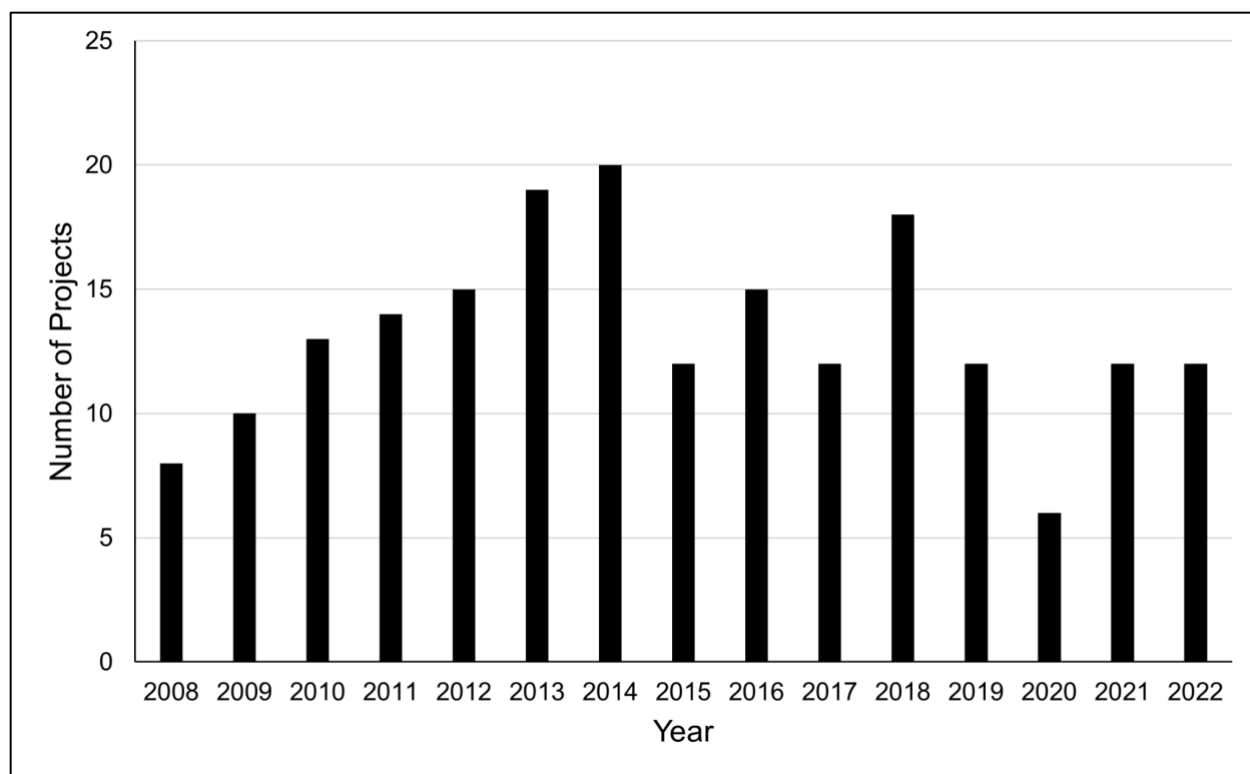
Research activity was assessed using a variety of metrics, including the number of research permits issued during the study period. A total of 42 permits were issued to 24 researchers from 2009 to 2022. Of these researchers, 58% obtained more than one permit (either via renewals or new applications). There was no statistically significant trend in the number of permits issued over time throughout the study period (Figure ES.S.1).

<sup>17</sup> Due to time constraints, a trend rating and associated confidence score for this question were not determined during the expert workshop. This trend rating and associated confidence score were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.



**Figure ES.S.1.** The number of new research permits issued for GRNMS, 2009–2022.

Importantly, not all research activities require permits; thus, the number of permits issued may not provide a complete picture of all research activity during the study period. Internal GRNMS data and expedition logs provided a fuller understanding of the number of research projects underway annually during the study period (Figure ES.S.2). Throughout the study period, research projects involved 47 unique partners, and there were an average of 14 projects underway in a given year. Project topics included, but were not limited to, benthic and fish assessments, animal movement, sound monitoring, habitat mapping, ocean acidification and algal abundance and distribution. There was no statistically significant trend in the number of active projects per year during the study period. However, research activity at GRNMS tends to vary seasonally, peaking in summer months.



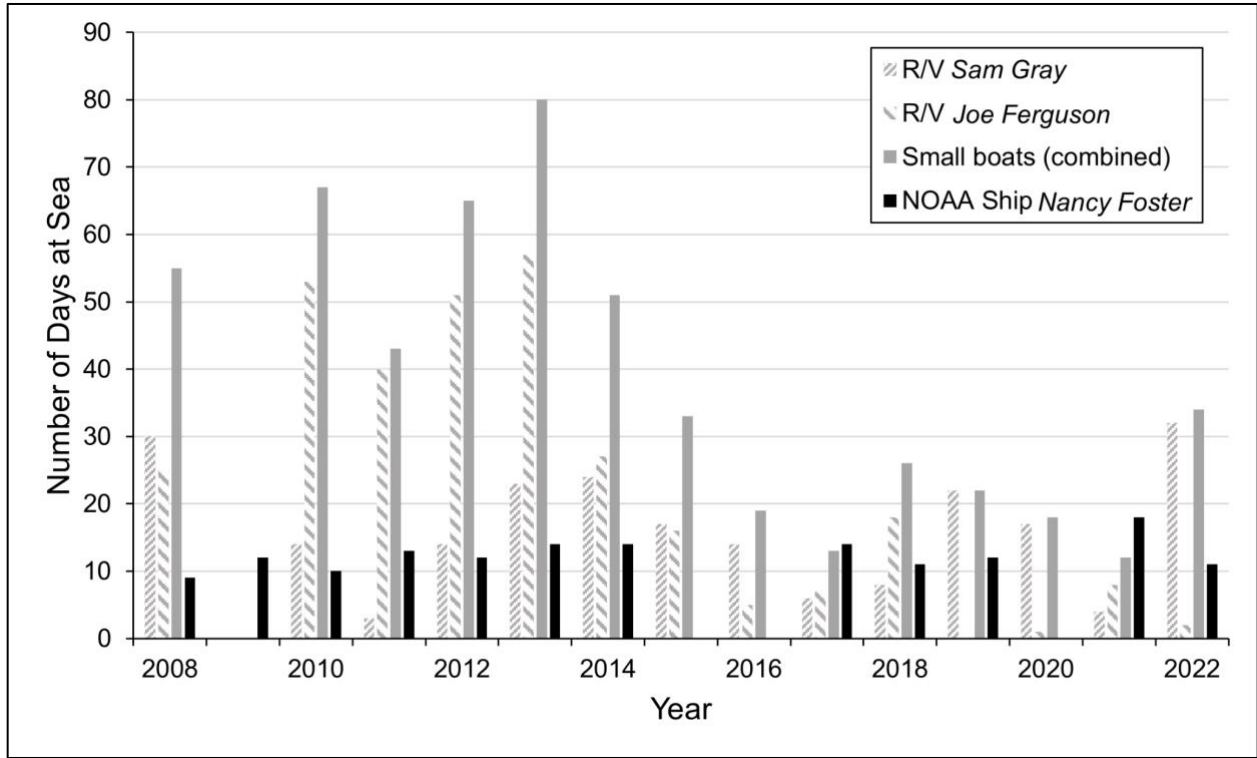
**Figure ES.S.2.** The number of active research projects at GRNMS from 2008 to 2022. Multi-year projects were counted in each year they occurred.

In addition to activities carried out by external partner researchers, internal research activities are carried out annually by GRNMS staff. From 2013 to 2019, GRNMS staff logged between 102 and 270 dive hours per year. In 2020, only one dive hour was logged as a result of the COVID-19 pandemic. Dive hours increased to 97 in 2021 and 210 in 2022, suggesting dive activity recovered to normal levels. With the exception of the sharp drop in dive activity due to the COVID-19 pandemic, there was no apparent temporal trend in dive activity.

### Vessel Time

Another important indicator of trends in science activities is the number of days spent at sea aboard research vessels. From 2008 to 2022, GRNMS operated two small vessels for research purposes: R/V *Sam Gray* (36 feet) and R/V *Joe Ferguson* (41 feet). In addition, GRNMS engaged in research aboard larger NOAA ships, primarily *Nancy Foster*. Figure ES.S.3 illustrates the number of days at sea aboard each of these vessels. Days at sea include all operational days, the majority of which directly support scientific research. There was no statistically significant trend in days at sea throughout the study period for *Sam Gray* or *Nancy Foster*. Days at sea aboard *Joe Ferguson* declined from 2013 to 2022 due to vessel maintenance issues, reduced budgets for vessel operations, and preparation for its decommissioning. Note that the last year *Joe Ferguson* was used to support science operations was 2018; days at sea in subsequent years represent operations associated with repairs. Additionally, from 2020–2022, GRNMS contracted private vessels and crews to conduct scientific instrument maintenance during the COVID-19 pandemic. Overall vessel availability, as well as funds for personnel to maintain and staff vessels, reduced the capacity for research in the sanctuary and may be

insufficient to fully meet GRNMS science goals. Although outside the study period for this report, GRNMS received a new research vessel in 2024, which may alleviate some concerns regarding vessel availability in the future.



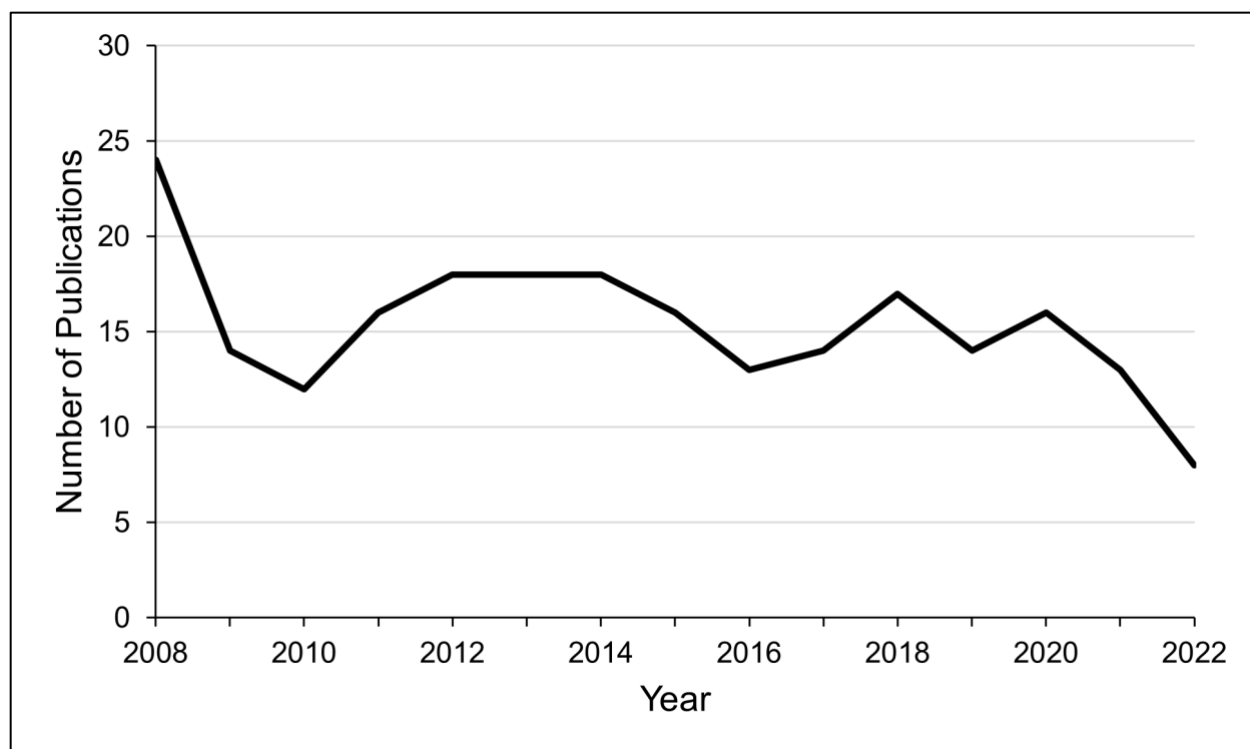
**Figure ES.S.3.** Days at sea within GRNMS for small boats R/V *Sam Gray* and R/V *Joe Ferguson*, as well as the NOAA ship *Nancy Foster*, 2008 to 2022. Small boats (combined) is the sum of days at sea aboard *Sam Gray* and *Joe Ferguson*. There was a gap in data availability for small boat days at sea in 2009. NOAA ship expeditions occurred in 2015 and 2016, but on vessels other than *Nancy Foster*. No NOAA ship expedition occurred in 2020 due to the COVID-19 pandemic.

### Volunteer Hours

Volunteers regularly support the execution of GRNMS science projects. Volunteer hours were assessed to understand the level of volunteer support for GRNMS science and operations during the study period. Hours varied without trend from 2013 to 2022, peaking at 1,022 hours in 2018. Although there was no trend for the entirety of the study period, volunteer hours were relatively low from 2020–2022 as a result of the COVID-19 pandemic.

### Science Publications

Information about scientific research in GRNMS is regularly communicated via peer-reviewed scientific publications and public-facing news outlets. Figure ES.S.4 illustrates the number of peer-reviewed publications focused on GRNMS published annually during the study period. There was no statistically significant temporal trend in the annual number of peer reviewed publications. Press articles featuring GRNMS ranged from 58 to 409 per year, and also varied without trend from 2008 to 2022.



**Figure ES.S.4.** Peer-reviewed scientific publications focused on GRNMS, 2008–2022. Source: Google Scholar

### Public Support for Research

In 2020, recreational anglers in Georgia, including those who did and did not fish within GRNMS (i.e., users and non-users), were surveyed regarding their attitudes toward and perceptions of the sanctuary (Samonte et al., 2023). About two-thirds of GRNMS users and three-quarters of non-users placed either high or extremely high value on the sanctuary’s ability to support scientific research. This level of support for scientific research at GRNMS did not statistically differ from a previous survey in 2010, suggesting no change in opinion during the study period.

### Conclusion

Although impacts from the COVID-19 pandemic are apparent across numerous indicators, nearly all metrics considered remained consistent throughout the study period, and the ability of GRNMS to support science was judged to be acceptable. Experts noted that GRNMS is a valuable location for conducting scientific research; however, some factors, particularly vessel availability, may limit the sanctuary’s capacity to support science activities. Further, key gaps in information were identified; these affected expert confidence in the status rating for this ecosystem service. Specifically, experts noted a need to assess (1) whether the science activities conducted during the study period successfully achieved science and management needs and (2) levels of internal and external funding for science activities during the study period. While outside the scope of this report, these are key areas for future study.

## Education

### The capacity to acquire and provide intellectual enrichment



**Status Description:** The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

**Rationale:** Staffing limitations hindered the ability of GRNMS to provide some education programming and community events during the study period; however, external partnerships and volunteers aided in filling this gap. Virtual engagement via the GRNMS website and social media generally remained stable, and a website redesign in early 2023 increased site traffic. Exhibits at partner institutions provided key opportunities to learn about the sanctuary, and interactive kiosks helped increase engagement. The dedication of the Gray’s Reef Ocean Discovery Center in 2022 was an important step toward increasing site capacity for education and outreach.

### *New Information in the 2008–2022 Condition Report*

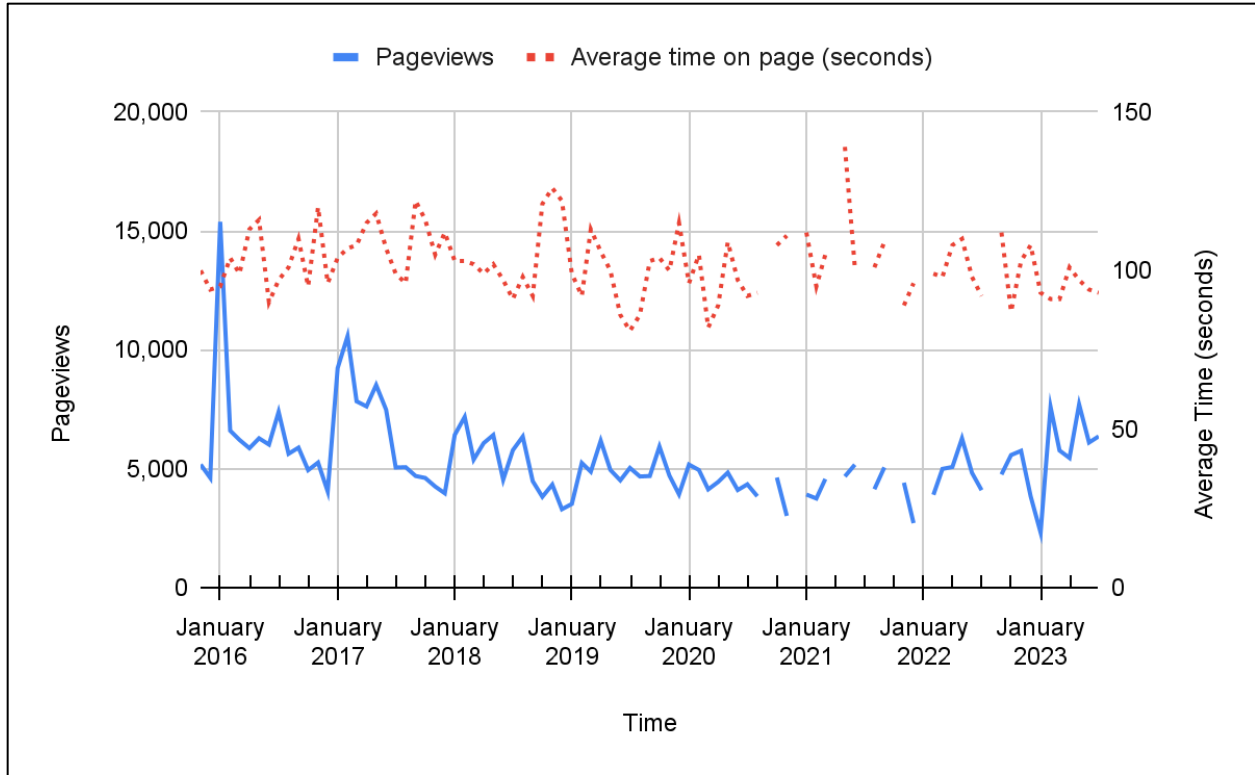
Indicators considered in the present report include virtual engagement via the sanctuary website and social media; visitation to exhibits at partner institutions and use of interactive touchscreen kiosks; community outreach events; K–12 education programs; and other metrics, including investment in education and volunteer engagement.

### Virtual Engagement

Mobile technology and social media have changed how people access information and learn about and interact with natural spaces. Virtual access to information is particularly important for a remote location like GRNMS, where comparatively few people will ever visit. Google Analytics, Meta Business Suite, and Twitter Analytics were used to assess GRNMS website visitation and social media engagement from November 2015 to December 2022. Metrics on the number of users that interacted with sanctuary content and the degree to which they engaged can aid in understanding how enrichment was received.

### Website

Visits to the GRNMS website (GRNMS, 2024) declined slightly, and seconds per page visit remained steady from November 2015 to December 2022 (Figure ES.E.1). The highest number of monthly pageviews occurred in January 2016 and January 2017, coinciding with the Gray’s Reef Ocean Film Festival. Throughout this seven year period, the website’s layout remained the same as the original structure and design of 2010. In January 2023, the GRNMS website was updated with a mobile-friendly design and reduced number of pages with more succinct content. In the six months since the rollout of the new web design, pageviews increased 23% compared to the previous three years.



**Figure ES.E.1.** Monthly GRNMS website data from November 2015 to July 2023. Pageviews are defined as the total number of website views per month (pageviews may include repeat visits from the same user). Average time is defined as the amount of time a user visits a page before clicking to another page. Suspected bot outliers were removed on seven occasions starting in September 2020 to avoid skewing data. A given month was determined to be affected by bots when page visits and average time were orders of magnitude higher and shorter, respectively, compared to the average values from November 2015 to July 2023. Source: Google, 2023

The GRNMS website hosts educational lesson plans and materials for teachers. Google Analytics for the subpages hosting these resources showed a similar trend of declining site-wide visitation over the measurable seven-year period.

### **Social Media**

GRNMS maintains accounts on two social media platforms: Facebook.com and Twitter.com (rebranded as “X” after the study period for this condition report). Each account is used regularly to share photos and videos, information from the website, or upcoming events in which the public can engage. Meta Business Suite and Twitter Analytics provide monthly data about new followers and engagement rates, which measure how many accounts viewed a particular post. On Facebook, there was no distinguishable trend in usage based on new followers per month or engagement rates from November 2015 through December 2022. On Twitter, there was a decline in new followers per month from December 2019 through December 2022. During this period, impressions per tweet, which measure how many accounts saw a particular post/tweet, became more variable.

Over the years, both Facebook and Twitter have changed how they define engagement, changed how analytics are reported to page administrators, and purged automated bot accounts. For

example, between November 2021 and June 2022, Facebook page “likes” were rounded to the next highest thousand, reducing resolution (e.g., page likes reported as 5,363 in October 2021 were displayed for the page administrator as 6,000 in the following eight months).

### **Exhibits**

GRNMS works with partners across the southeast U.S. to host sanctuary-specific exhibits in museums, aquaria, or visitor centers. These exhibits are a key strategy for sharing sanctuary messaging with larger audiences, particularly given limited education program staff capacity. All exhibits included static text and photos about GRNMS and select locations included touchscreen computer kiosks, which have reached over 120,000 people since 2013. Two types of computer kiosks were used across the report period: NOAA-provided kiosks, which collected data from 2013–2018, and Hamline University Center for Global Environmental Education kiosks (also known as Ocean Media Gallery), which collected data from 2021–present. For locations without a touchscreen kiosk, annual attendance was used to estimate Gray’s Reef exhibit visitation.

### ***Partner Institution Attendance***

Annual attendance at partner institutions with GRNMS exhibits ranged from 32,000 (Georgia Southern University History Museum in Statesboro, Georgia) to over 1,100,000 (Savannah Visitor Center in Savannah, Georgia) from 2014 to 2022. Education and outreach efforts by GRNMS do not directly relate to attendance, but it may be inferred that guests learned about GRNMS through the exhibits as part of their general admission. A long-standing, prominent sanctuary exhibit with well-tracked visitation data is located at the University of Georgia Marine Education Center and Aquarium on Skidaway Island, Georgia. Center visitation rose steadily from 17,113 to 26,903 from 2014 through 2023, except for limited attendance in 2020 and 2021 due to the COVID-19 pandemic.

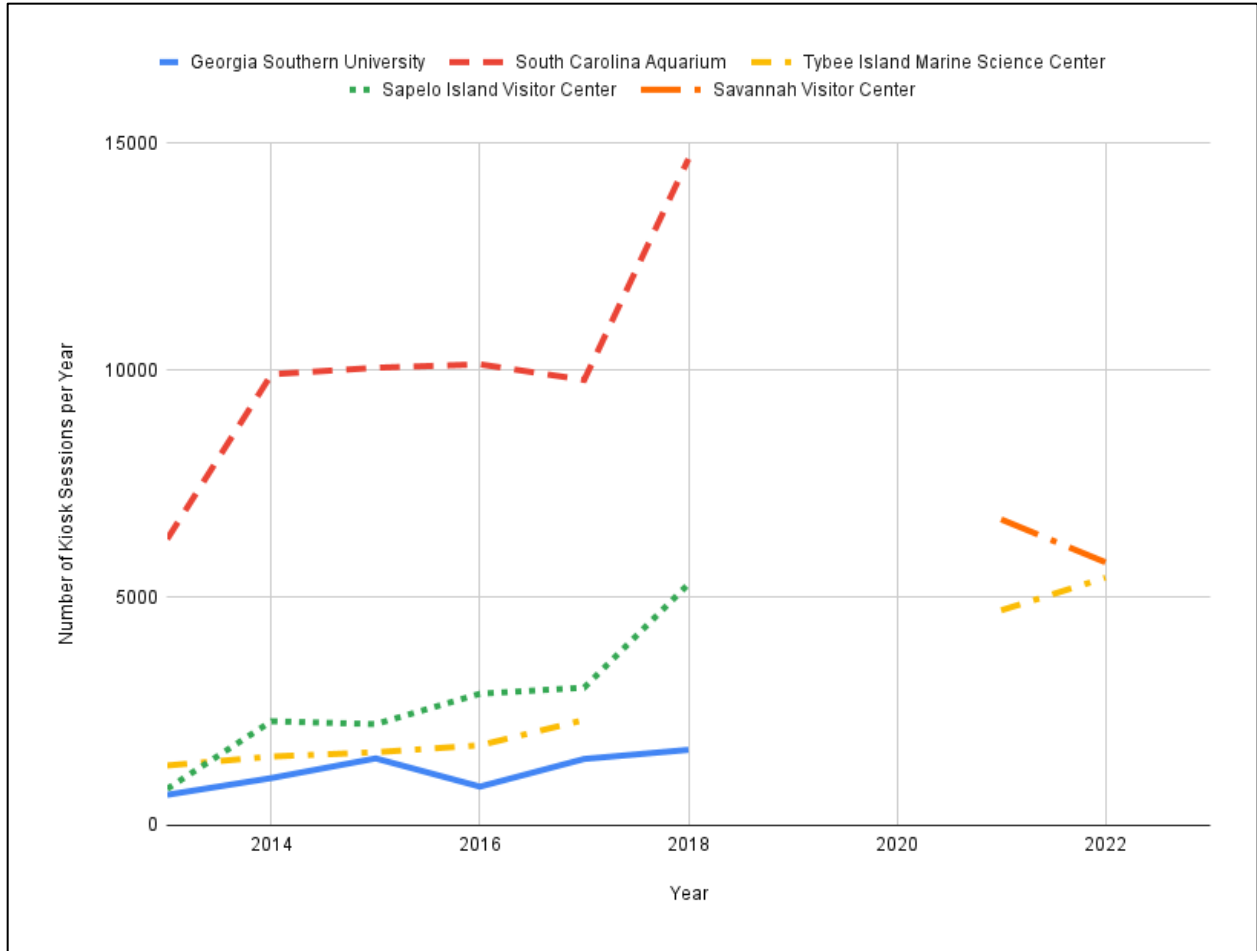
### ***Touchscreen Kiosks***

NOAA-provided kiosks operated from 2013–2018. While some of these kiosks remain operational, data reporting ended in 2018 and the kiosks are approaching the end of their computer hardware life. In 2020, GRNMS established a new partnership with Hamline University’s Center for Global Environmental Education to develop new interactive kiosks (Figure ES.E.2). Both kiosk models reported metrics of user engagement, including number of sessions per day, time per session, and types of content accessed. Because the two types of kiosks collected these data slightly differently, only the number of sessions and time per session were comparable for the purposes of this report.



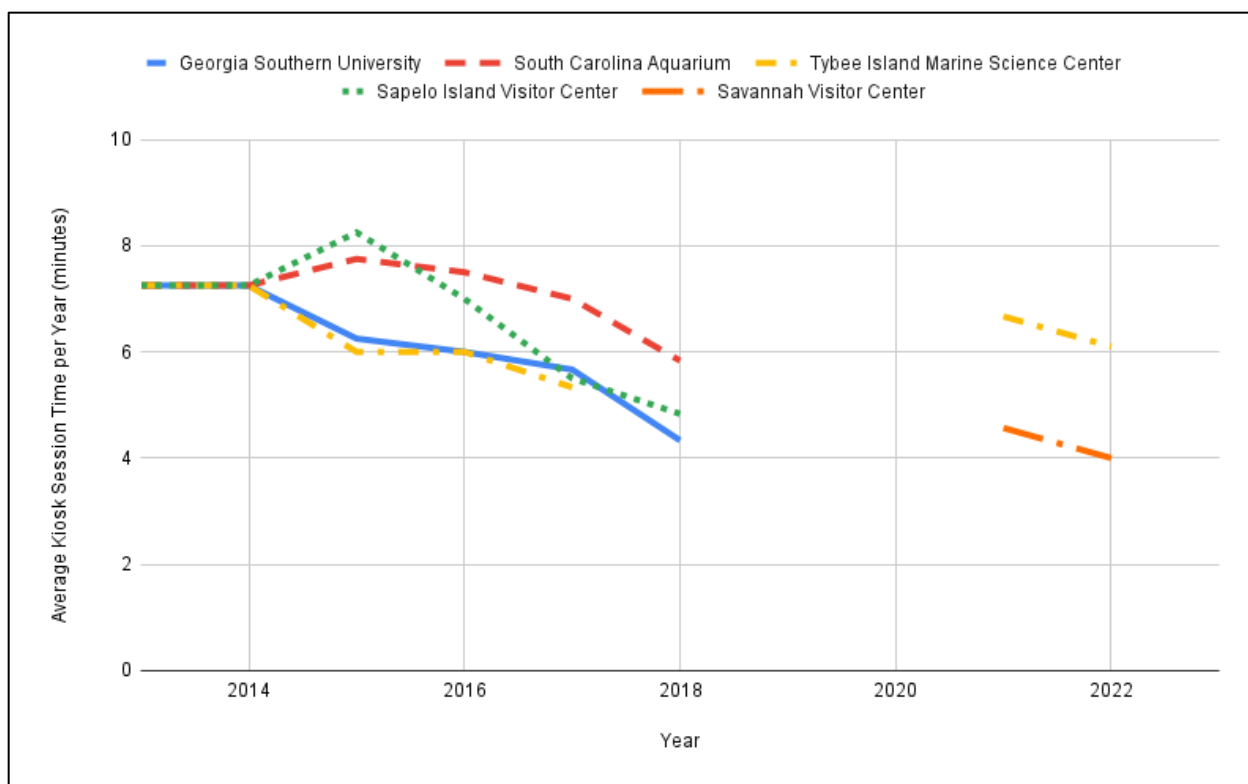
**Figure ES.E.2.** Examples of the touchscreen kiosks used to share information about GRNMS: A NOAA-provided kiosk (left) and an Ocean Media Gallery kiosk (right). Images: NOAA

Kiosk usage ranged from an annual average of 1,181 (Georgia Southern University Museum in Statesboro, Georgia, 2013–2018) to 10,133 (South Carolina Aquarium in Charleston, South Carolina, 2013–2018). Kiosk placement and partner institution popularity were key factors driving overall usage but no trend was available due to insufficient data. Higher-resolution data collected by the Ocean Media Gallery kiosks (Tybee Island Marine Science Center and the Savannah Visitor Center) showed seasonal variation across two years of available data, with a greater number of kiosk sessions but less time per session during peak tourist visitation in summer.



**Figure ES.E.3.** Number of kiosk sessions per year. Data from 2013–2018 are from four NOAA kiosks. Data from 2021–2022 are from two Ocean Media Gallery kiosks. Source: NOAA, 2018; Hamline University Center for Global Environmental Education, 2023

The amount of time each user spent interacting with a kiosk in a given session was also analyzed. From 2013–2018, NOAA kiosk session time declined approximately 30% (Figure ES.E.4). From 2021–2022, Ocean Media Gallery session time declined approximately 10%. Comparing session times across kiosk types is not a trustworthy analysis because the session time out feature varied in duration. For example, the NOAA kiosk would end a user session after 90 seconds of inactivity, and the Ocean Media Gallery kiosk would end a user session after 45 seconds of inactivity.



**Figure ES.E.4.** Average annual kiosk session duration at five locations. Data from 2013–2018 are from four NOAA kiosks. Data from 2021–2022 are from two Ocean Media Gallery kiosks. Session time was not collected using the same methods across kiosk type. Source: NOAA, 2018; Hamline University Center for Global Environmental Education, 2023

## Community Outreach Events

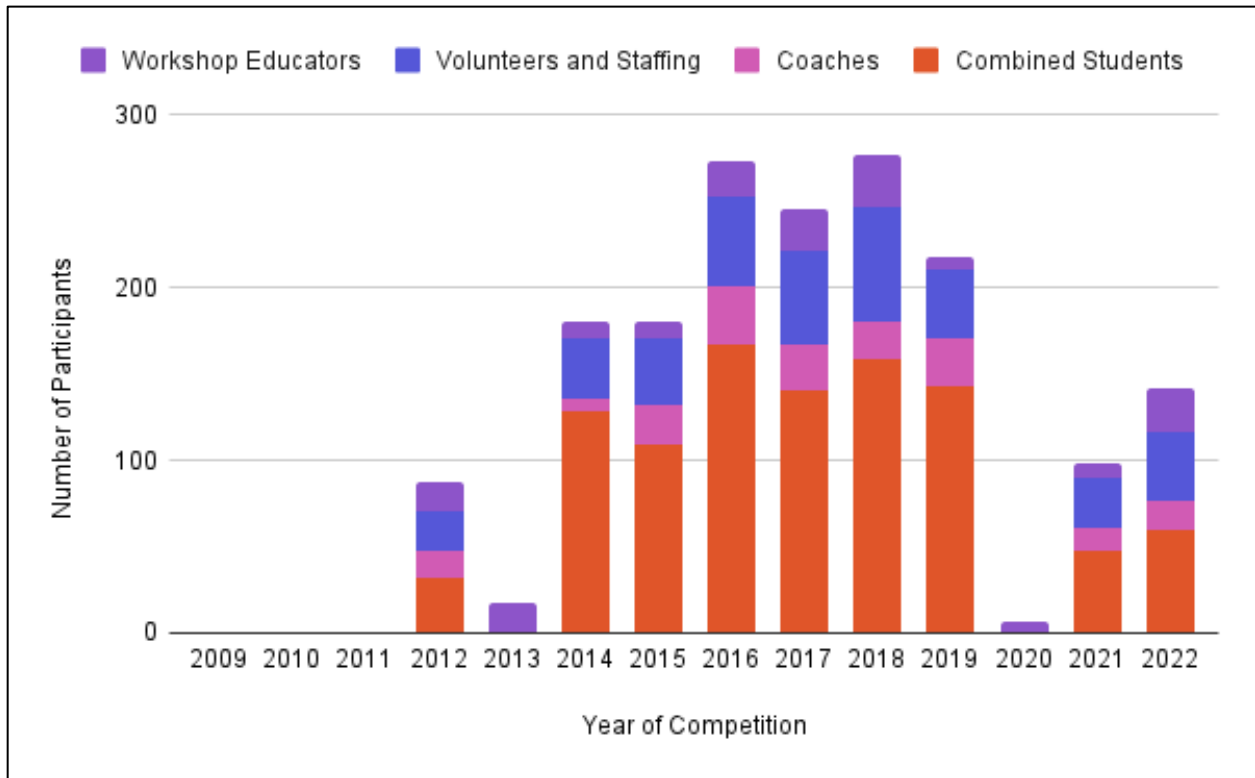
GRNMS engaged in three types of community outreach events:

- *GRNMS-sponsored public programs* are those planned, organized, and operated by GRNMS staff. Examples include the Gray’s Reef Ocean Film Festival and annual Marine Advanced Technology Education (MATE) Remotely Operated Vehicle (ROV) Competition.
- *Partner events* are those organized by other groups, for which GRNMS was invited to be an exhibitor or vendor. Examples include Skidaway Marine Science Day, Earth Day Savannah, and the Georgia Department of Natural Resources CoastFest.
- *Public speaking engagements* are occasions when GRNMS staff or volunteers present on sanctuary topics to a small audience. These have historically been in-person events, however virtual opportunities have become more common since 2020.

Prior to 2008 (the beginning of the condition report study period) through 2018, GRNMS education and outreach staff hosted annual community events, the primary examples being the Gray’s Reef Ocean Film Festival and the MATE ROV Competition. These events regularly attracted hundreds of visitors to engage and learn about the sanctuary. Data on participation and other metrics for these events was inconsistent throughout the condition report study period, with data gaps from 2008–2014.

In 2018, GRNMS utilized its partnership with the Gray’s Reef National Marine Sanctuary Foundation to increase the number of events where sanctuary messages could be presented to community partners. After 2018, partner-led events and speaking engagements became the dominant way GRNMS engaged with the public. Partner-led events ranged in attendance from several hundred to over 500,000 (Savannah St. Patrick’s Day parade float). Speaking engagement audience sizes are often measured in the dozens.

The longest continuous event for the sanctuary is the MATE ROV regional competition. Since 2004, GRNMS and the Gray’s Reef National Marine Sanctuary Foundation have sponsored this underwater robotics competition encouraging student teams (grades 5–12) and teachers to build their own underwater ROV, design and present technical posters, and sponsor teacher workshops to incorporate hands-on learning in their classrooms. Data on the number of students, coaches, and volunteers that supported the annual competition and associated workshops were available for 2012–2022 (Figure ES.E.5).



**Figure ES.E.5.** Annual MATE ROV Competition participation. The competition includes annual workshops conducted by GRNMS staff and Gray’s Reef National Marine Sanctuary Foundation staff. Competition participation data were not available for 2013. The organization of the competition was transferred to the Gray’s Reef National Marine Sanctuary Foundation beginning in 2019. No competition was held in 2020 due to the COVID-19 pandemic. Source: Gray’s Reef National Marine Sanctuary Foundation, 2023

## **K–12 Education**

GRNMS has not had an education coordinator on staff since 2016. From 2016 to 2018, outreach and communications staff led some limited K–12 education activities. From 2018 to 2022, K–12 education programs were primarily led by the Gray’s Reef National Marine Sanctuary Foundation, with minimal support from GRNMS staff. Examples of these education efforts include the annual Rivers To Reefs educator workshop and MATE ROV Competition, which have operated as both sanctuary-led and foundation-led activities. In 2022, GRNMS opened its first visitor center and resumed K–12 education programming (discussed in detail below). Metrics such as qualitative assessments of workshops and programs represent a data gap for the condition report study period.

The largest audience for a K–12 education program during the study period was for the 2017 Live Exploration of Gray’s Reef event. An estimated 45,000 students from across the state of Georgia attended the virtual field trip (Georgia Public Broadcasting, 2017). In partnership with Georgia Public Broadcasting, GRNMS staff and partner researchers guided Georgia classrooms on a 30-minute virtual field trip of the reef, teaching students about the animals that call the sanctuary home, how the seafloor serves as a habitat, and ways they can help protect the reef from major threats. The event included supplemental classroom resources and an extended Q & A session with the GRNMS hosts.

## **Other Indicators**

### ***Investment In Education***

External partnerships, education staffing, student internships and fellowships, and program budgets factor into how GRNMS defines its investment in education programs. GRNMS has consistently invested in the development of external partnerships, increasing its number of educational partners from two in 2015 to five after 2020. From 2016 to 2022, there was an annual average of 0.3 full-time employees dedicated to education. Budget variability and staffing limitations restricted sanctuary-related education in the community during the condition report study period. The 2022 dedication of the Gray’s Reef Ocean Discovery Center, a brick and mortar visitor center in downtown Savannah, Georgia that was years in development, as well as a firm management commitment to hire a full-time education coordinator and a full-time education specialist, represented key steps forward and renewed dedication to education and outreach for GRNMS.

### ***Volunteer Engagement***

Volunteers have been and continue to be an essential part of the GRNMS mission and program, particularly given limited education and outreach staffing during the study period. Volunteers support GRNMS primarily in education and outreach, and also in scientific research, resource protection, administration, and vessel operations. Most volunteers support one particular project. Volunteers contributed 13,016 hours toward GRNMS projects from 2013–2022. These hours equate to an in-kind benefit of \$374,410 (2022 USD) to GRNMS as assessed by the Independent Sector Estimate of the Value of Volunteer Time (Independent Sector, 2023). Volunteer time does not include hours for non-GRNMS events such as the MATE ROV Competition post-2018. Volunteer hours steadily increased from 2014–2018 and declined

significantly from 2019–2022. The decline in hours stemmed from the departure of the GRNMS volunteer coordinator in 2019 and engagement restrictions due to the COVID-19 pandemic beginning in 2020.

### ***Conclusion***

Education and outreach related to GRNMS relied heavily on virtual engagement, exhibits, and public events during the condition report study period; however, gaps in data prior to 2014 were present for virtually all metrics. Available data showed that engagement with the GRNMS website remained steady during the reporting period, and increased following a redesign in early 2023. Social media engagement was variable but generally stable, with the exception of a decrease in new Twitter followers. Tens of thousands to over a million people had the opportunity to view GRNMS exhibits at a variety of partner institutions, and touchscreen kiosks provided new opportunities to engage. While a shift in kiosk technology resulted in some data gaps, in general, the number of kiosk sessions increased over time, while the time per session decreased. Continued data collection will aid in understanding trends in kiosk use. Staffing limitations and shifts in site priorities affected the ability of GRNMS to lead community outreach events and K-12 programming; however, new partnerships and volunteers aided in filling this gap.

## Heritage

### Recognition of historical and heritage legacy and cultural practices



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** Recent research has improved the understanding of past human connections and demonstrated that the region that is now GRNMS was used by prehistoric cultures. In recent history, GRNMS has developed a legacy as an important site for scientific research. Coastal Georgia and GRNMS have strong heritage connections to fishing, documented in recent years through development of extensive oral history archives. Gullah/Geechee cultural ties to fishing, ocean use, and scientific discoveries at GRNMS have also been documented through oral histories. While knowledge and understanding of heritage connections to GRNMS and surrounding waters have increased, more information is needed, particularly to understand the connections between the sanctuary and Indigenous peoples, both in the past and today.

#### ***New Information in the 2008–2022 Condition Report***

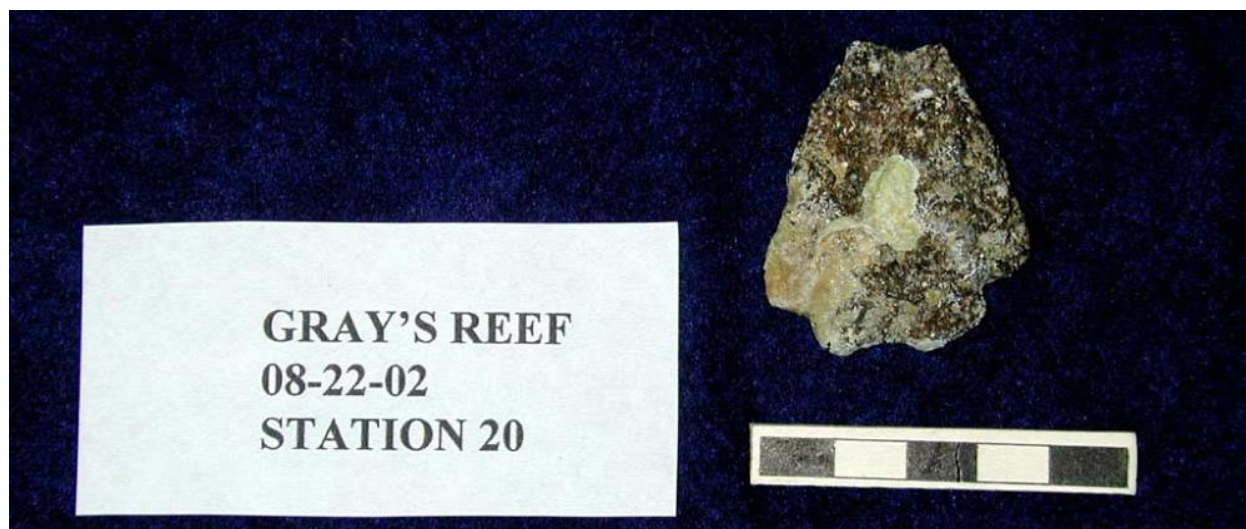
Indicators considered in the present report include paleolandscape and archaeological resources, science heritage, commercial fishing heritage, and associated Gullah/Geechee heritage.

#### **Paleolandscape and Archaeological Resources**

During the Last Glacial Maximum (~18,000 years before present), the area now designated as GRNMS was entirely terrestrial (Garrison et al., 2016). From that time until approximately 5,000 years before present, GRNMS was slowly inundated, reaching its present depth of approximately 15–20 m below the ocean’s surface. Given its history of exposure and inundation, GRNMS is an important site for paleolandscape and archaeological studies.

A total of 554 paleolandscape samples, including rocks, fossils, geo-sediment cores, sediment samples, shells, bone, wood, and Clovis Period bone and stone artifacts, have been collected from GRNMS and nearby JY Reef (Garrison, 2022). These samples are temporarily archived at the University of Georgia; however, a new, permanent storage facility that meets federal standards for curation is needed.

A number of artifacts recovered from GRNMS provide evidence of human habitation during the Archaic (approximately 10,000 to 3,000 years before present) and PaleoAmerican (13,000 to 10,000 years before present) periods. These include a stone projectile point (Figure ES.H.1) and a flaked stone scraper, both likely of Archaic Period origin, as well as a bone/antler artifact of either Archaic or PaleoAmerican origin (Garrison et al., 2016). The latter artifact may be an atlatl, a tool used to increase leverage in throwing arrows or javelins; atlatls are associated with early human history and have been found in many parts of the world.



**Figure ES.H.1.** A projectile point, believed to be from the Archaic Period, found in GRNMS. Photo: NOAA

Although the recognition of submerged paleolandscapes has increased and important archaeological discoveries have been shared throughout the condition report study period, additional research on this topic is needed. Furthermore, there is a critical gap in knowledge related to heritage connections between GRNMS and recent past and modern Indigenous peoples.

### Science Heritage

GRNMS has a marine research legacy that dates back to the 1960s. University of Georgia biologist Milton “Sam” Gray was tipped off to the location of the reef, then known by fishers as “Sapelo Live Bottom,” in 1961. Gray spent several years collecting and cataloging biological specimens from the productive reef, which began to gain recognition within the scientific community (GRNMS, 2023b). This trailblazing work ultimately led to the 1981 designation of GRNMS, named in Gray’s honor, to protect the site and its unique ecology. The scientific and conservation value of the sanctuary is widely recognized today (Whittle, 2019).

The designation of GRNMS was a catalyst for promoting research activity in the region, both by NOAA and partner organizations. A total of 139 conservation, academic, and/or science organizations have been identified as GRNMS research stakeholders throughout its history (Botta et al., 2024). Science activities at GRNMS have spanned a variety of disciplines, including biology, geology, oceanography, chemistry, archaeology, and paleontology (see the Science section of this chapter for more detail on these activities). In 1997, a NOAA monitoring buoy was placed within GRNMS. This buoy provides local weather and sea condition data to the public in near real time, and is also equipped with CO<sub>2</sub> and pH sensors to monitor ocean acidification (Pacific Marine Environmental Laboratory, 2022; Figure ES.H.2).



**Figure ES.H.2.** The NOAA buoy within GRNMS generates important data that are used by scientists and the public. Photo: Alison Soss/NOAA

In 2011, the sanctuary’s reputation as a significant location for scientific exploration was further established via the designation of a Research Area (Roberson et al., 2020). With the exception of vessel transits and permitted research, human activities are prohibited within the Research Area, allowing for studies that discriminate scientifically between natural and human-induced change to species, communities, and associated habitats. Roberson et al. (2020) details a variety of these studies and their results. While sanctuary regulations limit human activities within the sanctuary to help safeguard the natural ecology of the designated research area, they do not prevent potential impacts from human activities conducted outside the sanctuary.

### **Commercial Fishing Heritage**

Fishing has been an important aspect of lives and livelihoods in coastal Georgia for centuries. Recent audio and film projects have captured oral histories from past and present fishers in Georgia (Hoskins, 2015; Sakas & Caglayan, 2018; Sweeney Tookes & Fluech, 2018, 2022). These works illustrate the important role fishing has played throughout generations of families. However, a common theme among these oral histories is that younger generations are increasingly not entering or remaining in commercial fisheries due to a variety of factors, including economic challenges. Despite this trend, Georgia’s fishing heritage continues to be celebrated through modern events such as annual “blessing of the fleet” festivals in locations like Darien, Brunswick, and Thunderbolt, as well as through interpretive signage at visitor venues and in some coastal fishing communities. Recreational fishing at GRNMS increased as public awareness of the site grew during the second half of the 20th century. The sanctuary’s role as a modern fishing destination is described in more detail within the Sense of Place section of this chapter.

## **Associated Gullah/Geechee Heritage**

Although not directly tied to the sanctuary, the Gullah/Geechee culture has heritage connections to coastal Georgia that date back centuries. The Gullah/Geechee people descend primarily from West Africans who were enslaved on plantations along the lower Atlantic coast in the 18th and 19th centuries (Gullah Geechee Cultural Heritage Corridor Commission, 2012). GRNMS is situated in waters associated with the Middle Passage—waters through which enslaved people were transported to coastal Georgia (Bell, 2020). Fishing has historically been an important part of Gullah/Geechee culture, first as a way to supplement the rations of enslaved Africans, then to support subsistence and trade following emancipation, and ultimately as a means of self-employment (Hoskins-Brown, 2020). Traditional skills and practices related to fishing have been passed down from generation to generation, and fishing is closely tied to the Gullah/Geechee core value of independence (Hoskins-Brown, 2020). However, participation in fishing as a full-time occupation has declined among African Americans in coastal Georgia since the early 20th century (Hoskins-Brown, 2020).

Individual stories from African American fishers in Georgia, many of whom are Gullah/Geechee, were recorded as part of the NOAA Voices Oral History Archives (Hoskins, 2015). One of the interviews from this project was with George Walker, a Gullah/Geechee waterman who served as a crew member, and later captain, aboard University of Georgia research vessels during Sam Gray's studies of GRNMS, including the expedition during which the location of the Sapelo Live Bottom was first recorded with precision. Walker made many trips to the reef area with Gray, and recounted his experiences in a 2009 interview. In describing Sam Gray's first discovery of the live-bottom reef, now known as Gray's Reef, Mr. Walker said "they were dragging a tumbler dredge...and they hooked that rock...that's how they found it." Walker recalled that over the years, Gray "might...go out once a month...[to] collect a lot of fishes...shells and different things" (Walker, 2009). For years, Walker and the crew were sworn to secrecy about the location of the reef so that Gray and the research team could study the ecology of the live bottom in its natural state.

## **Conclusion**

Strong heritage connections to Georgia's coastal waters, including GRNMS, have been documented. These connections are illustrated through archaeological evidence of prehistoric use of GRNMS, a rich legacy of science within the sanctuary, and oral histories that describe coastal Georgia's fishing heritage and Gullah/Geechee cultural ties to the sea. However, some knowledge gaps related to modern Indigenous connections to the sanctuary preclude a more complete understanding of the site's heritage. Further, while breakthrough archaeological discoveries have been made in recent decades, this research has ebbed in recent years, and a permanent space for curation of artifacts from GRNMS is needed. Despite these challenges, overall awareness of heritage connections to coastal Georgia and GRNMS has grown over time as a result of new research and partnerships.

## Sense of Place

### Aesthetic attraction, spiritual significance, and location identity



**Status Description:** The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

**Rationale:** For people who are aware of and appreciate Gray’s Reef, the sanctuary’s aesthetic attraction, significance, and location identity remain strong. Proxy measures such as recreational fishing activity, popularity of iconic marine species, and interest in scuba diving reflected this value. Although awareness of the sanctuary improved during the study period, lack of awareness among most people remained a problem. Appreciation of Gray’s Reef predates GRNMS, but efforts to measure the sense of place ecosystem service are new. Ocean user surveys have not previously targeted sense of place values, so more complete and direct data for understanding this service is needed.<sup>18</sup>

A wide range of intangible meanings can be attributed to a specific place by people, both individually and collectively. A strong sense of place can promote physical and mental wellbeing among individuals and communities, and can also increase support for ecological conservation (Hausmann et al., 2015). “Place identity” develops over time (Hernández et al., 2007), and is often defined by a variety of reciprocal human-ecosystem relationships. Measuring sense of place requires mixed social science and psychological methods using various types of interviews and survey instruments (Van Putten et al., 2018; Duggan et al., 2023). These types of studies represent a data gap for this report. Although the indicators considered in this report are proxies for more direct measures, they provide insight into the current understanding of sense of place at GRNMS.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include site awareness, the role of GRNMS as a modern fishing and diving destination, Gullah/Geechee sense of place, and iconic species (including red snapper, kingfish, loggerhead sea turtles, North Atlantic right whales, and black sea bass).

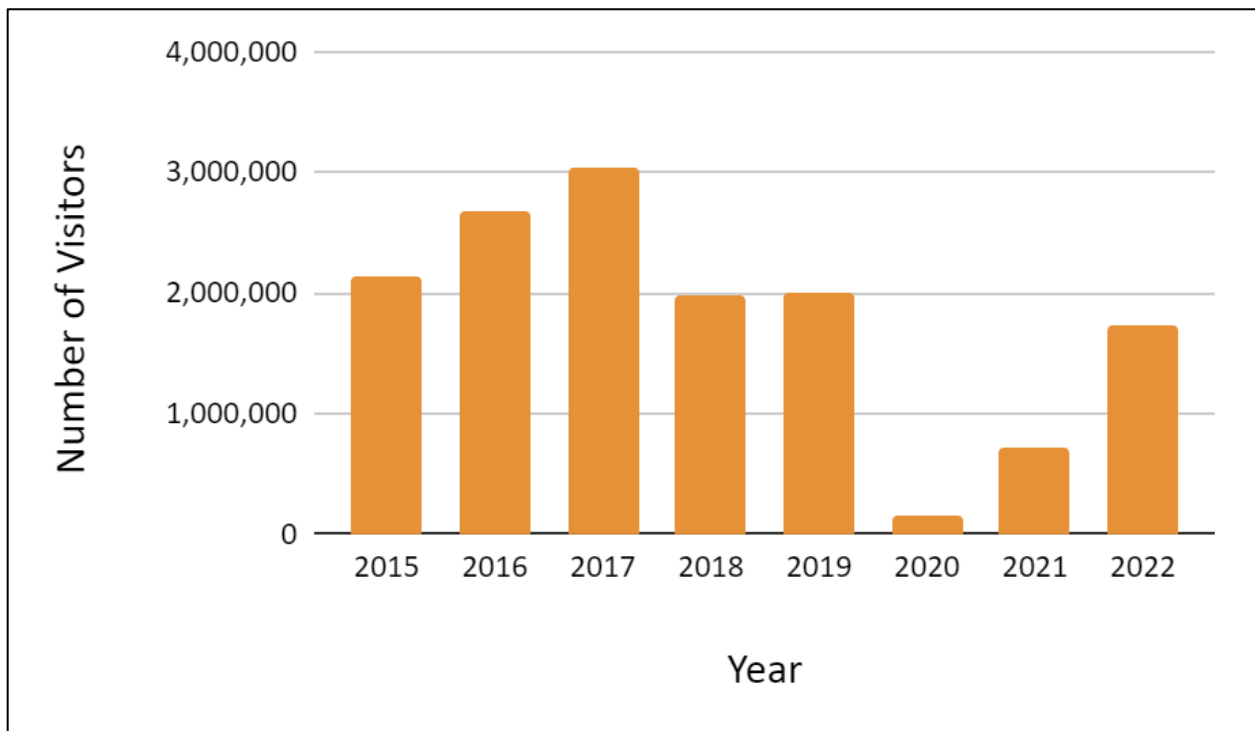
### **Site Awareness**

Gray’s Reef was first discovered by Georgia offshore fishers who valued it as a productive fishing area known as Sapelo Live Bottom. Their knowledge of the area led Sam Gray to find it and conduct exclusive scientific investigations there for several years, which subsequently prompted research dive surveys. Later, recreational divers learned about and visited the reef. Today, broader public awareness of the remote site, which can enhance development of a sense of place related to the sanctuary, is promoted primarily through news, journal, and magazine articles;

<sup>18</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

research publications; television programs; video documentaries; educational exhibits; social media; and special outreach events.

Media stories, publications, and public exhibits introduce and interpret the nature and history of GRNMS to the public, thus potentially helping to foster a sense of place. Between 2013 and 2022, a total of 316 references to GRNMS appeared in national and international online media outlets, for an average of 32 articles per year. GRNMS exhibits have been displayed at eight interpretive venues across Georgia and South Carolina for many years. Since 2015, over 14.5 million visitors have had the opportunity to view GRNMS educational exhibits at a variety of locations. In October 2022, the Georgia Aquarium, the largest aquarium in the U.S., opened a new exhibit highlighting the history of GRNMS. That same month, GRNMS dedicated the Ocean Discovery Center in Savannah's museum district; the center will allow some of the 15+ million people who visit the city each year to visit the sanctuary virtually.



**Figure ES.SP.1.** Aggregate annual visitor statistics for public interpretive venues in Georgia and South Carolina that displayed GRNMS exhibits from 2015 to 2022. These venues include the Savannah Visitor Center, South Carolina Aquarium, Fernbank Museum of Natural History, Savannah International Trade and Convention Center, Georgia Southern University Museum, and Tybee Island Marine Science Center.

### Modern Fishing Destination

Condition reports consider fishing from a number of different perspectives (i.e., as an indicator for human activities that may adversely influence living resources and the ecosystem service of consumptive recreation). Here, the recognition of GRNMS as a modern fishing destination is considered. The site enjoys a strong reputation as a sport fishing destination. Data from the NOAA Marine Recreational Information Program (2022) show a gradual increase in recreational fishing trips, as well as landings and the number of fish caught and released, in

federal waters off Georgia from 1990 to 2021. Because these data cover all federal waters off Georgia, they only provide indirect and proxy measures of recreational fishing within GRNMS.

A review of fishing websites indicated that GRNMS has been identified as a hotspot for fishing tournaments, and law enforcement has reported as many as 100 boats in the sanctuary on any given tournament day (Georgia Fishing Spots, 2023). Popular sport fish species include snapper, grouper, king mackerel, and black sea bass. In 2019, ONMS conducted a survey of recreational anglers' knowledge, attitudes, and perceptions about GRNMS and their activities in and around the sanctuary (Samonte et al., 2023). The survey revealed that anglers were highly involved in a variety of ocean and coastal leisure activities, including fishing, diving, wildlife viewing, and sailing.

Of note, despite angler appreciation of GRNMS as a fishing destination, only 4% of respondents in a 2023 ONMS survey correctly located GRNMS on a chart. Care must be taken in interpreting this result, however, as GRNMS is located 19 miles offshore and modern anglers do not typically navigate by visual reference to coastal features; rather, courses are set by satellite navigation. It is both possible and even likely that many ocean users can travel to and appreciate an area offshore yet not be visually familiar with its location on a chart. For many users, GRNMS is simply somewhere off Sapelo Island (Samonte et al., 2023).



**Figure ES.SP.2.** Fishing is a popular recreational activity in GRNMS. Photo: The Excursion with David Zelski

## **Gullah/Geechee Sense of Place**

This indicator is closely related to Gullah/Geechee heritage and history in the region, and, lacking more current data, serves to indicate the ONMS priority of increasing focus on community values of cultural identity, ocean resources, and conservation. The Gullah/Geechee honor the sea as a source of life, and many refer to their connection to the water as a cultural aspect (Hoskins-Brown, 2020). Many Gullah/Geechee communities are located at the water's edge, and boating, fishing, and preparing seafood are key parts of their identity. The sea represents independence, and though few Gullah/Geechee commercial fishers remain, fishing for subsistence is still a strong tradition and enjoyable pastime. These values are tied broadly to Georgia's coastal and ocean waters, and do not focus solely on the sanctuary. However, Gullah/Geechee watermen, including George Walker, captained, navigated, served as deckhands, and maintained vessels used in some of the first scientific explorations of Sapelo Live Bottom, which later became GRNMS. They also kept the location of the reef confidential, as urged by Sam Gray, to ensure the reef could be studied with minimal disturbance from human activity (see the Heritage section of this chapter for more information). Ultimately, given the limited information on Gullah/Geechee sense of place as it relates to GRNMS, this indicator is largely considered as a data gap.

## **Iconic Species**

GRNMS is home to “iconic” marine species. These are species that are important to people for their ecological, cultural, economic, and/or social value (Horsley, 2020), and are often noted as iconic in association to a particular place (Horsley et al., 2020). The appreciation of and connection to iconic species in and around the boundaries of GRNMS can thus be used as a qualitative measure of the public's sense of place as it relates to the sanctuary. Five species were selected to exemplify how they create a sense of appreciation for and connection to GRNMS and the surrounding ocean for not only fishers, but the conservation community as a whole.

### ***Red Snapper***

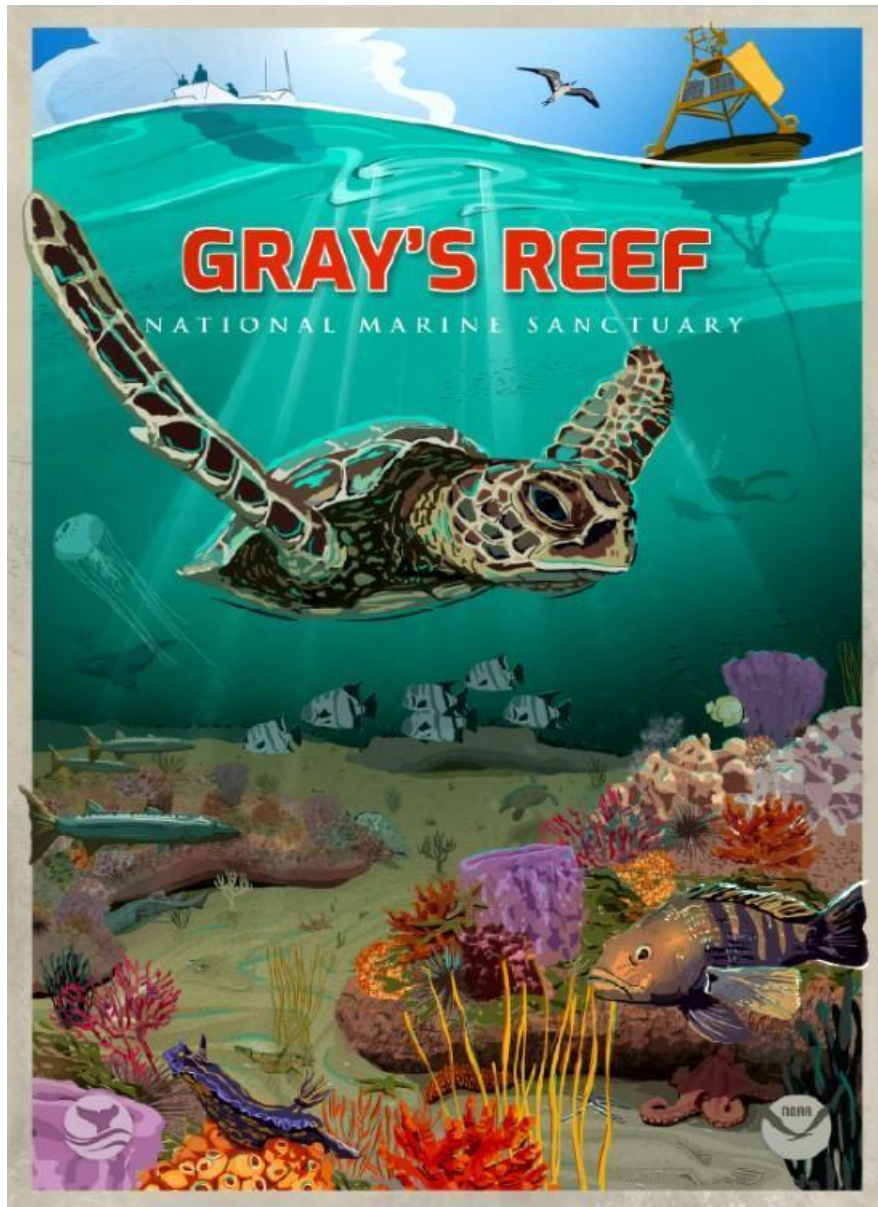
Red snapper have been extremely popular among fishers for decades, and remain an icon of southeast fisheries and fishing lore. Season and catch limits are a common topic of controversy (e.g., Busenbark, 2023), and the red snapper name and image continue to be an intrinsic part of the region's culture and communal identity, appearing on business signs, boats, clothing, artwork, and restaurant menus. Google searches in Georgia for the term “red snapper” increased from 2016 to 2022, even as the number of authorized sport fishing days remained extremely low.

### ***King Mackerel***

Also known as kingfish, king mackerel are large and aggressive fish that are popular with sport fishers across the southeast. The Southern Kingfish Association now organizes up to 40 regional fishing competitions annually. Important kingfish tournaments have occurred in Georgia coastal communities for decades, and as noted above, GRNMS is a hotspot for these tournaments. However, Georgia internet searches for the term kingfish decreased slightly from 2016 to 2022.

### ***Loggerhead Sea Turtle***

Loggerhead sea turtles frequent the coastline, are highly revered, and are protected by law, as well as by the people of coastal Georgia. Loggerhead images appear in business logos, on specialized license plates, posters, apparel, works of art, and a variety of items. Sea turtles are featured in local visitor guides, tourism videos, television news stories, newspaper articles, magazines, and social media messaging. For several decades, volunteer organizations throughout coastal Georgia, such as the Georgia Sea Turtle Center and Tybee Island Marine Science Center, have helped protect nest sites and rehabilitate and return injured and sick sea turtles to the ocean. Loggerhead sea turtles are frequently encountered at the ocean surface and on the seafloor within GRNMS. In fact, GRNMS staff have made this species a central figure of sanctuary outreach products for many years (Figure ES.SP.3).



**Figure ES.SP.3.** GRNMS poster featuring an image of the iconic loggerhead sea turtle. Image: NOAA

### ***North Atlantic Right Whales***

North Atlantic right whales are critically endangered, with only about 360 individuals remaining globally. These whales are Georgia’s official state marine mammal and are protected by both federal and state laws. GRNMS lies within the whales’ only known calving area, active from mid-November to mid-April each year.

### ***Black Sea Bass***

Black sea bass are a popular fish for offshore anglers in the southeast U.S. and are a signature species at GRNMS, spotted on practically every dive. They are an essential part of the trophic structure within the sanctuary and an iconic representative of the vibrant live bottom ecosystem. Black sea bass are present at GRNMS year-round.

### **Modern Diving Destination**

The reputation of and desire to visit GRNMS as a scuba diving destination also contributes to the site’s sense of place. Like fishing, diving was considered as an indicator in multiple parts of this report (i.e., human activities that may adversely influence habitat and non-consumptive recreation). Data for understanding GRNMS as a modern diving destination were gathered from several sources, including: ONMS internal data, interviews with dive companies, AP news articles, and internet search data for 2016–2023. GRNMS staff reviewed 114 articles and 7,780 web pages containing information about diving at GRNMS. At present, there is only one dive charter operator that regularly visits the sanctuary. Approximately 20 dive trips were scheduled for 2022; this remained fairly steady from 2018–2022. GRNMS is regarded as a special dive destination, featuring a live bottom composed of a colorful carpet of encrusting sponges and tunicates with a vertical profile of rocky ledges and supporting more than 200 species of fish and an amazing array of nearly 1,000 different kinds of invertebrates. As a diving destination, GRNMS was described by one writer as a “spectacular seascape” (Whittle, 2019). While there is a local core of probably six to eight repeat divers visiting GRNMS, the majority of recreational dives conducted there are by people from outside of the coastal Georgia area, who travel specifically to dive within the sanctuary (K. Hunnicutt/Latitude 31 Dive Company, personal communication, February 10, 2023). In 2023, the GRNMS Advisory Council recommended the installation of mooring buoys within the sanctuary to facilitate safer recreational diving.

Despite growing awareness, GRNMS is a place suited to advanced divers familiar with offshore conditions, currents, and unpredictable visibility. Distance offshore and the associated cost to get to the sanctuary may inhibit some divers from accessing the reef. Therefore, GRNMS is not a well-known or frequently visited site for most sport divers compared to more accessible or shallower locations. Searches in Google for information about “diving in Georgia” have been fairly consistent since 2016. For GRNMS itself, the number of web visits to the sanctuary’s diving page varied seasonally, but was consistent annually from 2016 to 2023.



**Figure ES.SP.4.** The GRNMS live bottom is composed of sponges, tunicates, and both soft and hard corals. It supports more than 200 species of fish. Photo: NOAA

### ***Conclusion***

Experts agreed that GRNMS possesses strong elements of sense of place, some of which clearly predate the establishment of the sanctuary. These place values (e.g., awareness, fishing, conservation of iconic species, diving) are closely interrelated and also overlap with other elements of sanctuary condition assessed in this report. Available data were primarily qualitative; compiling more direct, quantitative metrics for this ecosystem service is an important future goal. Additionally, the use of proxy measures such as online word/phase searches and Google site visits may not represent long-time resident values as much as visitor interests. New mixed-methods studies of residents and visitors would aid in future assessment of this ecosystem service, including the effects and perception of threats to cultural ecosystem services such as sense of place, including climate change. Despite challenges to rating this particular ecosystem service, it is important to assess existing information pertaining to this service to aid in prioritizing sanctuary management, including outreach efforts, public engagement, resource protection actions, and research.

## Consumptive Recreation

### Recreational activities that result in the removal of or harm to natural or cultural resources



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** Surveys of fishing permit holders, observations of vessels, vessel registration data, and recreational landings data indicate that waters off the coast of Georgia, including GRNMS, continue to provide opportunities for recreational fishing. However, many available data sets were not specific to the sanctuary. Experts noted that while some key species remain plentiful in the sanctuary, the ability to harvest others has declined due to new federal regulations. The available evidence, though limited for GRNMS specifically, does not suggest significant changes in use of the sanctuary for consumptive recreation.

### *New Information in the 2008–2022 Condition Report*

Indicators considered in the present report include days spent at sea, boat counts, vessel registrations, angler landings, expenditures and economic contributions, and attitudes and perceptions.

#### Days Spent at Sea

Georgia Saltwater Information Program (SIP) permit holders reported spending an average of 34.9 days participating in ocean recreation in and around coastal Georgia in 2020, with an average of one annual visit to GRNMS<sup>19</sup> (Burns et al., 2022). Further, respondents reported 26.6 days of private fishing and 6.1 days of charter fishing annually, with an average of 3.2 people on a trip. On average, of the total time spent fishing in a given year, respondents fished in inshore open water 48.3% of time, in offshore open water 13.0% of time, and at offshore natural reefs 4.8% of time. The most common times reported for fishing were fall (September to November; 47.9% of the time) and summer (June to August; 33.1% of the time).

#### Boat Counts

As discussed in greater detail in the section on human activities, Kendall et al. (2020) assessed vessel use patterns in GRNMS using a variety of observational methods, and found that most vessels that visited GRNMS were center console outboards typically used for ocean recreation and fishing (other vessels observed included yachts, sportfishers, and sailboats). Each boat typically had 3–4 people on board. The Georgia Department of Natural Resources conducted 66 patrols in GRNMS from 2014–2019, encountering zero boats on 54% of patrols. Among boats that were encountered, 75% had an average of 3.7 fishers. Boats were also observed from GRNMS research vessels from May to November of 2019. During this time, 22 boats were

<sup>19</sup> Although the Georgia SIP data set is specific only to permit holders in the state of Georgia, who constitute a large percentage of users at GRNMS, anglers from Florida and South Carolina are also known to fish at GRNMS and in surrounding areas; fishing activity specific to anglers from these states was not assessed as part of this report.

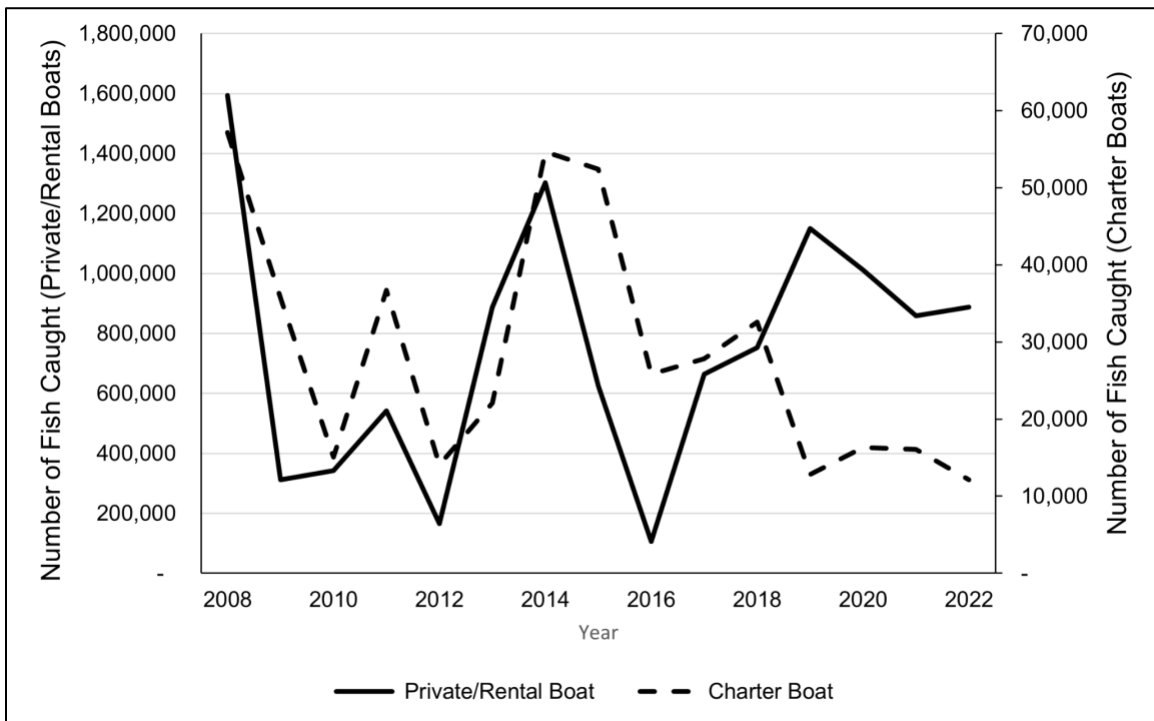
observed, with an average of three people aboard each boat. Consumptive recreation activities that may occur aboard boats include trolling and bottom fishing.

### Vessel Registrations

From 2015 to 2021, the number of Class A (<16 feet) and Class 1 (16 to <26 feet) vessel registrations increased in Georgia (Ozburn, 2023). The number of Class 1 registrations peaked in 2020 and 2021, with about 2,700 registrations in the seven coastal Georgia counties in each year. At the same time, the total number of SIP permits issued in the same counties declined from 2015 to 2022 (Ozburn, 2022). The number of SIP permits issued does not reflect fishing effort, but is an indicator of potential participation in saltwater fishing.

### Angler Landings

Although data specific to GRNMS were not available, data for federal waters off of Georgia from 2008 to 2022 show that angler landings from both private rental boats and charter boats varied with no clear trend (Figure ES.CR.1). The top landed species from charter boats were black sea bass, vermillion snapper, and Spanish mackerel. The top species landed by private/rental boats were herring, black sea bass, and sheepshead.



**Figure ES.CR.1.** Total angler harvest<sup>20</sup> in federal waters off Georgia. Landings from private/rental boats were greater than those from charter boats (note difference in scale). Source: NOAA Marine Recreational Information Program, 2022

<sup>20</sup> Harvest includes Type A and Type B1 as defined by the NOAA Marine Recreational Information Program. Caught/Available Catch (Type A) is an estimate of effort for all trips for a selected species that was caught, brought back and identified by the sampler. Harvested/Unavailable Catch (B1) are effort estimates for all trips in which the species was caught and killed, but the sampler did not see the fish for identification (NOAA Fisheries, 2024c).

### Expenditures and Economic Contributions

Data on expenditures by SIP permit holders and fishers were available for both GRNMS and the state of Georgia. However, data were only available for one year in each area. For the state of Georgia, the amount spent by for-hire anglers averaged \$328<sup>21</sup> per day in 2017 (Lovell et al., 2020). The greatest angler-day expenditures by for-hire anglers were guide fees/tournament fees (\$197), lodging (\$67), and restaurants (\$19). Average expenditures for private boats per angler-day were \$50, and the largest daily expenditures were fuel (\$11), groceries (\$8), and bait (\$7). Expenditures by for-hire anglers totaled \$6,087,590 in 2017. This supported 87 jobs, \$10,417,940 in sales, and \$3,514,480 in labor income. Private/rental boat expenditures were \$72,086,310 in 2017. These expenditures supported 769 jobs, \$69,780,230 in sales, and \$22,329,770 in labor income.

A 2020 survey of Georgia SIP permit holders found that the average trip to GRNMS cost visitors (for any use, including fishing) a total of \$160 (Burns et al., 2022). Respondents who visited GRNMS specifically to fish reported spending \$152 per trip. Interestingly, survey respondents thought a typical trip to GRNMS would cost \$350, more than twice the reported spending of anglers who visited GRNMS. Respondents reported visiting GRNMS on average 2.5% of the time when engaged in fishing annually. The most important factors that influenced a respondent's decision to make a trip to GRNMS for any type of ocean recreation were ocean conditions, weather conditions, and the season for catching certain fish species.

A more recent study surveyed resident and non-resident Georgia SIP permit holders to understand their recreational fishing expenditures (Frimpong, 2023). The study found that resident saltwater recreational anglers spent an average of \$475 per angler-day for private boat trips. Anglers in coastal counties spent \$313 per angler-day on private boat trips. Non-resident private boat anglers spent an average of \$908 per angler-day. Recreational private boat fishers from Georgia supported 2,341 jobs and \$232.6 million in output (the value of all sales of goods and services), while non-residents supported nine jobs and \$1.0 million in output. The survey found that 6.3% of respondents fished offshore (beyond 15 nautical miles from the shoreline).

### Attitudes and Perceptions

A study analyzing the attitudes and perceptions of SIP permit holders in Georgia found that 72.1% of respondents valued GRNMS positively for its support of recreational activities (Samonte et al., 2023). Respondents had mixed opinions on the condition of pelagic fish species; 35% felt that pelagic fish populations have stayed the same, while 35% felt they were getting somewhat to a lot better. The remaining 30% felt that the condition of these species was getting somewhat to a lot worse. GRNMS users reported being extremely to somewhat concerned about overfishing (53.7%), pollution (68.3%), coral health/other live bottom habitat (65.9%), and marine animal health (63.4%).

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<sup>21</sup> All dollar estimates in this section are reported in April 2023 U.S. dollars and were adjusted using the Consumer Price Index inflation calculator (U.S. Bureau of Labor Statistics, 2024).

### ***Conclusion***

Saltwater anglers spent a little more than one month per year recreating in coastal Georgia, and visited GRNMS an average of once per year. The number of boats present in the sanctuary varied by survey method, but most boats observed were center console vessels typically used for recreation. Small vessel registrations increased during the study period, but the number of SIP permits declined from 2015 to 2022. Recreational landings varied throughout the study period, with no apparent trend. For-hire and private vessel angler expenditures supported the coastal Georgia economy. SIP permit holders had varying perceptions, but those who visited GRNMS were generally concerned about resource conditions. The majority of data used in this assessment were not specific to GRNMS. While state- and county-level data provide important context for activity in GRNMS and are used as a proxy, future efforts should focus on collection of sanctuary-specific data.

## Non-Consumptive Recreation

**Recreational activities that do not result in intentional removal of or harm to natural or cultural resources**



**Status Description:** The capacity to provide the ecosystem service is compromised, but performance is acceptable.

**Rationale:** Opportunities for non-consumptive recreation, specifically boating and scuba diving, are available in GRNMS. However, some opportunities are limited by a lack of infrastructure (i.e., mooring buoys for diving), the sanctuary’s distance from shore, and economic factors (e.g., cost to get to the sanctuary). Although data were limited, vessel presence and transits, as well as awareness of and demand for diving in the sanctuary have increased.

### ***New Information in the 2008–2022 Condition Report***

Indicators considered in the present report include days spent at sea, vessel traffic, and for-hire diving.

#### **Days Spent at Sea**

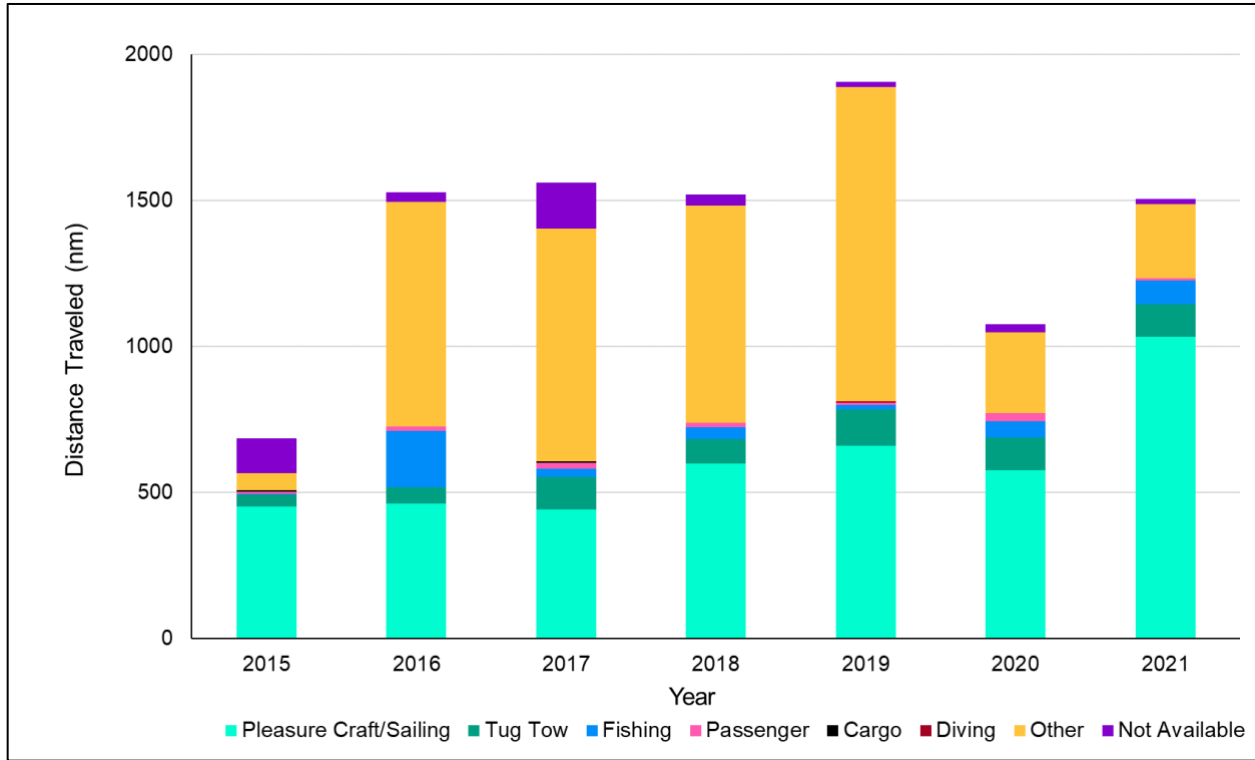
A 2020 survey of Georgia SIP permit holders asked respondents about recreational activities and their frequency within and around GRNMS (Burns et al., 2022). In a typical year, survey respondents spent 32.9 days engaging in ocean recreation in and around coastal Georgia, but an average of just one day in GRNMS. In and around coastal Georgia, respondents spent an average of 24.5 days per year boating (all types), 13.9 days on non-fishing activities, 11.0 days on charter diving, and 7.6 days on private boating.

GRNMS users reported ocean conditions (wind, waves, etc.), weather conditions, the time of year, and time off work (free time in schedule) as important factors that influenced their decision to visit the sanctuary (Burns et al., 2022). The survey found that 40.3% of respondents most commonly used a public boat ramp to access GRNMS. Public marinas (19.0%), private marinas (15.8%), and private residences (8.3%) were also common access points.

#### **Vessel Traffic**

Figure S.HA.6 shows the types of vessels equipped with AIS that spend time in GRNMS; these data include vessels that stopped within the sanctuary as well as those that transited through. As reviewed in the earlier section on human activities, the most common type of AIS-equipped vessel conducting non-consumptive recreation in the sanctuary AIS was pleasure craft/sailing vessels. There appeared to be an increase in the number of such vessels present in the sanctuary over time; however, this increase may reflect an increase in the number of pleasure craft and recreational vessels equipped with AIS. Only one diving vessel was detected in the AIS data from 2015 to 2021, and it traveled a total of five nautical miles within the sanctuary.

AIS also provides information on the distance each vessel travels within GRNMS. Pleasure craft/sailing vessels traveled greater distances within the sanctuary compared to most other types of vessels (Figure ES.NCR.1).



**Figure ES.NCR.1.** Distance traveled by vessel type in GRNMS. The “other” category includes research vessels, which transit the sanctuary frequently (see Figure S.HA.2 for more information). Source: U.S. Coast Guard Navigation Center, 2022

### For-Hire Diving

As reviewed in the earlier section on human activities, one dive charter (Latitude 31 Dive Company) has been known to visit GRNMS since 2018, making about 20 trips to the sanctuary annually with six divers per trip (K. Hunnicutt/Latitude 31 Dive Company, personal communication, February 10, 2023). Each trip includes two dives at different locations within the sanctuary. The cost of this dive experience is \$175 per person. The majority of divers are from outside coastal Georgia and ask for hotel and restaurant accommodations, indicating they are spending money on lodging and food within the local economy when diving in GRNMS. Most customers travel to the area specifically to dive at GRNMS. Lastly, multiple divers are repeat customers, which likely means they are satisfied with their experience and the quality of the dive sites. It is worth noting that the operator has not observed divers from private boats in GRNMS during their trips. The majority of recreational divers on these charters have been from Atlanta and other areas outside coastal Georgia, although 6–8 repeat local divers are known to visit the sanctuary. Additionally, awareness of the uniqueness of diving in GRNMS has been increasing over time (K. Hunnicutt/Latitude 31 Dive Company, personal communication, February 10, 2023).

### ***Conclusion***

Although the number of and distance traveled by pleasure craft and sailing vessels in the sanctuary increased during the study period, more data are required to understand how these metrics correlate to non-consumptive recreation in GRNMS. The status and trend of non-consumptive recreation were primarily based on scuba diving. Opportunities for scuba diving exist in GRNMS, however demand is not fully met due to difficulties in accessing the sanctuary, including distance from shore, cost, and lack of mooring buoys. However, chartered dive trips to GRNMS have been offered since 2018, increasing the amount of recreational diving.

## Response to Pressures

National marine sanctuaries use “adaptive management,” wherein threats are addressed as they are identified and understood, and decisions to change management actions are made in response to changing conditions or circumstances. Adaptive management is an iterative learning exercise rather than a predetermined solution to an identified problem (Marshall & Schuttenberg, 2006). For national marine sanctuaries, the most significant changes in management actions are typically made through the management plan review process, when a combination of status assessments, proposed changes, and public input result in a forward-looking plan for future management of the sanctuary. As part of the management plan, specific action plans are proposed to address priority issues and emerging concerns.

This report identifies the most prominent pressures on the GRNMS ecosystem and, in some cases, presents evidence to show declines in the quality of certain resources from 2008 to 2022. Some of these issues require more research to fully understand their causes and identify appropriate management actions to mitigate impacts. Others are understood well enough to warrant more immediate measures to prevent further declines or ensure protection before changes become irreversible. Management actions that were in place or undertaken in response to pressures and concerns during the study period (2008–2022) are described below.

### *Visitation and Use*

The sanctuary’s location 20 miles from shore creates operational challenges for visitors to GRNMS. Since 1997, NOAA has maintained data buoy 41008 (GRNMS data buoy) near the center of the sanctuary. The buoy transmits hourly updates on sea conditions (e.g., wind speed, surface temperature, and wave height) at the reef that are made available to the public via the internet and NOAA Weather Radio broadcasts. This near real-time data, coupled with NOAA marine forecasts for the sanctuary and surrounding area, helps prospective visitors determine if traveling to Gray’s Reef is prudent on any given day, and thus reduces risks of maritime incidents and resulting emergency response activities that could potentially harm sanctuary resources. Even for those with the means to access the sanctuary, the dynamic nature of offshore sea conditions and associated safety considerations limit the number of visitors, as well as the nature and volume of their impacts.

Beyond the natural constraints that limit visitor impacts, NOAA has implemented regulations that prohibit human activities that could impair sanctuary habitats, resources, and qualities (15 C.F.R. § 922.92). Anchoring of vessels, altering the seafloor, and constructing or placing anything on submerged lands are prohibited throughout the sanctuary, unless permitted by sanctuary management. Use of explosives or electric charges is also explicitly prohibited, unless permitted or exempted. Additional sanctuary-wide prohibitions are discussed in the paragraphs below. In 2011, NOAA established an eight-square-mile area in the southern third of the sanctuary exclusively for scientific research (the Research Area). In addition to sanctuary-wide regulations, specific prohibitions were implemented for the Research Area (15 C.F.R. § 922.94) that prohibit diving, fishing, transporting unsecured fishing gear, and stopping a vessel within the zone. Law enforcement patrols of GRNMS by the NOAA Office of Law Enforcement, U.S.

Coast Guard, and Georgia Department of Natural Resources promote regulatory compliance and address illegal activities.

The two largest recreational user groups regularly visiting GRNMS are recreational scuba divers and fishers. As prospective ambassadors for the reef, these users have been a significant focus for GRNMS outreach and education efforts. GRNMS staff have reached out to scuba divers to share published best diving practices for those visiting the sanctuary. Additionally, GRNMS offers 360-degree virtual tours of the sanctuary that are shared online and at events, as well as web and social media content, online and printed magazine articles, interpretive signage at boat ramps and marinas, and regional exhibits about the sanctuary. Messaging and outreach focus on the natural wonders of the sanctuary and how the public can enjoy and help conserve the marine life and unique live-bottom habitat through personal stewardship and knowledge of protective rules for the site. To provide two-way communication between sport diving representatives and sanctuary management, a dedicated Sport Diving seat has existed on the GRNMS Advisory Council since the council's creation in 1999.

Though anchoring is prohibited throughout the sanctuary, divers are allowed to temporarily deploy small floats with a tethered anchor weight totaling  $\leq 10$  pounds as a dive site marker. However, such floats and associated tackle must be completely removed within 12 hours of deployment. Breaking, cutting, damaging, taking, or removing any bottom formation for aquaria or any other reason is a violation of federal regulations. Injuring, catching, harvesting, or collecting, or attempting to injure, catch, harvest, or collect, any marine organism, or any part thereof, living or dead, within the sanctuary by any means is prohibited, except in the course of fishing by use of rod-and-reel or handline gear. Sanctuary regulations include a rebuttable presumption that any marine organism, or part thereof, found in the possession of a person within the sanctuary has been collected from the sanctuary.

### **Fishing**

From 2008 to 2022, GRNMS staff engaged fishers through publication of best fishing practices within the sanctuary; distribution of free descending devices (in collaboration with national fishing conservation organizations); sport fishing representation on the GRNMS Advisory Council; presentations at fishing tournament captains meetings; television and online video features; web and social media content; online and printed magazine and journal articles; interpretive signage at boat ramps and marinas; and regional GRNMS exhibits. Similar to diver outreach, messaging focuses on awareness of regulations and stewardship of sanctuary resources.

Fishing gear is strictly regulated within GRNMS to prevent damage to sanctuary habitats. Only rod-and-reel and handline fishing are allowed, as gear types like traps and trawl nets cause unacceptable damage to live-bottom reef habitat. Spearfishing is also prohibited throughout the sanctuary because it facilitates unsustainable, targeted removal of the largest, most reproductive fish within the relatively small confines of GRNMS. Though anchoring is prohibited throughout the sanctuary, fishers are allowed to temporarily deploy small floats with a tethered anchor weight totaling  $\leq 10$  pounds as a visual reference marker for drift fishing. However, such floats and associated tackle must be completely removed within 12 hours of deployment.

Kendall et al. (2020) conducted an assessment of boater use at GRNMS that correlated fishing activity at the sanctuary with specific weather and sea conditions on-site. Their results have enabled sanctuary managers to predict when fishing is most likely to occur at GRNMS and to coordinate with law enforcement to optimize patrols that ensure user compliance with sanctuary regulations.

When lost, snagged, or tangled fishing gear is found within GRNMS, sanctuary staff, marine researchers, charter boat divemasters, and volunteers are encouraged to remove it unless it has become integrally entwined with natural habitat features such that removal would create further habitat damage.

### **Vessel Discharges**

To reduce the impacts of vessel activity, sanctuary regulations prohibit discharging or depositing any material or other matter, except fish or fish parts, bait or chumming materials; effluent from marine sanitation devices (MSDs); and vessel cooling water. However, because Type I and Type II MSDs are only required to remove suspended solids and treat for potential human pathogens, their effluents still include nutrients and potentially other pollutants that could degrade local water quality. Type III MSDs are simply holding tanks, and current sanctuary regulations do not explicitly prohibit discharges from these MSDs, which could release solid waste and human pathogens into the sanctuary. Currently, greywater, deck runoff, bilge water, and engine exhaust are not excepted from discharge restrictions. Violation of any U.S. boating rule or regulation within the sanctuary also constitutes a violation of sanctuary regulations, and can therefore be enforced by NOAA law enforcement personnel and partners, in addition to the U.S. Coast Guard.

### **Scientific Research**

Exploration, research, and monitoring are major activities at GRNMS. Research activities that involve or could require prohibited activities within the sanctuary are vetted through the ONMS permit system. A proposed project is only permitted if it meets a set of defined criteria and the superintendent determines that the expected end value of the activity will further national marine sanctuary goals and purposes, and outweighs any potential adverse impacts on sanctuary resources and qualities. Each permit includes terms and conditions tailored to mitigate and reduce environmental/cultural impacts of the proposed work, and each authorized activity is subject to compliance inspections. All permittees are required to submit after-action reports detailing the outcome(s) of the permitted activity and noting any loss of equipment or damage to natural resources or qualities. Failure to comply with permit requirements can result in permit revocation, difficulty obtaining future permits, and civil penalties. GRNMS staff consider the impacts of each individual project as well as the cumulative impacts of all permitted activity in the sanctuary when making permitting decisions. Even sanctuary site staff must apply to ONMS for a multi-year managerial permit authorizing anticipated prohibited activities staff and contractors will need to perform as part of research, monitoring, and other conservation duties. In addition to internal review, the sanctuary permit process requires consideration of and compliance with other federal environmental laws, such as the National Environmental Policy Act, The Endangered Species Act, The Marine Mammal Protection Act, The Magnuson-Stevens Fishery Conservation and Management Act, the Clean Water Act, and more. The

GRNMS permit coordinator collaborates with the various agencies enforcing these laws to ensure that issuance of any sanctuary permit is consistent with related legal requirements.

### **Changing Ocean Conditions**

In response to the growing evidence of global climate change impacts, GRNMS has established local oceanographic monitoring partnerships; coordinated with the National Data Buoy Center to maintain the GRNMS data buoy; leveraged NOAA-gathered oceanographic data for assessment of regional trends; increased planning and vigilance; and considered the need to reduce non-climate stressors in order to maximize resource resistance and resilience.

GRNMS lies along a biogeographic transitional zone at the peripheries of both northern and southern species ranges, thus hosting a diverse ecological community. Some mobile species are year-round residents, while others come and go with the seasons. Whereas the arrival of a tropical species into a firmly temperate ecosystem might signal a potential climate change impact (i.e., range shift), the presence of a variety of temperate and tropical species at GRNMS is routine. The dynamic ecology of the reef, coupled with an incomplete catalog of indigenous species, complicates detection of range shifts and new species arrivals that could be indicative of climate change impacts within the sanctuary.

The data buoy at the heart of GRNMS provides real-time wave height, wind data, water surface temperature, and salinity, as well as pH and  $p\text{CO}_2$  through a collaboration between NOAA and the University of Georgia. A surface seawater pH sensor was added to the data buoy in 2011. By measuring pH in addition to  $p\text{CO}_2$  (collected at the buoy since 2006), local researchers are able to more accurately and precisely study the changes associated with ocean acidification within the sanctuary—an important indicator of climate change.

The climate-change-related shifts observed at GRNMS—rising sea surface temperature (Figure SW.Q.9), increased tropical storm frequency (Figure S.WQ.13), and suspected decreases in pH (Figure S.WQ.15) and salinity (Figure S.WQ.17)—have not yet resulted in observed, measurable effects on sanctuary habitats or living resources. Nevertheless, consistent monitoring and analysis of key oceanographic indicators and an established ecosystem baseline will be important for future assessment of climate impacts on the sanctuary. Therefore, GRNMS has focused its climate change response on monitoring key oceanographic indicators (pH,  $p\text{CO}_2$ , temperature, and salinity) and has worked with partners to begin cataloging and characterizing species in the sanctuary to establish an ecosystem baseline for future comparative analyses and more effective detection of changes. However, there is currently no comprehensive plan or available funding for creating a profile of native species at GRNMS.

### **Non-Indigenous Species**

Observations during ongoing research at GRNMS have confirmed the presence of some non-indigenous species. Given the widespread impact of the lionfish invasion elsewhere in the Western Atlantic, GRNMS staff have opportunistically removed those found in the sanctuary when possible. From 2012 to 2017, 97 lionfish were sighted in the sanctuary, and 54 were removed. Fewer than five lionfish have been observed in recent years.

To date, there have been no dedicated surveys to detect and catalog non-indigenous species within GRNMS, and there is currently no specific research to quantify key metrics (e.g., species composition, densities, and trends) of non-native species to determine if they pose a threat to the ecosystem. Lack of a comprehensive profile of native species at GRNMS hinders identification of an observed species as native, non-indigenous, or new observations as a result of a range expansion due to climate change.

Due to the low number, abundance, and proliferation of non-indigenous species detections in the sanctuary to date, sanctuary managers have not implemented coordinated intervention or removal programs, but all known non-indigenous species within the sanctuary should be monitored on a long-term basis for any signs of proliferation or invasive characteristics.

### ***Coastal Development and Nearshore Construction***

The physical oceanographic and ecological connections between the coast and GRNMS are well documented (Gleason & Cohen, 2012). Though GRNMS managers have no jurisdictional authority over coastal development, these connections make it imperative that the superintendent and/or the Sanctuary Advisory Council make every effort and take every opportunity to track, review, and advise on proposed onshore and nearshore activities with a potential nexus to GRNMS. This includes coastal construction (commercial and residential development, docks, roads, and utilities), dredging and dredge disposal, coastal/offshore energy infrastructure and seafloor transmission lines, artificial reefs, port development, shipping traffic patterns and port access routes, and fill and displacement of coastal wetlands. In 2015, the 20-member GRNMS Advisory Council sent a letter to the U.S. Bureau of Ocean Energy Management opposing a proposed draft oil and gas leasing program for the continental shelf within the Atlantic Region due to potential negative impacts of oil and gas activities on the sanctuary. The superintendent and Sanctuary Advisory Council can also promote proactive efforts to conserve habitats and resources important to sanctuary health. In 2021, the Sanctuary Advisory Council sent recommendations to NOAA about President Biden's Conserving America the Beautiful initiative to conserve 30% of U.S. lands and waters by 2030 and formed a working group to develop more specific recommendations about marine conservation programs and needs in the South Atlantic Bight.

GRNMS managers monitor regional efforts to conserve nearshore habitats, such as the South Atlantic Salt Marsh Initiative, and offer support and input for coastal protection and restoration programs with a nexus to the sanctuary. GRNMS has supported scientific research on microplastic pollution linkages between coastal Georgia and the sanctuary, and incorporates citizen stewardship messaging in its education and outreach programs that encourage individual actions to curb pollution and conserve natural resources.

### ***Nonpoint Source Pollution***

Regulations that prohibit nonpoint source pollution within GRNMS boundaries have been promulgated. Discharging or depositing any material or other matter into the sanctuary is a federal violation, subject to civil penalties and damages, with very limited exceptions for fish or fish parts, bait, or chumming materials; effluent from marine sanitation devices; and vessel cooling water.

GRNMS education and outreach programs and interpretive enforcement<sup>22</sup> by federal and state officers use a variety of tools to inform the public about sanctuary regulations and best management practices to help prevent inadvertent regulatory violations within the sanctuary.

### **Marine Debris**

Discharging or abandoning any gear or object into sanctuary waters or on the seafloor is prohibited, and any associated damage to habitat or sanctuary resources from such discharge/abandonment could constitute an added charge and penalty. Sanctuary regulations are enforced on a strict liability basis and thus apply regardless of intent. In addition to fines for regulatory violations, NOAA can file a civil suit against offenders for damages to natural resources to recover government costs for response, damage assessment, restoration planning, restoration implementation, monitoring, and restitution for the fair-market value of lost ecological services until the site is restored to its condition immediately prior to the time of the incident.

When debris is found in the sanctuary and can be recovered, GRNMS divers and volunteers typically remove it. No large debris items have been discovered in the sanctuary. Only one vessel casualty has occurred in GRNMS since its designation in 1981, and the small capsized boat ultimately floated beyond sanctuary boundaries.

GRNMS education and outreach programs and interpretive enforcement by federal and state officers utilize a variety of tools to inform the public about sanctuary regulations and best management practices to help prevent pollution violations within the sanctuary.

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<sup>22</sup> Interpretive enforcement is verbal education and guidance by law enforcement personnel about laws, regulations, and best management practices. It is preventive and non-punitive in nature and may also include online information provided via enforcement and marine resource protection websites.

## Concluding Remarks

### **Concluding Statement from Gray’s Reef National Marine Sanctuary Superintendent Stan Rogers**

This condition report uses the best available information and subject matter expert opinion to assess the status and trends of GRNMS resources and ecosystem services. The report assesses water quality, habitat, and living resources, and also includes our first ever evaluation of the status and trends of the sanctuary’s ecosystem services—the benefits that humans derive from different ecosystem attributes for their lives, lifestyles, and livelihoods.

The report concludes that the primary direct human pressures on sanctuary water quality, habitat, and living resources were visitation and use; coastal development and nearshore construction; and nonpoint source pollution. Changing ocean conditions, including ocean warming and acidification, and non-indigenous species were also identified as significant threats to sanctuary resources.

From 2008–2022, GRNMS resources remained in good to good/fair condition. The sanctuary’s offshore location limits direct human pressures on water quality, habitat, and living resources, and most data suggest that observed changes in the sanctuary have been largely driven by natural factors. However, some climate indicators have worsened, and some focal species for GRNMS, such as North Atlantic right whales, have faced ongoing threats and pressures.

The process of evaluating status and trends within the sanctuary revealed several critical data gaps that precluded a full assessment of trends in some aspects of water quality, contaminants, and the status and trends of some focal species. Looking ahead, we will work with partners to further improve our understanding of ecological functions and the interconnectedness of live-bottom, other benthic, and pelagic habitats and their connections to coastal estuarine and salt marsh habitats, as well as deeper benthic habitats along the continental shelf and Blake Plateau. We will also study the roles of vertebrate and invertebrate species within these habitats and marine ecosystems.

With the delivery of our new sanctuary research vessel in January 2024, GRNMS and partners are now able to establish a more comprehensive, multi-season approach for the long-term monitoring of key indicators needed to inform management decisions. The addition of the research vessel will also allow GRNMS to focus valuable NOAA ship time on greater-ranging expeditions across the South Atlantic Bight.

The condition report process also revealed a lack of capacity to provide effective sanctuary education and outreach during the study period, as well as limited public awareness of the sanctuary and GRNMS and partner-led programs. However, recent investments in education/outreach staffing and the establishment of the Gray’s Reef Ocean Discovery Center in downtown Savannah, Georgia in 2022 will significantly increase public awareness and create a deeper human connection to the resources and a stronger sense of place.

## Concluding Remarks

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GRNMS ecosystem services, assessed for the first time in this report, were determined to be in good/fair to fair condition from 2008–2022. Ecosystem services such as science and education were impacted by limited capacity and investment in other priority areas. The modest rating for sense of place is also strongly tied to limited resources to promote public awareness and enjoyment of the offshore marine sanctuary. Lack of awareness and limited access to the sanctuary along with other factors resulted in modest recreational use and enjoyment of the site.

This condition report will provide key supporting information for an upcoming review and update of the GRNMS management plan and regulations. These findings will help us establish impactful goals, objectives and annual management activities based on identified needs for sanctuary resources and the user communities. We look forward to working with partners, stakeholders, and the public throughout the management plan review process and beyond.

This assessment and report would not have been possible without the dedicated support and input of numerous contributors and reviewers. On behalf of ONMS, I want to express our sincerest gratitude for both past and ongoing contributions to sanctuary scientific research and monitoring, resource protection, management, and education and outreach programs. It is only through these continued collaborations and partnerships that we will successfully conserve and protect this significant ocean treasure for generations to come and improve our understanding of the greater South Atlantic Bight.

Sincerely,

A handwritten signature in black ink that reads "Stan Rogers". The signature is fluid and cursive, with a long horizontal stroke extending to the right.

Stan Rogers, Superintendent, Gray's Reef National Marine Sanctuary

## Acknowledgements

The production of this report would not have been possible without the participation and contributions of federal and state agencies, academic and non-governmental organizations, the Sanctuary Advisory Council, consortia, partners, and researchers. With gratitude, we recognize these individuals, who participated in meetings and workshops, contributed information, reviewed drafts, and/or provided general support to this effort:

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## Literature Cited

- Alexander, C. (2016). Geospatial characterization studies for advancing estuarine restoration and management in Georgia. Final Report to the Georgia Department of Natural Resources.
- Alexander, C., Venherm, C., & Robinson, M. (2020). Project 15: Geospatial sediment assessment for Georgia estuarine, coastal, and shelf environments. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic) (pp. 151–156). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries.  
<https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/grnms-research-area-report-final-for-publication-5-21-20.pdf>
- Anderson, M. J., Ford, R. B., Feary, D. A., & Honeywill, C. (2004). Quantitative measures of sedimentation in an estuarine system and its relationship with intertidal soft-sediment infauna. *Marine Ecology Progress Series*, 272, 33–48. <https://doi.org/10.3354/meps272033>
- Arthur, C., Baker, J., & Bamford, H. (Eds.). (2009). Proceedings of the international research workshop on the occurrence, effects, and fate of microplastic marine debris. Technical Memorandum NOS-OR&R-30. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Marine Debris Program. <https://repository.library.noaa.gov/view/noaa/2509>
- Asche, F., Oglend, A., & Smith, M. D. (2022). Global markets and the commons: The role of imports in the US wild-caught shrimp market. *Environmental Research Letters*, 17(4), 045023.  
<https://doi.org/10.1088/1748-9326/ac5b3e>
- Aumack, C., & Cohen, R. (2021). GRNMS macroalgae surveys, 2018–2021 [Unpublished data set]. Georgia Southern University.
- Auster, P. J. (2020). Project 11. Assessing variation in composition of mixed-species groups of piscivores, 2009–2011 and 2013–2014. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic) (pp. 116–122). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.  
<https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/grnms-research-area-report-final-for-publication-5-21-20.pdf>
- Auster, P. J., Godfrey, J., Watson, A., Paquette, A., & McFall, G. (2009). Behavior of prey links midwater and demersal piscivorous reef fishes. *Neotropical Ichthyology*, 7(1), 109–112.  
<https://doi.org/10.1590/S1679-62252009000100014>
- Auster, P. J., Kracker, L., Price, V., Heupel, E., McFall, G., & Grenda, D. (2013). Behavior webs of piscivores at subtropical live-bottom reefs. *Bulletin of Marine Science*, 89(1), 377–396.  
<https://doi.org/10.5343/bms.2011.1123>
- Auster, P. J., Campanella, F., Kurth, R., Muñoz, R. C., & Taylor, J. C. (2020a). Identifying habitat associations of sea turtles within an area of offshore sub-tropical reefs (NW Atlantic). *Southeastern Naturalist*, 19(3), 460–471. <https://doi.org/10.1656/058.019.0302>
- Auster, P. J., Lindholm, J., Pereira, J., Fangman, S., Bolton, H., Cramer, A., Jensen, L., & Moye, J. (2020b). Project 10. Preliminary results assessing movement patterns of select demersal piscivores at the sub-tropical reefs of Gray's Reef National Marine Sanctuary (Northwest Atlantic, Carolinian

## Literature Cited

- Province, 2008–2013. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic) (pp. 98–115). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://sanctuaries.noaa.gov/science/conservation/grnms-research-area-report-2020.html>
- Auster, P. J., & Giacalone, L. (2021). Virtual reality camera technology facilitates sampling of interactions between reef piscivores and prey. *Marine Technology Society Journal*, 55(2), 54–63. <https://doi.org/10.4031/MTSJ.55.2.1>
- Avio, C. G., Gorbi, S., & Regoli, F. (2017). Plastics and microplastics in the oceans: From emerging pollutants to emerged threat. *Marine Environmental Research*, 128, 2–11. <https://doi.org/10.1016/j.marenvres.2016.05.012>
- Balthis, W. L., Hyland, J. L., Cooksey, C., Fulton, M. H., & McFall, G. (2007). Long-term monitoring of ecological conditions in Gray's Reef National Marine Sanctuary: Comparison of soft-bottom benthic assemblages and contaminant levels in sediments and biota in spring 2000 and 2005. NOAA Technical Memorandum NOS-NCCOS-68. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal and Ocean Science. <https://repository.library.noaa.gov/view/noaa/9288>
- Balthis, W. L., Hyland, J. L., Cooksey, C., Fulton, M. H., & Wirth, E. F. (2015). Long-term monitoring of ecological conditions in Gray's Reef National Marine Sanctuary: Soft-bottom benthic assemblages and contaminant levels in sediments and biota (2000, 2005, and 2012/2013). NOAA Technical Memorandum NOS-NCCOS-206. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal and Ocean Science. <http://doi.org/10.7289/V5/TM-NOS-NCCOS-206>
- Barker, N. H. L., & Roberts, C. M. (2004). Scuba diver behavior and the management of diving impacts on coral reefs. *Biological Conservation*, 120(4), 481–489. <https://doi.org/10.1016/j.biocon.2004.03.021>
- Bauer, L. J., Kendall, M. S., & Jeffrey, C. F. G. (2008). Incidence of marine debris and its relationships with benthic features in Gray's Reef National Marine Sanctuary, Southeast USA. *Marine Pollution Bulletin*, 56, 402–413. <https://doi.org/10.1016/j.marpolbul.2007.11.001>
- Bauer, L. J., Kendall, M. S., & McFall, G. (2010). Assessment and monitoring of marine debris in Gray's Reef National Marine Sanctuary. NOAA Technical Memorandum NOS NCCOS 113. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, Biogeography Branch and Office of National Marine Sanctuaries, Gray's Reef National Marine Sanctuary. <https://repository.library.noaa.gov/view/noaa/12040>
- Bell, K. (2020). Atlantic slave trade to Savannah. *New Georgia Encyclopedia*. <https://www.georgiaencyclopedia.org/articles/history-archaeology/atlantic-slave-trade-to-savannah/>
- Borggaard, D. L., Dick, D. M., Star, J., Zoodsma, B., Alexander, M. A., Asaro, M. J., Barre, L., Bettridge, S., Burns, P., Crocker, J., Dortch, Q., Garrison, L., Gulland, F., Haskell, B., Hayes, S., Henry, A., Hyde, K., Milliken, H., Quinlan, J., ...& Walsh, H. (2020). North Atlantic right whale (*Eubalaena glacialis*) scenario planning summary report. NOAA Technical Memorandum NMFS-OPR-68. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. <https://repository.library.noaa.gov/view/noaa/33878>
- Botta, R., Eynon, J., & Schwarzmann, D. (2024). Evaluation of and motivations for conservation science in Gray's Reef National Marine Sanctuary. National Marine Sanctuaries Conservation Series ONMS-24-

07. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.  
<https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2024-conservation-science-in-grays-reef.pdf>
- Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63(2–3), 616–626.  
<https://doi.org/10.1016/j.ecolecon.2007.01.002>
- Burns, R. C., Andrew, R. G., Hurtado, M., & Lemmen, M. (2022). National marine sanctuary visitor counting process Gray's Reef pilot study [Unpublished report]. West Virginia University.
- Busenbark, S. (2023, May 26). Red snapper season announced for South Atlantic and it's abysmal. *Florida Sportsman*. <https://www.floridasportsman.com/editorial/red-snapper-season-announced-for-south-atlantic/474100>
- Campanella, F., Auster, P. J., Taylor, J. C., & Muñoz, R. C. (2019). Dynamics of predator-prey habitat use and behavioral interactions over diel periods at sub-tropical reefs. *PLoS ONE*, 14(2), e0211886.  
<https://doi.org/10.1371/journal.pone.0211886>
- Campanella, F., Auster, P. J., Taylor, C., Muñoz, R., & Fribance, D. (2020). Patterns of predator-prey co-occurrence and behavioral interactions over diel periods at sub-tropical reefs: results from 2016 observations. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), *Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic)* (pp. 86–97). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://sanctuaries.noaa.gov/science/conservation/grnms-research-area-report-2020.html>
- Carballo, J. L., & Bell, J. J. (2017). Climate change, ocean acidification, and sponges: Impacts across multiple levels of organization. Springer Cham. <https://doi.org/10.1007/978-3-319-59008-0>
- Carlson, J. K., McCandless, C. T., Cortes, E., Grubbs, R. D., Andrews, K. I., MacNeil, M. A., & Musick, J. A. (2009). An update on the status of the sand tiger shark, *Carcharias taurus* in the northwest Atlantic Ocean. NOAA Technical Memorandum NMFS-SEFSC-585. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center. <https://repository.library.noaa.gov/view/noaa/8654>
- Chan, F., Barth, J. A., Blanchette, C. A., Byrne, R. H., Chavez, F., Cheriton, O., Feely, R. A., Friederich, G., Gaylord, B., Gouhier, T., Hacker, S., Hill, T., Hofmann, G., McManus, M. A., Menge, B. A., Nielsen, K. J., Russell, A., Sanford, E., Sevadjian, J., & Washburn, L. (2017). Persistent spatial structuring of coastal ocean acidification in the California Current System. *Scientific Reports*, 7, 2526.  
<https://doi.org/10.1038/s41598-017-02777-y>
- Compagno, L. J. V. (1984). *FAO species catalogue: Vol. 4, Part 1 sharks of the world; An annotated and illustrated catalogue of shark species known to date*. FAO Fisheries Synopsis No. 125. United Nations Development Programme, Food and Agriculture Organization of the United Nations.  
<https://www.fao.org/3/ad122e/ad122e.pdf>
- Conant, T. A., Dutton, P. H., Eguchi, T., Epperly, S. P., Fahy, C. C., Godfrey, M. H., MacPherson, S. L., Possardt, E. E., Schroeder, B. A., Seminoff, J. A., Snover, M. L., Upite, C. M., & Witherington, B. E. (2009). *Loggerhead sea turtle (Caretta caretta) 2009 status review under the U.S. Endangered Species Act*. Report of the Loggerhead Biological Review Team to the National Marine Fisheries Service.  
<https://repository.library.noaa.gov/view/noaa/16204>

- Convention on Biological Diversity. (2006). *Article 2. Use of terms*. United Nations Environment Programme. <https://www.cbd.int/convention/articles/?a=cbd-02>
- Cooksey, C., Hyland, J., Balthis, W. L., Fulton, M., Scott, G., & Bearden, D. (2004). *Soft-bottom benthic assemblages and levels of contaminants in sediments and biota at Gray's Reef National Marine Sanctuary and nearby shelf waters off the coast of Georgia (2000 and 2001)*. NOAA Technical Memorandum NOS NCCOS 6. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science. <https://repository.library.noaa.gov/view/noaa/17764>
- Coral Reef Conservation Program. (n.d.). *Coral facts*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://coralreef.noaa.gov/education/coralfacts.html>
- Côté, I. M. & Smith, N. S. (2018). The lionfish *Pterois* sp. invasion: Has the worst-case scenario come to pass? *Journal of Fish Biology*, 92(3), 660–689. <https://doi.org/10.1111/jfb.13544>
- Craig, J. K., Kellison, G. T., Binion-Rock, S. M., Regan, S. D., Karnauskas, M., Lee, S., He, R., Allen, D. M., Bachelor, N. M., Blondin, H., Buckel, J. A., Burton, M. L., Cross, S. L., Freitag, A., Groves, S. H., Hayes, C. A., Kimball, M. E., Morley, J. W., Munoz, R. C., ... Volkov, D. L. (2021). *Ecosystem status report for the U.S. South Atlantic region*. NOAA Technical Memorandum NMFS-SEFSC-753. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center. <https://doi.org/10.25923/qmgr-pro3>
- Daniel, A., & Gleason, D. (2021). *Impacts of tropical cyclones on benthic invertebrates of Gray's Reef National Marine Sanctuary, 2010–2019* [Unpublished data set]. Georgia Southern University.
- Dayton, P. K. (1972). Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. In B. C. Parker (Ed.), *Proceedings of the colloquium on conservation problems in Antarctica* (pp. 81–96). Allen Press.
- Ding, D. S., Patel, A. K., Singhanian, R. R., Chen, C. W., & Dong, C. D. (2022). Effects of temperature and salinity on growth, metabolism and digestive enzymes synthesis of *Goniopora columna*. *Biology*, 11(3), 436. <https://doi.org/10.3390/biology11030436>
- Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2009). Ocean acidification: The other CO<sub>2</sub> problem. *Annual Review of Marine Science*, 1, 169–192. <https://doi.org/10.1146/annurev.marine.010908.163834>
- Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate change impacts on marine ecosystems. *Annual Review of Marine Science*, 4, 11–37. <https://doi.org/10.1146/annurev-marine-041911-111611>
- Duggan, J., Cvitanovic, C., & van Putten, I. (2023). Measuring sense of place in social-ecological systems: A review of literature and future research needs. *Ecosystems and People*, 19(1), 2162968. <https://doi.org/10.1080/26395916.2022.2162968>
- Eggleton, J., & Thomas, K. V. (2004). A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. *Environment International*, 30(7), 973–980. <https://doi.org/10.1016/j.envint.2004.03.001>
- Evans, D. R., Carthy, R. R., & Ceriani, S. A. (2019). Migration routes, foraging behavior, and site fidelity of loggerhead sea turtles (*Caretta caretta*) satellite tracked from a globally important rookery. *Marine Biology*, 166, 134. <https://doi.org/10.1007/s00227-019-3583-4>

- Federal Geographic Data Committee. (2012). *Coastal and marine ecological classification standard*, version 4.0. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee.
- Ferreira J. G., Andersen J. H., Borja, A., Bricker S. B., Camp, J., Cardoso da Silva, M., Garcés, E., Heiskanen, A., Humborg, C., Ignatiades, L., Lancelot, C., Menesguen, A., Tett, P., Hoepffner, N., & Claussen, U. (2011). Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. *Estuarine, Coastal and Shelf Science*, 93(2), 117–131. <https://doi.org/10.1016/j.ecss.2011.03.014>
- Fisher, B., & Turner, R. K. (2008). Ecosystem services: Classification for valuation. *Biological Conservation*, 141(5), 1167–1169. <https://doi.org/10.1016/j.biocon.2008.02.019>
- Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, 68(3), 643–653. <https://doi.org/10.1016/j.ecolecon.2008.09.014>
- Florida Fish and Wildlife Conservation Commission. (2024). *Asian green mussel*. <https://myfwc.com/research/saltwater/mollusc/other-molluscs/asian-green-mussels/>
- Flower Garden Banks National Marine Sanctuary. (2024). *Invasive cup coral*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://flowergarden.noaa.gov/education/invasivecupcoral.html>
- Fodrie, F. J., Heck, K. L., Jr., Powers, S. P., Graham, W. M., & Robinson, K. L. (2010). Climate-related, decadal-scale changes of seagrass-associated fishes in the northern Gulf of Mexico. *Global Change Biology*, 16(1), 48–59. <https://doi.org/10.1111/j.1365-2486.2009.01889.x>
- Fofonoff, P. W., Ruiz, G. M., Steves, B., Simkanin, C., & Carlton, J. T. (2023, May 31). *National Exotic Marine and Estuarine Species Information System (NEMESIS)* [Data set]. Smithsonian Institution. <https://invasions.si.edu/nemesis/>
- Fogarty, H. E., Burrows, M. T., Pecl, G. T., Robinson, L. M., & Poloczanska, E. S. (2017). Are fish outside their usual ranges early indicators of climate-driven range shifts? *Global Change Biology*, 23(5), 2047–2057. <https://doi.org/10.1111/gcb.13635>
- Food and Agriculture Organization of the United Nations. (2023). *FishStatJ: Software for Fishery and Aquaculture Statistical Time Series; Global Aquatic Trade, By Partner Country, Quantities and Values, 2019–2021* [Data set]. [www.fao.org/fishery/en/statistics/software/fishstatj](http://www.fao.org/fishery/en/statistics/software/fishstatj)
- Frimpong, E. (2023). *Economic impact of saltwater recreational fishing in Georgia*. Marine Extension and Georgia Sea Grant, University of Georgia. <https://gacoast.uga.edu/wp-content/uploads/2024/02/EconomicImpactofSaltwaterRecreationalFishinginGeorgia-508.pdf>
- Froehlich, H. E., Gentry, R. R., Lester, S. E., Cottrell, R. S., Fay, G., Branch, T. A., Gephart, J. A., White, E.R., & Baum, J. K. (2021). Securing a sustainable future for US seafood in the wake of a global crisis. *Marine Policy*, 124, 104328. <https://doi.org/10.1016/j.marpol.2020.104328>
- Gabriel, S., Auster, P. J., & Kracker, L. (2020). Assessing patterns of prey fish abundance and patchiness at live-bottom reefs using hydroacoustics, 2011–2013. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), *Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic)* (pp. 77–85). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://sanctuaries.noaa.gov/science/conservation/grnms-research-area-report-2020.html>
- Galgani, F., Leaute, J. P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., Mahe, J. C., Poulard, J. C., & Nerisson, P. (2000). Litter on the sea floor along

## Literature Cited

- European coasts. *Marine Pollution Bulletin*, 40(6), 516–527. [https://doi.org/10.1016/S0025-326X\(99\)00234-9](https://doi.org/10.1016/S0025-326X(99)00234-9)
- Garrison, E. (2022). *Gray's Reef National Marine Sanctuary paleontological/archaeological accession* [Data Set]. Department of Anthropology, University of Georgia.
- Garrison, E. G., Hale, J. C., Cameron, C. S., & Smith, E. (2016). The archeology, sedimentology and paleontology of Gray's Reef National Marine Sanctuary and nearby hard bottom reefs along the mid continental shelf of the Georgia Bight. *Journal of Archaeological Science: Reports*, 5, 240–262. <https://doi.org/10.1016/j.jasrep.2015.11.009>
- Geiger, S. (2021). *An analysis of distribution and abundance of microplastics in water and sediments from the lower Wassaw Sound estuary and Gray's Reef National Marine Sanctuary* [Master's thesis, Savannah State University]. ProQuest Dissertations Publishing.
- Georgia Department of Natural Resources. (2021). *Guidelines for eating fish from Georgia waters*. <https://epd.georgia.gov/watershed-protection-branch/watershed-planning-and-monitoring-program/fish-consumption-guidelines>
- Georgia Department of Natural Resources. (2022). *Annual internal summary reports to NOAA Office of Law Enforcement on resource expenditures and enforcement outcomes related to GRNMS patrols, 2012–2021* [Unpublished reports].
- Georgia Department of Public Health. (2014). *Coastal Georgia harmful algal bloom response plan: A public health and natural resources response*. <https://coastalhealthdistrict.org/wp-content/uploads/2011/04/Coastal-HAB-Plan-REV.-6.11.14-FINAL.pdf>
- Georgia Fishing Spots. (2023). *Georgia fishing spots: Georgia GPS fishing spots for saltwater fishing and lake fishing*. <https://Gafishingspots.com>
- Georgia Public Broadcasting. (2017). *Local content and service report 2017*. [https://www.gpb.org/sites/default/files/2020-06/gpb\\_local\\_content\\_and\\_services\\_report\\_2017.pdf](https://www.gpb.org/sites/default/files/2020-06/gpb_local_content_and_services_report_2017.pdf)
- Georgia River Network. (2023). *Altamaha River: Quick facts about the river*. <https://garivers.org/altamaha-river/>
- Gleason, D. (2010). New stresses, new strategies: Managing marine protected areas in an age of global environmental change. *Current: The Journal of Marine Education*, 26(2), 35–40.
- Gleason, D. F. (2020). Project 1. Assessments of sessile benthic invertebrate communities inside and outside Gray's Reef National Marine Sanctuary Research Area, 2011–2016. In Roberson, K. W., Auster, P. J., Fangman, S., & Harvey, M. (Eds.), *Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic)* (pp. 36–51). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/grnms-research-area-report-final-for-publication-5-21-20.pdf>
- Gleason, D. F., & Cohen, R. A. (2012). *Transport of waterborne substances from Georgia rivers to offshore reefs of the South Atlantic Bight* [Unpublished report]. Final report for a project funded by Environmental Protection Agency Region 4. Georgia Southern University.
- Gleason, D. F., Harbin, L. R., Divine, L. M., & Matterson, K. O. (2018). The role of larval supply and competition in controlling recruitment of temperate coral *Oculina arbuscula*. *Journal of Experimental Marine Biology and Ecology*, 506, 107–144. <https://doi.org/10.1016/j.jembe.2018.06.006>

## Literature Cited

- Gleason, D.F., Stefaniak, L., Reigel-Parker, A., Varnerin, B., Cohen, R., Matterson, K., Poirson, B., Daniel, A., & Soss, A. (2022). *The effects of implementing a protected area on the community structure of sessile invertebrates in Gray's Reef National Marine Sanctuary: The first 11 years, 2011–2022* [Unpublished data set]. Georgia Southern University.
- Gleason, D. F., Harvey, A. W., & Vives, S. P. (2023, May 9). *A guide to the benthic invertebrates and cryptic fishes of Gray's Reef. Field Guide to Invertebrates of Gray's Reef*. Retrieved June 12, 2023, from <https://sites.google.com/georgiasouthern.edu/graysreefinvertebrates/home>
- Goldberg, N. A., & Heine, J. N. (2012). Macroalgae at Gray's Reef National Marine Sanctuary, Georgia. *Southeastern Naturalist*, 11(3), 477–486. [https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/science/publications/pdfs/goldberg\\_heine\\_2012.pdf](https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/science/publications/pdfs/goldberg_heine_2012.pdf)
- Google. (2023). *Google analytics for graysreef.noaa.gov, November 2015 to December 2022* [Unpublished data set].
- Grant, A., & Middleton, R. (1998). Contaminants in sediments: Using robust regression for grain-size normalization. *Estuaries*, 21(2), 197–203. <https://doi.org/10.2307/1352468>
- Gray, J., Wu, R. S., & Or, Y. Y. (2002). Effects of hypoxia and organic enrichment on the coastal marine environment. *Marine Ecology Progress Series*, 238, 249–279. <https://doi.org/10.3354/meps238249>
- Gray's Reef National Marine Sanctuary. (2021a). *Sea turtle sightings, 2010–2021* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.
- Gray's Reef National Marine Sanctuary. (2021b). *SanctSound hydrophone surveys, 2018–2021* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.
- Gray's Reef National Marine Sanctuary. (2023a). *Lionfish sightings, 2007–2023* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.
- Gray's Reef National Marine Sanctuary. (2023b). *Sam Gray*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://graysreef.noaa.gov/about/sanctuary/history/sam-gray.html>
- Gray's Reef National Marine Sanctuary. (2024). *Gray's Reef National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://graysreef.noaa.gov/>
- Gray's Reef National Marine Sanctuary Foundation. (2023). *MATE ROV Competition participation, 2012 to 2022* [Unpublished dataset].
- Greene, A. K. (2008). *Invertebrate endofauna associated with sponge and octocoral epifauna at Gray's Reef National Marine Sanctuary off the coast of Georgia* [Master's thesis]. College of Charleston. <https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/science/publications/pdfs/i-12.pdf>
- Gullah Geechee Cultural Heritage Corridor Commission. (2012). *Gullah Geechee Cultural Heritage Corridor management plan*. Prepared by U.S. Department of Interior, National Park Service, Denver Service Center. <https://gullahgeecheecorridor.org/resources/management-plan/>
- Hagen, M., Kissling, W. D., Rasmussen, C., De Aguiar, M. A. M., Brown, L. E., Carstensen, D. W., Alves-Dos-Santos, I., Dupont, Y. L., Edwards, F. K., Genini, J., Guimarães, P. R., Jr., Jenkins, G. B., Jordano, P., Kaiser-Bunbury, C. N., Ledger, M. E., Maia, K. P., Marquitti, F. M. D., Mclaughlin, O., Morellato, L.

## Literature Cited

- P. C.,...& Olesen, J. M. (2012). 2–Biodiversity, species interactions and ecological networks in a fragmented world. *Advances in Ecological Research*, 46, 89–210. <https://doi.org/10.1016/B978-0-12-396992-7.00002-2>
- Hamline University Center for Global Environmental Education. (2023). *Ocean Media Gallery usage metrics, March 2021 to December 2022*. [Unpublished data set].
- Harding, J. L., & Henry, V. J. (1990). *Geological history of Gray's Reef National Marine Sanctuary*. A final report to U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine and Estuarine Management Division under cooperative agreement NA-87-AA-H-CZ033. <https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/science/publications/pdfs/b-03.pdf>
- Harley, C. D. G., Hughes, A. R., Hultgren, K. M., Miner, B. G., Sorte, C. J. B., Thornber, C. S., Rodriguez, L. F., Tomanek, L., & Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters*, 9, 228–241. <https://doi.org/10.1111/j.1461-0248.2005.00871.x>
- Haugan, P. M., & Drange, H. (1996). Effects of CO<sub>2</sub> on the ocean environment. *Energy Conversion and Management*, 37(6–8), 1019–1022. [https://doi.org/10.1016/0196-8904\(95\)00292-8](https://doi.org/10.1016/0196-8904(95)00292-8)
- Hausmann, A., Slotow, R., Burns, J. K., & Di Minin, E. (2015). The ecosystem service of sense of place: Benefits for human well-being and biodiversity conservation. *Environmental Conservation*, 43(2), 117–127. <https://doi.org/10.1017/S0376892915000314>
- Hernández, B., Hidalgo, M. C., Salazar-Laplace, M. E., & Hess, S. (2007). Place attachment and place identity in natives and non-natives. *Journal of Environmental Psychology*, 27(4), 310–319. <https://doi.org/10.1016/j.jenvp.2007.06.003>
- Hobday, A. J., Alexander, L. V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C. J., Benthuyzen, J. A., Burrows, M. T., Donat, M. G., Feng, M., Holbrook, N. J., Moore, P. J., Scannell, H. A., Gupta, A. S., & Wernberg, T. (2016). A hierarchical approach to defining marine heatwaves. *Progress in Oceanography*, 141, 227–238. <https://doi.org/10.1016/j.pocean.2015.12.014>
- Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., Caldeira, K., Knowlton, N., Eakin, C. M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R. H., Dubi, A., & Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, 318(5857), 1737–1742. <https://doi.org/10.1126/science.1152509>
- Horsley, S. (2020). *Iconic species and a sense of place* [Doctoral dissertation, University of Georgia]. ProQuest Dissertations Publishing.
- Horsley, S., Hohbein, R., Morrow, K., & Green, G. T. (2020). What's in a name? A content analysis of environmental NGOs' use of "iconic species" in press releases. *Biodiversity and Conservation*, 29, 2177–2728. <https://doi.org/10.1007/s10531-020-01995-7>
- Hoskins, D. (2015). *Georgia Black fishermen* [Data set]. Voices Oral History Archives. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries. <https://voices.nmfs.noaa.gov/collection/georgia-black-fishermen>
- Hoskins-Brown, D. L. (2020). Tales of landings and legacies: African Americans in Georgia's coastal fisheries. *Culture, Agriculture, Food and Environment*, 42(1), 36–50. <https://doi.org/10.1111/cuag.12248>
- Hunt, J. L. (1974). *The geology and origin of Gray's Reef, Georgia continental shelf* [Master's thesis]. University of Georgia.

## Literature Cited

- Hyland, J., Cooksey, C., Balthis, W. L., Fulton, M., Bearden, D., McFall, G. F., & Kendall, M. (2006). The soft-bottom macrobenthos of Gray's Reef National Marine Sanctuary and nearby shelf waters off the coast of Georgia, USA. *Journal of Experimental Marine Biology and Ecology*, 330(1), 307–326. <https://doi.org/10.1016/j.jembe.2005.12.036>
- Independent Sector. (2023). *Value of volunteer time*. <https://independentsector.org/resource/value-of-volunteer-time/>
- Integrated Ocean Observing System. (2023). *SanctSound: Gray's Reef National Marine Sanctuary*. [https://sanctsound.ioos.us/s\\_grnms.html](https://sanctsound.ioos.us/s_grnms.html)
- Keeling, R. F., Körtzinger, A., & Gruber, N. (2010). Ocean deoxygenation in a warming world. *Annual Review of Marine Science*, 2, 199–229. <https://doi.org/10.1146/annurev.marine.010908.163855>
- Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., Cook, G. S., Lorenz, J. J., & Boyer, J. N. (2013). The EBM-DPSEER conceptual model: Integrating ecosystem services into the DPSIR framework. *PLoS ONE*, 8(8), e70766. <https://doi.org/10.1371/journal.pone.0070766>
- Kendall, M. S., Jensen, O. P., McFall, G., Bohne, R., Field, D., Alexander, C., & Monaco, M. E. (2003). *Benthic habitats of Gray's Reef National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment. <https://repository.library.noaa.gov/view/noaa/17804>
- Kendall, M. S., Jensen, O. P., Alexander, C., Field, D., McFall, G., Bohne, R., & Monaco, M. E. (2005). Benthic mapping using sonar, video transects, and an innovative approach to accuracy assessment: A characterization of bottom features in the Georgia Bight. *Journal of Coastal Research*, 21(6), 1154–1165. <https://doi.org/10.2112/03-0101R.1>
- Kendall, M. S., & Eschelbach, K. A. (2006). *Boundary options for a research area within Gray's Reef National Marine Sanctuary*. NOAA Technical Memorandum NOS NCCOS 31. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science. <https://repository.library.noaa.gov/view/noaa/9280>
- Kendall, M. S., Bauer, L. J., & Jeffrey, C. F. G. (2007). *Characterization of the benthos, marine debris and bottom fish at Gray's Reef National Marine Sanctuary*. NOAA Technical Memorandum NOS NCCOS 50. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science. <https://repository.library.noaa.gov/view/noaa/482>
- Kendall, M. S., Bauer, L. J., & Jeffrey, C. F. G. (2008). Influence of benthic features and fishing pressure on size and distribution of three exploited reef fishes from the southeastern United States. *Transactions of the American Fisheries Society*, 137(4), 1134–1146. <https://doi.org/10.1577/TO7-210.1>
- Kendall, M. S., Bauer, L. J., & Jeffrey, C. F. G. (2009). Influence of hard bottom morphology on fish assemblages of the continental shelf off Georgia, southeastern USA. *Bulletin of Marine Science*, 84(3), 265–286.
- Kendall, M. S., Battista, T. A., Carson, M., Caskey, W., Grissom, K., Guthrie, B., Head, M., Jeffrey, C. F. G., Kuzemchak, M., Roberson, K. W., Rowell, T. J., Shortland, B., & Stanley, J. A. (2020). *Observations of visitation to Gray's Reef National Marine Sanctuary*. NOAA Technical Memorandum NOS-NCCOS-281. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal and Ocean Science. <https://doi.org/10.25923/hct8-6y08>
- Khan, M. N., & Mohammad, F. (2014). Eutrophication: Challenges and solutions. In A. A. Ansari & S. S. Gill (Eds.), *Eutrophication: Causes, consequences and control* (pp. 1–15). Springer. [https://doi.org/10.1007/978-94-007-7814-6\\_1](https://doi.org/10.1007/978-94-007-7814-6_1)

## Literature Cited

- Kimball, M.E., Miller, J. M., Whitfield, P. E., & Hare, J. A. (2004). Thermal tolerance and potential distribution of invasive lionfish (*Pterois volitans/miles* complex) on the east coast of the United States. *Marine Ecology Progress Series*, 283, 269–278. <https://doi.org/10.3354/meps283269>
- Kusku, H., Yigit, M., Ergun, S., Yigit, U., & Taylor, N. (2018). Acoustic noise pollution from marine industrial activities; exposure and impacts. *Aquatic Research*, 1(4), 148–161. <https://doi.org/10.3153/AR18017>
- Lakhan, V. C., Cabana, K., & LaValle, P. D. (2003). Relationship between grain size and heavy metals in sediments from beaches along the coast of Guyana. *Journal of Coastal Research*, 19(3), 600–608. <https://www.jstor.org/stable/4299201>
- Lamb, J. B., True, J. D., Piromvaragorn, S., & Willis, B. L. (2014). Scuba diving damage and intensity of tourist activities increases coral disease prevalence. *Biological Conservation*, 178, 88–96. <http://dx.doi.org/10.1016/j.biocon.2014.06.027>
- Leeworthy, V. R. (2013). *Technical appendix: Knowledge, attitudes and perceptions of management strategies and regulations of the Gray's Reef National Marine Sanctuary by users and non-users of the sanctuary: Version 2*. Marine Sanctuaries Conservation Series ONMS-13-03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. [https://nmssanctuaries.blob.core.windows.net/sanctuariesprod/media/archive/science/conservation/pdfs/kap\\_tech2.pdf](https://nmssanctuaries.blob.core.windows.net/sanctuariesprod/media/archive/science/conservation/pdfs/kap_tech2.pdf)
- Lemmen, M., Burns, R. C., Andrew, R. G., & Moreira, J. C. (2023). Visitors' environmental concerns in Gray's Reef National Marine Sanctuary: An offshore marine protected area. *Water*, 15(7), 1425. <https://doi.org/10.3390/w15071425>
- Levin, P. S., & Hay, M. E. (1996). Responses of temperate reef fishes to alterations in algal structure and species composition. *Marine Ecology Progress Series*, 134, 37–47. <https://doi.org/10.3354/meps134037>
- López-Figueroa, N. B., Walters, T. L., Laureano-Rosario, A. E., DiGeronimo, S. P., Hallock, P., Frischer, M. E., Rodríguez-Santiago, A. E., & Gibson, D. M. (2023). Zooplankton community variability in the South Atlantic Bight (2015–2017). *Journal of Plankton Research*, 45(2), 312–324. <https://doi.org/10.1093/plankt/fbad001>
- Lovell, S., Hilger, J., Rollins, E., Olsen, N. A., & Steinback, S. (2020). *The economic contribution of marine angler expenditures on fishing trips in the United States, 2017*. NOAA Technical Memorandum NMFS-F/SPO-201. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. <https://spo.nmfs.noaa.gov/sites/default/files/TM201.pdf>
- Maloni, M., Paul, J. A., & Gligor, D. M. (2013). Slow steaming impacts on ocean carriers and shippers. *Maritime Economics and Logistics*, 15, 151–171. <https://doi.org/10.1057/mel.2013.2>
- Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., Santurtún, M., Tien, N., & Ulrich, C. (2006). Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. *Canadian Journal of Fisheries and Aquatic Sciences*, 63(3), 510–533. <https://doi.org/10.1139/f05-238>
- Marshall, P., & Schuttenberg, H. (2006). *A reef manager's guide to coral bleaching*. Great Barrier Reef Marine Park Authority. [https://www.coris.noaa.gov/activities/reef\\_managers\\_guide/reef\\_managers\\_guide.pdf](https://www.coris.noaa.gov/activities/reef_managers_guide/reef_managers_guide.pdf)

## Literature Cited

- Matthews, L. P., & Parks, S. E. (2021). An overview of North Atlantic right whale acoustic behavior, hearing capabilities, and responses to sound. *Marine Pollution Bulletin*, 173, 113043. <https://doi.org/10.1016/j.marpolbul.2021.113043>
- Mayle, M. C. (2010, March 22). Oil spill shuts down Savannah River. *Savannah Morning News*. <https://www.savannahnow.com/story/news/2010/03/22/oil-spill-shuts-down-savannah/13699087007/>
- Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: A framework for assessment*. Washington, DC: Island Press. <https://millenniumassessment.org/en/Framework.html>
- Mitchell, W. A., Kellison, G. T., Bachelor, N. M., Potts, J. C., Schobernd, C. M., & Hale, L. F. (2014). Depth-related distribution of postjuvenile red snapper in southeastern U.S. Atlantic Ocean waters: Ontogenic patterns and implications for management. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 6(1), 142–155. <https://doi.org/10.1080/19425120.2014.920743>
- Monacci, N., Cross, J., Bott, R., Kozyr, A., Andersson, A. J., Bates, N. R., Cai, W.-J., Cronin, M. F., De Carlo, E. H., Hales, B., Howden, S. D., Lee, C. M., Manzello, D. P., McPhaden, M. J., Meléndez, M., Mickett, J. B., Newton, J. A., Noakes, S. E., Noh, J. H.,...& Weller, R. A. (2019). Autonomous seawater pCO<sub>2</sub> and pH time series from 40 surface buoys and the emergence of anthropogenic trends. *Earth System Science Data*, 11(1), 421–439. <https://doi.org/10.5194/essd-11-421-2019>.
- Moore, E. (2022). *Time and tide: A history of the National Marine Sanctuary System*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://sanctuaries.noaa.gov/media/docs/2022-time-and-tide-a-history-of-the-national-marine-sanctuary-system.pdf>
- Muñoz, R. (2019). *Snapper/grouper, schooling prey fishes, juvenile habitat utilization, and threatened sea turtles associated with biodiversity “hot spot” ledges in GRNMS* [Oral presentation]. Presentation to Gray’s Reef National Marine Sanctuary Science Advisory Group, Savannah, GA, United States.
- Muñoz, R. C., Currin, C. A., & Whitfield, P. E. (2011). Diet of invasive lionfish on hard bottom reefs of the Southeast USA: insights from stomach contents and stable isotopes. *Marine Ecology Progress Series*, 432, 181–193. <https://doi.org/10.3354/meps09154>
- Muñoz, R., Buckel, C., Fangman, S., & Roberson, K. (2019). *Benthic fish community and structural habitat surveys, 2010–2019* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries, Southeast Fisheries Science Center.
- Muñoz, R. C., Buckel, C. A., & Fangman, S. A. (2020). Project 5. Benthic fish communities and structural habitat measurements from Gray’s Reef National Marine Sanctuary, 2010–2016. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), *Review of scientific research in and around the designated Research Area of Gray’s Reef National Marine Sanctuary (NW Atlantic)* (pp. 36–51). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/grnms-research-area-report-final-for-publication-5-21-20.pdf>
- Muñoz, R. C., Howard, K., Roberson, K., & Buckel, C. A. (2021). *The benthic fish community of Gray’s Reef National Marine Sanctuary and recent examples of tropicalization* [Oral presentation]. Georgia Climate Conference 2021, Jekyll Island Convention Center, Jekyll Island, GA, United States.
- Musick, J. A., Branstetter, S., & Colvocoresses, J. A. (1993). Trends in shark abundance from 1974 to 1991 for the Chesapeake Bight region of the U.S. Mid-Atlantic coast. In S. Branstetter (Ed.), *Conservation*

## Literature Cited

- biology of elasmobranchs* (pp. 1–18). NOAA Technical Report NMFS 115. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- National Centers for Coastal Ocean Science. (2015). *Harmful algal bloom monitoring system*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://coastalscience.noaa.gov/project/tools-managing-ciguatera-poisoning-risks-caribbean/>
- National Centers for Coastal Ocean Science. (2023). *Phytoplankton Monitoring Network data* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://coastalscience.noaa.gov/monitoring-and-assessments/pmn/data/>
- National Centers for Coastal Ocean Science. (n.d.) *The role of temperature and depth in fish community distribution off North Carolina with implications for invasive lionfish distribution*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://coastalscience.noaa.gov/project/temperature-depth-invasive-lionfish-distribution/>
- National Centers for Environmental Information. (2020). *Climate at a glance: Global time series; December temperature anomalies, 1880–2019* [Data set]. <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series>
- National Data Buoy Center & Southwest Fisheries Science Center. (2023). *NDBC standard meteorological buoy data, 1970–present* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service and National Marine Fisheries Service. <https://coastwatch.pfeg.noaa.gov/erddap/tabledap/cwvcNDBCMet.html?&station=%2241008%22&longitude=-80.869&latitude=31.402>
- National Marine Sanctuary Foundation & National Opinion Research Center at the University of Chicago. (2022). *Ocean protection in the United States: Exploring the public’s thoughts*. <https://marinesanctuary.org/wp-content/uploads/2022/09/National-Marine-Sanctuary-Foundation-Survey-Report-FINAL-1.pdf>
- National Marine Sanctuary Program. (2004). *A monitoring framework for the national marine sanctuary system*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://repository.library.noaa.gov/view/noaa/10811>
- National Oceanic and Atmospheric Administration. (2018). *Quarterly kiosk exhibit visitation, 2013 to 2018* [Unpublished data set]. U.S. Department of Commerce.
- National Oceanic and Atmospheric Administration. (2020). *The Integrated Ecosystem Assessment approach*. U.S. Department of Commerce. <https://www.integratedecosystemassessment.noaa.gov/about-iea/iea-approach>
- National Oceanic and Atmospheric Administration. (2024). *Climate change: Ocean heat content*. U.S. Department of Commerce. <https://www.climate.gov/news-features/understanding-climate/climate-change-ocean-heat-content#:~:text=Rising%20amounts%20of%20greenhouse%20gases,over%20the%20past%20few%20decades.>
- National Park Service. (2021). *Vital signs monitoring*. <https://www.nps.gov/im/vital-signs.htm>
- National Weather Service. (2023). *NOAA 2023 Atlantic hurricane season outlook*. Climate Prediction Center. <https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml>
- Nelson, R. S., & Parker, R. D. (1986). *A quantitative approach to estimating reef fish abundance and community composition using scuba divers in the Gray’s Reef National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine

## Literature Cited

- Fisheries Service. <https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/science/publications/pdfs/a-26.pdf>
- NOAA CoastWatch. (2023). *CoastWatch data portal* [Data set]. <https://coastwatch.noaa.gov/cwn/data-access-tools/coastwatch-data-portal.html>
- NOAA Fisheries. (2022). *COPEPODITE: Spatiotemporal data and time series toolkit*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.st.nmfs.noaa.gov/copepod/toolkit/>
- NOAA Fisheries. (2023a). *North Atlantic right whale (Eubalaena glacialis): Western Atlantic stock*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.fisheries.noaa.gov/s3/2023-08/North-Atlantic-Right-Whale-Western-Atlantic-2022.pdf>
- NOAA Fisheries. (2023b). *Species directory: King mackerel*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.fisheries.noaa.gov/species/king-mackerel>
- NOAA Fisheries. (2024a). *Fisheries One Stop Shop: Landings* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. [https://www.fisheries.noaa.gov/foss/f?p=215:200:::~](https://www.fisheries.noaa.gov/foss/f?p=215:200:::)
- NOAA Fisheries. (2024b). *Species directory: North Atlantic right whale*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.fisheries.noaa.gov/species/north-atlantic-right-whale>
- NOAA Fisheries. (2024c). *Recreational fishing data glossary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.fisheries.noaa.gov/recreational-fishing-data/recreational-fishing-data-glossary>
- NOAA Global Monitoring Laboratory. (2024). *Annual Greenhouse Gas Index (AGGI)*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://gml.noaa.gov/aggi/aggi.html>
- NOAA Marine Debris Program. (2016). *Report on marine debris impacts on coastal and benthic habitats*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://repository.library.noaa.gov/view/noaa/21429>
- NOAA Marine Recreational Information Program. (2022). *Recreational fisheries statistics queries* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries. <https://www.fisheries.noaa.gov/data-tools/recreational-fisheries-statistics-queries>
- Noakes, S. (2020). Project 14. Carbon dioxide and water quality monitoring at Gray's Reef National Marine Sanctuary, 2006–2014. In K. W. Roberson, P. J. Auster, S. Fangman, & M. Harvey (Eds.), *Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic)* (pp. 36–51). National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://sanctuaries.noaa.gov/science/conservation/grnms-research-area-report-2020.html>
- Noakes, S. (2022a). *Temperature, pH, CO<sub>2</sub>, and salinity data, 2006 to 2022* [Unpublished data set]. University of Georgia.
- Noakes, S. (2022b). *Storm and hurricane data, 2008 to 2022* [Unpublished data set]. University of Georgia.
- Noakes, S. (2023). *Gray's Reef MAPCO<sub>2</sub> buoy dissolved oxygen records, 2011–2022* [Unpublished data set]. University of Georgia.

## Literature Cited

- Noakes, S. E., Pyenson, N. D., & McFall, G. (2013). Late Pleistocene gray whales (*Eschrichtius robustus*) offshore Georgia, U.S.A., and the antiquity of gray whale migration in the North Atlantic Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 392, 502–509. <https://doi.org/10.1016/j.palaeo.2013.10.005>
- Nuttle, W. K., & Fletcher, P. J. (Eds.) (2013). *Integrated conceptual ecosystem model development for the Florida Keys/Dry Tortugas coastal marine ecosystem*. NOAA Technical Memorandum OAR-AOML101/NOS-NCCOS-161. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. [https://www.aoml.noaa.gov/ocd/ocdweb/docs/MARES/NOAA%20Tech%20Memo-OAR-AOML-101\\_FKDT\\_20150422\\_MainBody.pdf](https://www.aoml.noaa.gov/ocd/ocdweb/docs/MARES/NOAA%20Tech%20Memo-OAR-AOML-101_FKDT_20150422_MainBody.pdf)
- O'Brien, T. D., & Oakes, S. A. (2020). Visualizing and exploring zooplankton spatio-temporal variability. In M. A. Teodósio & A. B. Barbosa (Eds.), *Zooplankton ecology* (pp. 192–224). CRC Press. <https://doi.org/10.1201/9781351021821>
- Office of National Marine Sanctuaries. (2008). *Gray's Reef National Marine Sanctuary condition report 2008*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. [https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/condition/pdfs/grnms\\_conditionreport08.pdf](https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/condition/pdfs/grnms_conditionreport08.pdf)
- Office of National Marine Sanctuaries. (2012). *Gray's Reef National Marine Sanctuary condition report addendum 2012*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. [https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/condition/pdfs/grnms\\_addendum\\_lr.pdf](https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/condition/pdfs/grnms_addendum_lr.pdf)
- Office of National Marine Sanctuaries. (2014). *Gray's Reef National Marine Sanctuary final management plan*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. [https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/management/mgmtplan/pdfs/grnms\\_mgmt\\_plan\\_072014.pdf](https://nmsgraysreef.blob.core.windows.net/graysreef-prod/media/archive/management/mgmtplan/pdfs/grnms_mgmt_plan_072014.pdf)
- Office of National Marine Sanctuaries. (2018). *Guide for developing national marine sanctuary condition reports*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2018-condition-report-guidance.pdf>
- Office of National Marine Sanctuaries. (2020). *Climate change impacts: Gray's Reef National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://sanctuaries.noaa.gov/media/docs/20200820-climate-change-impacts-grays-reef-national-marine-sanctuary.pdf>
- Office of National Marine Sanctuaries. (2022). *Our vision for America's treasured ocean places: A five-year strategy for the National Marine Sanctuary System*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.
- Office of National Marine Sanctuaries. (2023). *Online sanctuary permitting, reporting and evaluation system (OSPREY) database* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.
- Office of National Marine Sanctuaries, & U.S. Navy. (2021). *Octave band sound pressure levels at 1 hertz and 1 hour resolution recorded at SanctSound Site GRO1\_01, SanctSound data products*. NOAA National Centers for Environmental Information. <https://sanctsound.portal.axds.co/#sanctsound/chart/sanctsound.GRO1.sound-levels.octave-level.hour.stackedplot>

- Office of Response and Restoration. (2022). *Raw incident data* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. <https://incidentnews.noaa.gov/raw/index>
- Olenin, S., Alemany, F., Cardoso, A. C., Gollasch, S., Gouletquer, P., Lehtiniemi, M., McCollin, T., Minchin, D., Miossec, L., Occhipinti Ambrogi, A., Ojaveer, H., Rose Jensen, K., Stankiewicz, M., Wallentinus, I., & Aleksandrov, B. (2010). *Marine strategy framework directive: Task group 2 report; Non-indigenous species*. EUR 24342 EN. Luxembourg: Publications Office of the European Union. <https://publications.jrc.ec.europa.eu/repository/handle/JRC58108>
- Organisation for Economic Co-operation and Development. (2024). *GDP and spending*. <https://doi.org/10.1787/4537dc58-en>
- Ozburn, J. (2023). *Georgia vessel registration database* [Data set]. Georgia Department of Natural Resources, License and Boat Registration. <https://api.gooutdoorsgeorgia.com/exports/DataRequest.aspx>
- Ozburn, J. (2022). *Georgia Saltwater Information Program permit database* [Data set]. Georgia Department of Natural Resources, License and Boat Registration. <https://api.gooutdoorsgeorgia.com/exports/DataRequest.aspx>
- Pacific Marine Environmental Laboratory. (2022). *Gray's Reef*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://www.pmel.noaa.gov/co2/story/Grays+Reef>
- Paine, R. T. (1966). Food web complexity and species diversity. *The American Naturalist*, 100(910), 65–75.
- Parker, R. W. R., & Tyedmers, P. H. (2014). Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, 16(4), 684–696. <https://doi.org/10.1111/faf.12087>
- Pfeiler, E. Q. (2020). *Investigating the presence and impact of a novel Akashiwo sanguinea bloom in the Skidaway River Estuary* [Master's thesis]. University of Georgia.
- Physical Sciences Laboratory. (2022). *Marine heatwaves* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. <https://psl.noaa.gov/marine-heatwaves/>
- Prosser, D. J., Jordan, T. E., Nagel, J. L., Seitz, R. D., Weller, D. E., & Whigham, D. F. (2018). Impacts of coastal land use and shoreline armoring on estuarine ecosystems: an introduction to a special issue. *Estuaries and Coasts*, 41, 2–18. <https://doi.org/10.1007/s12237-017-0331-1>
- Rees, M. J., Knott, N. A., Hing, M. L., Hammond, M., Williams, J., Neilson, J., Swadling, D. S., & Jordan, A. (2021). Habitat and humans predict the distribution of juvenile and adult snapper (*Sparidae: Chrysophrys auratus*) along Australia's most populated coastline. *Estuarine, Coastal, and Shelf Science*, 257, 107397. <https://doi.org/10.1016/j.ecss.2021.107397>
- Reigel, A. M. (2015). *The role of artificial structures in facilitating range expansion of the introduced barnacle Megabalanus coccopoma in the southeastern U.S.A.* [Master's thesis]. Georgia Southern University.
- Renaud, P. E., Riggs, S. R., Ambrose, W. G., Jr., Schmid, K., & Snyder, S. W. (1997). Biological-geological interactions: Storm effects on macroalgal communities mediated by sediment characteristics and distribution. *Continental Shelf Research*, 17(1), 37–56. [https://doi.org/10.1016/0278-4343\(96\)00019-2](https://doi.org/10.1016/0278-4343(96)00019-2)
- Ries, J. B., Cohen, A. L., & McCorkle, D. C. (2010). A nonlinear calcification response to CO<sub>2</sub>-induced ocean acidification by the coral *Oculina arbuscula*. *Coral Reefs*, 29, 661–674. <https://doi.org/10.1007/s00338-010-0632-3>

## Literature Cited

- Rigby, C. L., Carlson, J., Derrick, D., Dicken, M., Pacoureaux, N., & Simpfendorfer, C. (2021). *Carcharias taurus*. *The IUCN Red List of Threatened Species 2021*, e.T3854A2876505. <https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T3854A2876505.en>
- Roberson, K. W., Auster, P. J., Fangman, S. A., & Harvey, M. (Eds.). (2020). *Review of scientific research in and around the designated Research Area of Gray's Reef National Marine Sanctuary (NW Atlantic)*. National Marine Sanctuaries Conservation Series ONMS-20-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/grnms-research-area-report-final-for-publication-5-21-20.pdf>
- Rogers, S. H. (2019). *The combined effects of pH and temperature on the physiology of the temperate coral *Oculina arbuscula** [Honors college thesis]. Georgia Southern University. <https://digitalcommons.georgiasouthern.edu/honors-theses/427/>
- Rosenfeld, J. S. (2002). Functional redundancy in ecology and conservation. *Oikos*, 98(1), 156–162. <https://doi.org/10.1034/j.1600-0706.2002.980116.x>
- Ruzicka, R., & Gleason, D. F. (2009). Sponge community structure and anti-predator defenses on temperate reefs of the South Atlantic Bight. *Journal of Experimental Marine Biology and Ecology*, 380, 36–46. <https://doi.org/10.1016/j.jembe.2009.08.011>
- Sakas, C. J., & Caglayan, M. (2018). *Shifting baselines* [Film]. Blue Voyage Productions, LLC.
- Samonte, G., Damato, N., & Schwarzmann, D. (2023). *Knowledge, attitudes, and perceptions: Gray's Reef National Marine Sanctuary*. National Marine Sanctuaries Conservation Series ONMS-23-12. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/20231215-grnms-knowledge-attitudes-perceptions.pdf>
- Sandulli, R., & Pinckney, R. (1999). Patch sizes and spatial patterns of meiobenthic copepods and benthic microalgae in sandy sediments: a microscale approach. *Journal of Sea Research*, 41(3), 179–187. [https://doi.org/10.1016/S1385-1101\(98\)00048-3](https://doi.org/10.1016/S1385-1101(98)00048-3)
- Searles, R. B. (1987). Phenology and floristics of seaweeds from the offshore waters of Georgia. *Northeast Gulf Science*, 9, 99–108. <https://doi.org/10.18785/negs.0902.04>
- Shein, K., Cavanaugh, J., Scalliet, H., Hutto, S., Roberson, K., Shortland, B., & Wenzel, L. (2019). *Rapid vulnerability assessment for Gray's Reef National Marine Sanctuary*. National Marine Sanctuaries Conservation Series ONMS-19-01. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. <https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/20190207-rapid-vulnerability-assessment-grnms.pdf>
- Silva, E., Marco, A., da Graça, J., Pérez, H., Abella, E., Patino-Martinez, J., Martins, S., & Almeida, C. (2017). Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings. *Journal of Photochemistry and Photobiology B: Biology*, 173, 240–249. <https://doi.org/10.1016/j.jphotobiol.2017.06.006>
- South Atlantic Fishery Management Council. (2024). *The South Atlantic Fishery Management Council: Managing federal fisheries from North Carolina to Florida*. <https://safmc.net/>
- Southeast Data, Assessment, and Review. (2020). *SEDAR 38 update: South Atlantic king mackerel; Stock assessment report*. <https://sedarweb.org/documents/2019-update-sedar-38-update-assessment-report-south-atlantic-king-mackerel/>

## Literature Cited

- Southeast Data, Assessment, and Review. (2021). *SEDAR 73: South Atlantic red snapper; Section II: Assessment report*. <https://sedarweb.org/documents/sedar-73-stock-assessment-report-south-atlantic-red-snapper/>
- Southeast Data, Assessment, and Review. (2023). *SEDAR 76: South Atlantic black sea bass; Stock assessment report*. <https://sedarweb.org/documents/sedar-76-stock-assessment-report-south-atlantic-black-sea-bass/>
- Stanley, J. A., Van Parijs, S. M., Davis, G. E., Sullivan, M., & Hatch, L. T. (2021). Monitoring spatial and temporal soundscape features within ecologically significant U.S. national marine sanctuaries. *Ecological Applications*, 31(8), e02439. <https://doi.org/10.1002/eap.2439>
- Stefanski, S. F., & Shimshack, J. P. (2016). Valuing marine biodiversity in the Gulf of Mexico: Evidence from the proposed boundary expansion of the Flower Garden Banks National Marine Sanctuary. *Marine Resource Economics*, 31(2), 211–232. <https://doi.org/10.1086/685109>
- Steward, D. N., Paxton, A. B., Bacheler, N. M., Schobernd, C. M., Mille, K., Renchen, J., Harrison, Z., Byrum, J., Martore, R., Brinton, C., Riley, K. L., Taylor, J. C., & Kellison, G. T. (2022). Quantifying spatial extents of artificial versus natural reefs in the seascape. *Frontiers in Marine Science*, 9, 980384. <https://doi.org/10.3389/fmars.2022.980384>
- Suatoni, L., Creation Justice Ministries, Georgia Interfaith Power and Light, Queen Quet, & Oceans Connect. (2024). *The Blake Plateau: A southern treasure*. National Resource Defense Council. <https://www.nrdc.org/resources/blake-plateau-southern-treasure>
- Sumaila, U. R., Teh, L., Watson, R., Tyedmers, P., & Pauly, D. (2008). Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science*, 65(6), 832–840. <https://doi.org/10.1093/icesjms/fsn070>
- Swadling, D. S., Knott, N. A., Taylor, M. D., Coleman, M. A., Davis, A. R., & Rees, M. J. (2022). Seascape connectivity of temperate fishes between estuarine nursery areas and open coastal reefs. *Journal of Applied Ecology*, 59(5), 1406–1416. <https://doi.org/10.1111/1365-2664.14157>
- Sweeney-Tookes, J., & Fluech, B. (2018). *Fishing traditions and fishing futures in Georgia* [Data set]. Voices Oral History Archives. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries. <https://voices.nmfs.noaa.gov/collection/fishing-traditions-fishing-futures-georgia>
- Sweeney-Tookes, J., & Fluech, B. (2022). *Boat stories* [Data set]. Voices Oral History Archives. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries. <https://voices.nmfs.noaa.gov/collection/boat-stories>
- Texas Invasive Species Institute. (2014). *Titan acorn barnacle*. <https://tsusinvasives.org/home/database/megabalanus-coccopoma>
- Thaxton, W. C., Taylor, J. C., & Asch, R. G. (2020). Climate-associated trends and variability in ichthyoplankton phenology from the longest continuous larval fish time series on the east coast of the United States. *Marine Ecology Progress Series*, 650, 269–287. <https://doi.org/10.3354/meps13404>
- The Conversation. (2023). *Urban light pollution is a danger for marine ecosystems—new research*. <https://theconversation.com/urban-light-pollution-is-a-danger-for-marine-ecosystems-new-research-196525>
- University of Georgia Marine Extension and Georgia Sea Grant. (2024). *Salt marsh ecology*. <https://gacoast.uga.edu/about/georgia-coast/salt-marsh-ecology/>

## Literature Cited

- U.S. Bureau of Economic Analysis. (2024). *CAINC1 County and MSA personal income summary: Personal income, population, per capita personal income* [Data set]. U.S. Department of Commerce. <https://apps.bea.gov/>
- U.S. Bureau of Labor Statistics. (2024). *Consumer Price Index inflation calculator*. U.S. Department of Labor. <https://data.bls.gov/cgi-bin/cpicalc.pl>
- U.S. Centers for Disease Control and Prevention. (2023). *Clinical signs and symptoms caused by saltwater harmful algal blooms*. <https://www.cdc.gov/harmful-algal-blooms/hcp/clinical-signs/symptoms-saltwater-harmful-algal-blooms.html>
- U.S. Coast Guard. (2022). *Records of the number of vessel incident reports per year, spill violations per year, and the volume of discharge and types of discharge from vessel discharges per year received in Georgia regional waters, yearly from 2007–2022* [Unpublished data set]. U.S. Coast Guard Incident Management Division. <https://www.atlanticarea.uscg.mil/Our-Organization/District-8/District-Units/Sector-Lower-Mississippi-River/Sector-LMR-Organization/Incident-Management-Division/>
- U.S. Coast Guard Navigation Center. (2022). *Automatic identification system vessel traffic data* [Data set]. U.S. Department of Homeland Security. <https://marinecadastre.gov/>
- U.S. Department of the Navy. (2018). *Atlantic fleet training and testing final environmental impact statement/overseas environmental impact statement*. <https://www.nepa.navy.mil/aftt-phase-iii/>
- U.S. Energy Information Administration. (2024). *Petroleum and other liquids: Gasoline and diesel fuel update* [Data set]. U.S. Department of Energy. <https://www.eia.gov/petroleum/gasdiesel/>
- U.S. Environmental Protection Agency. (1999). *Phase I final rule and technical development document of uniform national discharge standards (UNDS): Distillation and reverse osmosis brine; nature of discharge*. [https://www.epa.gov/sites/default/files/2015-08/documents/2007\\_07\\_10\\_oceans\\_regulatory\\_unds\\_tddddocuments\\_appadistillation.pdf](https://www.epa.gov/sites/default/files/2015-08/documents/2007_07_10_oceans_regulatory_unds_tddddocuments_appadistillation.pdf)
- U.S. Environmental Protection Agency. (2011). *Exhaust gas scrubber washwater effluent*. EPA-800-R-11-006. [https://www3.epa.gov/npdes/pubs/vgp\\_exhaust\\_gas\\_scrubber.pdf](https://www3.epa.gov/npdes/pubs/vgp_exhaust_gas_scrubber.pdf)
- U.S. Environmental Protection Agency. (2021). *Impacts of mismanaged trash*. <https://19january2021snapshot.epa.gov/trash-free-waters/impacts-mismanaged-trash.html>
- U.S. Geological Survey. (2022). *National Land Cover Database* [Data set]. <https://www.usgs.gov/centers/eros/science/national-land-cover-database>
- U.S. Geological Survey. (2023). *National Water Information System: Web interface; USGS 02226160 Altamaha River near Everett City, GA* [Data set]. U.S. Department of the Interior. <https://waterdata.usgs.gov/nwis>
- Van Putten, I. E., Plagányi, É. E., Booth, K., Cvitanovic, C., Kelly, R., Punt, A. E., & Richards, S. A. (2018). A framework for incorporating sense of place into the management of marine systems. *Ecology and Society*, 23(4), 4. <https://doi.org/10.5751/ES-10504-230404>
- Vaquer-Sunyer, R., & Duarte, C. M. (2008). Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, 105(40), 15452–15457. <https://doi.org/10.1073/pnas.0803833105>
- Varnerin, B. V., Hopkinson, B. M., & Gleason, D. F. (2020). Recruits of the temperate coral *Oculina arbuscula* mimic adults in their resilience to ocean acidification. *Marine Ecology Progress Series*, 636, 63–75. <https://doi.org/10.3354/meps13228>

## Literature Cited

- Verity, P. G., & Borkman, D. G. (2010). A decade of change in the Skidaway River Estuary. III. Plankton. *Estuaries and Coasts*, 33, 513–540. <https://doi.org/10.1007/s12237-009-9208-2>
- Walker, G. (2009, August 17). *Interview with George Walker* [Interview]. Georgia Black Fishermen Collection. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Voices Oral History Archives. [https://voices.nmfs.noaa.gov/sites/default/files/2022-04/Walker\\_George.pdf](https://voices.nmfs.noaa.gov/sites/default/files/2022-04/Walker_George.pdf)
- Walsh, K. J. E., McBride, J. L., Klotzbach, P. J., Balachandran, S., Camargo, S. J., Holland, G., Knutson, T. R., Kossin, J. P., Lee, T., Sobel, A., & Sugi, M. (2016). Tropical cyclones and climate change. *WIREs Climate Change*, 7(1), 65–89. <https://doi.org/10.1002/wcc.371>
- Wang, C., Arneson, E. M., Gleason, D. F., & Hopkinson, B. M. (2020). Resilience of the temperate coral *Oculina arbuscula* to ocean acidification extends to the physiological level. *Coral Reefs*, 40, 201–214. <https://doi.org/10.1007/s00338-020-02029-y>
- Weisberg, R. H., Zheng, L., & Peebles, E. (2014). Gag grouper larvae pathways on the West Florida Shelf. *Continental Shelf Research*, 88, 11–23. <https://doi.org/10.1016/j.csr.2014.06.003>
- White House Office of Management and Budget. (2004). *Final information quality bulletin for peer review*. <https://georgewbush-whitehouse.archives.gov/omb/memoranda/fy2005/m05-03.pdf>
- Whitfield, P. E., Muñoz, R. C., Buckel, C. A., Degan, B. P., Freshwater, D. W., & Hare, J. A. (2014). Native fish community structure and Indo-Pacific lionfish *Pterois volitans* densities along a depth-temperature gradient in Onslow Bay, North Carolina, USA. *Marine Ecology Progress Series*, 509, 241–254. <https://doi.org/10.3354/meps10882>
- Whittle, P. (2019). How a small stretch of ocean stirred a conservation movement. *Associated Press*. <https://apnews.com/article/9ff147207ca44613ba2cbbbeabe262cb6>
- Williams, B. L., Roberson, K., Young, J., & Kendall, M. S. (Eds). (2019). *Using acoustic telemetry to understand connectivity of Gray's Reef National Marine Sanctuary to the U.S. Atlantic coastal ocean*. NOAA Technical Memorandum NOS NCCOS 259. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science. <https://doi.org/10.25923/r2ma-5m96>
- Witherington, B. E., & Bjorndal, K. A., (1991). Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles *Caretta caretta*. *Biological Conservation*, 55(2), 139–149. [https://doi.org/10.1016/0006-3207\(91\)90053-C](https://doi.org/10.1016/0006-3207(91)90053-C)
- Zabel, R. W., Harvey, C. J., Katz, S. L., Good, T. P., & Levin, P. S. (2003). Ecologically sustainable yield. *American Scientist*, 91, 150–157. <https://www.jstor.org/stable/27858183>

## Appendix A: Questions and Rating Schemes for Status and Trends of Sanctuary Resources

Below are descriptions of the questions and possible responses used to report the condition of sanctuary resources in condition reports for all national marine sanctuaries. ONMS and subject matter experts use this guidance, as well as their own understanding of the condition of resources, to make judgments about the status and trends of sanctuary resources.

The resource questions derive from the National Marine Sanctuary System’s mission (Office of National Marine Sanctuaries, 2022) and a system-wide monitoring framework (National Marine Sanctuary Program, 2004) developed to ensure the timely flow of data and information to those responsible for managing and protecting resources in the ocean and coastal zone, and to those that use, depend on, and study sanctuary resources. The resource questions are used to guide ONMS and its partners at each unit in the sanctuary system in the development of sanctuary condition reports. Some resource questions may not be assessed by individual sanctuaries in cases where they are not relevant; for example, the maritime heritage questions are not addressed for sanctuaries that have no known tangible maritime heritage resources. Evaluations of resource status and trends are based on the interpretation of quantitative and, when necessary, non-quantitative assessments and observations by scientists, managers, and users.

In 2012, ONMS reviewed and edited the resource questions and their possible responses that were developed for the first round of condition reports (drafted between 2007 and 2014; National Marine Sanctuary Program, 2004). The questions that follow are revised and improved versions of those original questions. Although all questions have been edited to some degree, both in their description and status ratings, the nature and intent of most questions have not changed. Five questions, however, are either new or are significantly altered and are therefore not directly comparable to the original questions posed in the first round of condition reports. For these, a new baseline will need to be established.

- In the Water Quality section, one climate change question was added. This was necessary to address the increasing awareness and attention to the issue following the original design of the condition report process, which began in 2002.
- Two Habitat questions were combined due to feedback received during the development of the first round of reports. A single question regarding the “integrity of major habitat types” has been created and combines prior questions that separately inquired about non-biogenic and biogenic habitats. Experience showed that experts considered the condition of certain species (e.g., kelp, corals, and seagrass) critical to their assessment of most habitat, including those often considered non-biogenic; thus separating the two provided little added value.
- Among the Living Marine Resources questions, one used in the first round of condition reports was removed entirely. It asked about “the status of environmentally sustainable fishing.” It was removed for a variety of reasons. First, it was the only question focused on a single, specific human activity rather than a particular resource. Second,

considerations of fishing activity are already included in the question regarding “human activities that may influence living resources.” Finally, living resources that would provide a basis for judgment for this question are typically considered as part of other living resource questions, and need not be covered twice. Another change to the Living Marine Resources questions pertains to the question about the “health of key species,” which was previously addressed in a single question, but is now split into two. The first asks specifically about the status of “keystone and foundation” species, the second about “other focal species.” In both cases, the health of any species of interest can be considered in the judgment of status and trends.

- One of the initial questions addressed potential environmental hazards presented by heritage resources like shipwrecks. While the assessment of such threats is important, it was decided that the question was more appropriately addressed in the water quality and habitat contaminant questions rather than apply specifically to historic maritime properties. Therefore, the question was removed from the Maritime Heritage Resources section of the report and the subject is discussed in the context of other questions.

Ratings for a number of questions depend on judgments of the “ecological integrity” within a national marine sanctuary. This is because one of the foundational principles behind the establishment of sanctuaries is to protect ocean ecosystems. The term ecological integrity is used to imply “the presence of naturally occurring species, populations and communities, and ecological processes functioning at appropriate rates, scales, and levels of natural variation, as well as the environmental conditions that support these attributes” (modified from national park vital signs monitoring [National Park Service, 2021]). Sanctuaries have ecological integrity when they have their native components intact, including abiotic components (i.e., the physical forces and chemical elements, such as water), biotic elements (such as habitats), biodiversity (i.e., the composition and abundance of species and communities), and ecological processes (e.g., competition, predation, symbioses). For purposes of this report, the level of integrity that is judged to exist is based on the extent to which humans have altered specific components of the system, and the effect of that change on the ability of an ecosystem to resist continued change and recover from it. The statements for many questions are intended to reflect this judgment. Reference is made in the rating system to “near-pristine” conditions, for which this report would imply a status as near to an unaltered ecosystem as can reasonably be presumed to exist, recognizing that there are virtually no ecosystems on Earth completely free from human influence.

Not all questions, however, use ecological integrity as a basis for judgment. One focuses on the impacts of water quality factors on human health. Two questions rate the status of keystone and key species compared with that expected in an unaltered ecosystem. One rates maritime heritage resources based on their historical, archaeological, scientific, and educational value. Finally, four ask specifically about the levels of ongoing human activities (i.e., pressures) that could affect resource condition.

During workshops in which status and trends are rated, subject matter experts discuss each resource question and relevant indicators, available data, literature (e.g., published scientific studies, reports), and experience associated with the topic. They then discuss the statements provided as options for judgments about status; these statements have been customized for each

question. Once a particular statement is agreed upon, a color code and status rating (e.g., good, fair, poor) is assigned. Experts can also decide that the most appropriate rating is “N/A” (i.e., the question does not apply), “undetermined” (i.e., resource status is undetermined due to a paucity of relevant information), or “mixed” (i.e., conflicting signals from indicators prevent the selection of a single status rating). A subsequent discussion is then held about the trend. Conditions are determined to be improving, remaining the same, or worsening over the time since the production of the prior condition report. Symbols used to indicate trends are the same for all questions: “▲”—conditions appear to be improving; “—” —conditions do not appear to be changing; “▼”—conditions appear to be worsening; “◆”—conditions appear to be mixed; “?”—trend is undetermined; “N/A”—the question does not apply.

## Human Drivers

### 1. What are the states of influential human drivers and how are they changing?

Driving forces are those characteristics of human societies that influence the nature and extent of pressures on resources. They are the underlying cause of change in coastal marine ecosystems, as they determine human use. Drivers are influenced by demographics (e.g., age structure, population, etc.), demand, economic circumstances, industrial development patterns, business trends, and societal values. They operate at global, regional, and local scales. Examples include increasing global demand for agricultural commodities, which increases the use of chemicals that degrade coastal water quality; difficult economic times that reduce fishing efforts for a period of time within certain regions; or local construction booms that alter recreational visitation trends. Other drivers could be the demands that govern trends, such as global greenhouse gas generation, regional shipping or offshore industrial development, local recreation and tourism, fishing, port improvement, manufacturing, and age-specific services (e.g., retirement). Each of these, in turn, influences certain pressures on natural and cultural resources.

Integrated into this question should be consideration of societal values, which include such matters as levels of conservation awareness, political leanings, opinion about environmental issues relative to other concerns, or changing opinions about the acceptability of specific behaviors (e.g., littering, fishing). Understanding these values gives one a better understanding of the likely future trends in drivers and pressures, as well as the nature of the societal tradeoffs in different uses of the ecosystem resources (e.g., the effects of multiple changing drivers on each other and the resources they affect). This can better inform policy and management responses and education and outreach efforts that are designed to change societal values with the intention to change drivers and reduce pressures.

In rating the status and trends for drivers, the following should be considered:

- the main driving forces behind each pressure affecting natural resources and the environment
- the best available indicators of each driving force
- the status and trend of each driving force
- societal values behind each driving force

- the best indicators of societal values
- the status and trend of societal values

Rating	Status Description
Good	Few or no drivers occur that have the potential to influence pressures in ways that will negatively affect resource qualities.
Good/Fair	Some drivers exist that may influence pressures in ways expected to degrade some attributes of resource quality.
Fair	Selected drivers are influencing pressures in ways that cause measurable resource impacts.
Fair/Poor	Selected drivers are influencing pressures in ways that result in severe impacts that are either widespread or persistent.
Poor	Selected drivers are influencing pressures in ways that result in severe, persistent, and widespread impacts.

## Human Dimensions

### 2. What are the levels of human activities that may adversely influence water quality and how are they changing?

Among the human activities in or near sanctuaries that affect water quality are those involving direct discharges and spills (vessels, onshore and offshore industrial facilities, public wastewater facilities), those that contribute contaminants to groundwater, stream, river, and water control discharges (agriculture, runoff from impermeable surfaces through storm drains, conversion of land use), and those releasing airborne chemicals that subsequently deposit via particulates at sea (vessels, land-based traffic, power plants, manufacturing facilities, refineries). In addition, dredging and trawling can cause resuspension of contaminants in sediments. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
Good	Few or no activities occur that are likely to negatively affect water quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade water quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

**3. What are the levels of human activities that may adversely influence habitats and how are they changing?**

Human activities that degrade habitat quality do so by affecting structural (physical), biological, oceanographic, acoustic, or chemical characteristics of the habitat. Structural impacts, such as removal or mechanical alteration of habitat, can result from various fishing methods (e.g., trawls, traps, dredges, longlines, and even hook-and-line in some habitats), dredging of channels and harbors, dumping dredge spoil, grounding of vessels, anchoring, laying pipelines and cables, installing offshore structures, discharging drill cuttings, dragging tow cables, and placing artificial reefs. Removal or alteration of critical biological components of habitats can occur due to several of the above activities, most notably trawling, groundings, and cable drags. Marine debris, particularly in large quantities (e.g., lost gill nets and other types of fishing gear), can degrade both biological and structural habitat components. Changes in water circulation often occur when channels are dredged, fill is added, coastlines are armored or other construction takes place. Management actions such as beach wrack removal or sand replenishment on high public-use beaches, may impact the integrity of the natural ecosystem. Alterations in circulations can lead to changes in food delivery, waste removal, water quality (e.g., salinity, clarity and sedimentation), recruitment patterns, and a host of other ecological processes. Chemical alterations most commonly occur following spills and can have both acute and chronic impacts. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
Good	Few or no activities occur that are likely to negatively affect habitat quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade habitat quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

#### **4. What are the levels of human activities that may adversely influence living resources and how are they changing?**

Human activities that degrade the condition of living resources do so by causing a loss or reduction of one or more species, by disrupting critical life stages, by impairing various physiological processes, or by promoting the introduction of non-indigenous species or pathogens. (Note: Activities that impact habitat and water quality may also affect living resources. These activities are dealt with in the following human activity questions, and some may be repeated here as they also directly affect living resources).

For most sanctuaries, recreational or commercial fishing and collecting have direct effects on animal or plant populations, either through removal or injury of organisms. Related to this, lost fishing gear can cause extended periods of loss for some species through entanglement and “ghost fishing.” In addition, some fishing techniques are size-selective, resulting in impacts to particular life stages. High levels of visitor use in some places also cause localized depletion, particularly in intertidal areas or on shallow coral reefs, where collecting and trampling can be chronic problems.

Mortality and injury to living resources has also been documented from cable drags (e.g., towed barge operations), dumping spoil or drill cuttings, vessel groundings, or repeated anchoring. Contamination caused by acute or chronic spills or increased sedimentation to nearshore ecosystems from road developments in watersheds (including runoff from coastal construction or highly built coastal areas), discharges by vessels, or municipal and industrial facilities can make habitats unsuitable for recruitment or other ecosystem services (e.g., as nurseries or spawning grounds). And while coastal armoring and construction can increase the availability of surfaces suitable for hard bottom species, the activity may disrupt recruitment patterns for other species (e.g., intertidal soft bottom animals), and natural habitat may be lost.

Oil spills (and spill response actions), discharges, and contaminants released from sediments (e.g., by dredging and dumping) can all cause physiological impairment and tissue contamination. Such activities can affect all life stages by direct mortality, reducing fecundity, reducing disease resistance, loss as prey and disruption of predator-prey relationships, and increasing susceptibility to predation. Furthermore, bioaccumulation results in some contaminants moving upward through the food chain, disproportionately affecting certain species.

Activities that promote the introduction of non-indigenous species include bilge discharges and ballast water exchange, commercial shipping and vessel transportation. Intentional or accidental releases of aquarium fish and plants can also lead to introductions of non-indigenous species.

Many of these activities are controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
<b>Good</b>	Few or no activities occur that are likely to negatively affect living resource quality.
<b>Good/Fair</b>	Some potentially harmful activities exist, but they have not been shown to degrade living resource quality.
<b>Fair</b>	Selected activities have caused measurable living resource impacts, but effects are localized and not widespread or persistent.
<b>Fair/Poor</b>	Selected activities have caused severe impacts that are either widespread or persistent.
<b>Poor</b>	Selected activities have caused severe, persistent, and widespread impacts.

**5. What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?**

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Some human activities threaten the archaeological or historical condition of maritime heritage resources. Archaeological or historical condition is compromised when elements are moved, removed, or otherwise damaged. Threats come from looting, inadvertent damage by recreational divers, improper research methods, vessel anchorings and groundings, and commercial and recreational fishing activities, among others. Other human activities may alter or damage heritage resources by impacting the landscape or viewshed of culturally significant places or locations. Many of these activities can be controlled through management actions in order to limit their impact to maritime heritage resources.

Rating	Status Description
Good	Few or no activities occur at maritime heritage resource sites that are likely to adversely affect their condition.
Good/Fair	Some potentially damaging activities exist, but they have not been shown to degrade maritime heritage resource condition.
Fair	Selected activities have caused measurable impacts to maritime heritage resources, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

## Water Quality

### 6. What is the eutrophic condition of sanctuary waters and how is it changing?

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. It is usually caused by an increase in the amount of nutrients (largely nitrogen and phosphorus) being discharged to the water body. As a result of accelerated algal production, a variety of interrelated impacts may occur, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation (Bricker et al., 1999). Indicators commonly used to detect eutrophication and associated problems include nutrient concentrations, chlorophyll content, rates of water column or benthic primary production, benthic algae cover, algae bloom frequency and intensity, oxygen levels, and light penetration.

Eutrophication of sanctuary waters can impact the condition of other sanctuary resources. Nutrient enrichment often leads to plankton and/or algae blooms. Blooms of benthic algae can affect benthic communities directly through space competition. Indirect effects of overgrowth and other competitive interactions (e.g., accumulation of algal-sediment mats) often lead to shifts in dominance in the benthic assemblage, oxygen depletion, etc. Disease incidence and frequency can also be affected by algae competition and changes in the chemical environment along competitive boundaries. Blooms can also affect water column conditions, including light penetration and plankton availability, which can alter pelagic food webs. HABs, some of which are exacerbated by eutrophic conditions, often affect other living resources, as biotoxins are consumed or released into the water and air, or decomposition depletes oxygen concentrations.

Rating	Status Description
Good	Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Eutrophication is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
Fair	Eutrophication has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Eutrophication has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Eutrophication has caused severe degradation in most if not all attributes of ecological integrity.

**7. Do sanctuary waters pose risks to human health and how are they changing?**

Human health concerns are generally aroused by evidence of contamination (usually bacterial or chemical) in bathing waters or seafood intended for consumption. They also arise when harmful algal blooms are reported or when cases of respiratory distress or other disorders attributable to harmful algal blooms increase dramatically. Any of these conditions should be considered in the course of judging the risk to humans posed by waters in a marine sanctuary.

Some sanctuaries may have access to specific information about beach closures and seafood contamination. In particular, beaches may be closed when criteria for water safety are exceeded. Shellfish harvesting and fishing may be prohibited when contaminant or biotoxin loads or infection rates exceed certain levels. Alternatively, seafood advisories may also be issued, recommending that people avoid or limit intake of particular types of seafood from certain areas (e.g., when ciguatera poisoning is reported). Any of these conditions, along with changing frequencies or intensities, can be important indicators of human health problems and can be characterized using the descriptions below.

Rating	Status Description
Good	Water quality does not appear to have the potential to negatively affect human health.
Good/Fair	One or more water quality indicators suggest the potential for human health impacts but human health impacts have not been reported.
Fair	Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Water quality problems have caused severe impacts that are either widespread or persistent.
Poor	Water quality problems have caused severe, persistent, and widespread human impacts.

**8. Have recent, accelerated changes in climate altered water conditions and how are they changing?**

The purpose of this question is to capture shifts in water quality, and associated impacts on sanctuary resources, due to climate change. Though temporal changes in climate have always occurred on Earth, evidence is strong that changes over the last century have been accelerated by human activities. Indicators of climate change in sanctuary waters include water temperature, acidity, sea level, upwelling intensity and timing, storm intensity and frequency, changes in erosion and sedimentation patterns, and freshwater delivery (e.g., rainfall patterns). Climate-related changes in one or more of these indicators can impact the condition of habitats, living resources, and maritime archaeological resources in sanctuaries.

Increasing water temperature has been linked to changing growth rates, reduced disease resistance, and disruptions in symbiotic relationships (e.g., bleaching on coral reefs), and changes in water temperature exposure may affect a species’ resistance or the capacity to adapt to disturbances. Acidification can affect the survival and growth of organisms throughout the food web, as well as the persistence of skeletal material after death (through changes in rates of dissolution and bioerosion). Recent findings also suggest acidification impacts at sensory and behavioral levels, which can alter vitality and species interactions. Sea level change alters habitats, as well as their use and persistence. Variations in the timing and intensity of upwelling is known to change water quality through factors such as oxygen content and nutrient flow, further disrupting food webs and the natural functioning of ecosystems. Changing patterns and intensities of storms alter community resistance and resilience within ecosystems that have, over long periods of time, adapted to such disturbances. Altered rates and volumes of freshwater delivery to coastal ecosystems affects salinity and turbidity regimes and can disrupt reproduction, recruitment, growth, disease incidence, phenology, and other important processes.

Rating	Status Description
Good	Climate-related changes in water conditions have not been documented or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Climate-related changes are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Climate-related changes have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Climate-related changes have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Climate-related changes have caused severe degradation in most if not all attributes of ecological integrity.

**9. Are other stressors, individually or in combination, affecting water quality, and how are they changing?**

The purpose of this question is to capture shifts in water quality due to anthropogenic stressors not addressed in other questions. For example, localized changes in circulation or sedimentation resulting from coastal construction or dredge spoil disposal can affect light penetration, salinity regimes, oxygen levels, productivity, waste transport, and other aspects of water quality that in turn influence the condition of habitats and living resources. Human inputs, generally in the form of contaminants from point or non-point sources, including fertilizers, pesticides, hydrocarbons, heavy metals, and sewage, are common causes of environmental degradation. When present in the water column, any of these contaminants can affect marine life by direct contact or ingestion, or through bioaccumulation via the food chain.

(Note: Over time, accumulation in sediments can sequester and concentrate contaminants. Their effects may manifest only when the sediments are resuspended during storm or other energetic events. In such cases, reports of status should be made under Question 11 – Habitat contaminants.)

Rating	Status Description
Good	Other stressors on water quality have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected stressors have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected stressors have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected stressors have caused severe degradation in most if not all attributes of ecological integrity.

## Habitat

### 10. What is the integrity of major habitat types and how are they changing?

Ocean habitats can be categorized in many different ways, including water column characteristics, benthic assemblages, substrate types, and structural character. There are intertidal and subtidal habitats. The water column itself is one habitat type (Federal Geographic Data Committee, 2012). There are habitats composed of substrates formed by rocks or sand that originate from purely physical processes. And, there are certain animals and plants that create, in life or after their death, substrates that attract or support other organisms (e.g., corals, kelp, beach wrack, drift algae). These are commonly called biogenic habitats.

Regardless of the habitat type, change and loss of habitat is of paramount concern when it comes to protecting marine and terrestrial ecosystems. Of greatest concern to sanctuaries are changes to habitats caused, either directly or indirectly, by human activities. Human activities like coastal development alter the distribution of habitat types along the shoreline. Changes in water conditions in estuaries, bays, and nearshore waters can negatively affect biogenic habitat formed by submerged aquatic vegetation. Intertidal habitats can be affected for long periods by oil spills or by chronic pollutant exposure. Marine debris, such trash and lost fishing gear, can degrade the quality of many different marine habitats including beaches, subtidal benthic habitats, and the water column. Sandy seafloor and hard bottom habitats, even rocky areas several hundred meters deep, can be disturbed or destroyed by certain types of fishing gear, including bottom trawls, shellfish dredges, bottom longlines, and fish traps. Groundings, anchors, and irresponsible diving practices damage submerged reefs. Cables and pipelines disturb corridors across numerous habitat types and can be destructive if they become mobile.

Integrity of biogenic habitats depends on the condition of particular living organisms. Coral, sponges, and kelp are well known examples of biogenic habitat-forming organisms. The diverse assemblages residing within these habitats depend on and interact with each other in tightly linked food webs. They may also depend on each other for the recycling of wastes, hygiene, and the maintenance of water quality. Other communities that are dependent on biogenic habitat include intertidal communities structured by mussels, barnacles, and algae and subtidal hard-bottom communities structured by bivalves, corals, or coralline algae. In numerous open ocean areas drift algal mats provide food and cover for juvenile fish, turtles, and other organisms. The integrity of these communities depends largely on the condition of species that provide structure for them.

This question is intended to address acute or chronic changes in both the extent of habitat available to organisms and the quality of that habitat, whether non-living or biogenic. It asks about the quality of habitats compared to those that would be expected in near-pristine conditions (see definition above).

Rating	Status Description
<b>Good</b>	Habitats are in near-pristine condition.
<b>Good/Fair</b>	Selected habitat loss or alteration is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
<b>Fair</b>	Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.
<b>Fair/Poor</b>	Selected habitat loss or alteration has caused severe degradation in some but not all attributes of ecological integrity.
<b>Poor</b>	Selected habitat loss or alteration has caused severe degradation in most if not all attributes of ecological integrity.

**11. What are contaminant concentrations in sanctuary habitats and how are they changing?**

Habitat contaminants result from the introduction of unnatural levels of chemicals or other harmful material into the environment. Contaminants may be introduced through discrete entry locations, called point sources (e.g., rivers, pipes, or ships) and those with diffuse origins, called non-point sources (e.g., groundwater and urban runoff). Chemical contaminants themselves can be very specific, as in a spill from a containment facility or vessel grounding, or a complex mix, as with urban runoff. Familiar chemical contaminants include pesticides, hydrocarbons, heavy metals, and nutrients. Contaminants may also arrive in the form of materials that alter turbidity or smother plants or animals, therefore affecting metabolism and production.

This question is focused on risks posed primarily by contaminants within benthic formations, such as soft sediments, hard bottoms, or structure-forming organisms (see notes below). Not only are contaminants within benthic formations consumed or absorbed by benthic fauna, but resuspension due to benthic disturbance makes the contaminants available to water column organisms. In both cases contaminants can be passed upwards through the food chain. While the contaminants of most common concern to sanctuaries are generally pesticides, hydrocarbons, and nutrients, the specific concerns of individual sanctuaries may differ substantially.

Notes: 1) Contaminants in the water column addressed in the water quality section of this report should be cited, but details need not be repeated here; 2) many consider noise a pollutant, but in the interest of focusing here on more traditional forms of habitat degradation caused by contaminants, ONMS recommends addressing the impacts of acoustic pollution within the living resource section, most likely as it impacts key species.

Rating	Status Description
Good	Contaminants have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected contaminants are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected contaminants have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected contaminants have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected contaminants have caused severe degradation in most if not all attributes of ecological integrity.

## ***Living Resources***

### **12. What is the status of keystone and foundation species and how is it changing?**

Certain species are defined as “keystone” within ecosystems, meaning they are species on which the persistence of a large number of other species in the ecosystem depends (Paine, 1966). They are the pillars of community stability (among other things, they strongly affect both resistance and resilience) and their contribution to ecosystem function is disproportionate to their numerical abundance or biomass. Their impact is therefore important at the community or ecosystem level. Keystone species are often called “ecosystem engineers” and can include habitat creators (e.g., corals, kelp), predators that control food web structure (e.g., Humboldt squid, sea otters), herbivores that regulate benthic recruitment (e.g., certain sea urchins), and those involved in critical symbiotic relationships (e.g., cleaning or co-habiting species).

“Foundation” species are single species that define much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes (Dayton, 1972). These are typically dominant biomass producers in an ecosystem and strongly influence the abundance and biomass of many other species. Examples include krill and other zooplankton, kelp, forage fish, such as rockfish anchovy, sardine, and coral. Foundation species exhibit similar control over ecosystems as keystone species, but their high abundance distinguishes them.

Changes in either keystone or foundation species may transform ecosystem structure through disappearances of or dramatic increases in the abundance of dependent species. Not only do the abundances of keystone and foundation species affect ecosystem integrity, but measures of condition can also be important to determining the likelihood that these species will persist and continue to provide vital ecosystem functions. Measures of condition may include growth rates, fecundity, recruitment, age-specific survival, contaminant loads, pathologies (e.g., disease incidence, tumors, deformities), the presence and abundance of critical symbionts, or parasite loads.

Rating	Status Description
<b>Good</b>	The status of keystone and foundation species appears to reflect near-pristine conditions and may promote ecological integrity (full community development and function).
<b>Good/Fair</b>	The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.
<b>Fair</b>	The status of keystone or foundation species suggests measurable but not severe degradation in some attributes of ecological integrity.
<b>Fair/Poor</b>	The status of keystone and foundation species suggests severe degradation in some but not all attributes of ecological integrity.
<b>Poor</b>	The status of keystone and foundation species suggests severe degradation in most if not all attributes of ecological integrity.

**13. What is the status of other focal species and how is it changing?**

This question targets other species of particular interest from the perspective of sanctuary management. These “focal species” may not be abundant or provide high value to ecosystem function, but their presence and health is important for the provision of other services, whether conservation, economic, or strategic. Examples include species targeted for special protection (e.g., threatened or endangered species), species for which specific regulations exist to minimize perturbations from human disturbance (e.g., touching corals, riding manta rays or whale sharks, disturbing white sharks, disturbing nesting birds), or indicator species (e.g., common murrens as indicators of oil pollution). This category could also include so-called “flagship” species, which include charismatic or iconic species associated with specific locations, ecosystems or are in need of specific management actions, are highly popular and attract visitors or business, have marketing appeal, or represent rallying points for conservation action (e.g., humpback and blue whales, Dungeness crab).

Status of these other focal species can be assessed through measures of abundance, relative abundance, or condition, as described for keystone species. In contrast to keystone and foundation species, however, the impact of changes in the abundance or condition of focal species is more likely to be observed at the population or individual level, and less likely to result in ecosystem or community effects.

Rating	Status Description
Good	Selected focal species appear to reflect near-pristine conditions.
Good/Fair	Reduced abundances in selected focal species are suspected but have not yet been measured.
Fair	Selected focal species are at reduced levels, but recovery is possible.
Fair/Poor	Selected focal species are at substantially reduced levels, and prospects for recovery are uncertain.
Poor	Selected focal species are at severely reduced levels, and recovery is unlikely.

**14. What is the status of non-indigenous species and how is it changing?**

This question allows sanctuaries to report on the threat posed and impacts caused by non-indigenous species. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their native distributional range, having arrived there by human activity, either deliberate or accidental. Activities that commonly facilitate invasions include vessel ballast water exchange, restaurant waste disposal, and trade in exotic species for aquaria. In some cases, climate change has resulted in water temperature fluctuations that have allowed range extensions for certain species.

Non-indigenous species that have damaging effects on ecosystems are called “invasive” species. Some can be extremely destructive, and because of this potential, non-indigenous species are usually considered problematic and warrant rapid response after invasion. For those that become established, however, their impacts can sometimes be assessed by quantifying changes in affected native species. In some cases, the presence of a species alone constitutes a significant threat (e.g., certain invasive algae and invertebrates). In other cases, impacts have been measured, and may or may not significantly affect ecosystem integrity.

Evaluating the potential impacts of non-indigenous species may require consideration of how climate change may enhance the recruitment, establishment, and/or severity of impacts of non-indigenous species. Altered temperature or salinity conditions, for example, may facilitate the range expansion, establishment and survival of non-indigenous species while stressing native species, thus reducing ecosystem resistance. This will also make management response decisions difficult, as changing conditions will make new areas even more hospitable for non-indigenous species targeted for removal.

Rating	Status Description
Good	Non-indigenous species are not suspected to be present or do not appear to affect ecological integrity (full community development and function).
Good/Fair	Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.
Fair	Non-indigenous species have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Non-indigenous species have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Non-indigenous species have caused severe degradation in most if not all attributes of ecological integrity.

### **15. What is the status of biodiversity and how is it changing?**

Broadly defined, biodiversity refers to the variety of life on Earth, and includes the diversity of ecosystems, species and genes, and the ecological processes that support them (Convention on Biological Diversity, 2006). This question is intended as an overall assessment of biodiversity compared to that expected in a near-pristine system (one as near to an unaltered ecosystem as people can reasonably expect, given that there are virtually no ecosystems completely free from human influence). It may include consideration of measures of biodiversity (usually aspects of species richness and evenness) and the status of functional interactions between species (e.g., trophic relationships and symbioses). Intact ecosystems require that all parts not only exist, but that they function together, resulting in natural symbioses, competition, predator-prey relationships, and redundancies (e.g., multiple species capable of performing the same ecological role). Intact structural elements, processes, and natural spatial and temporal variability are essential characteristics of community integrity and provide a natural adaptive capacity through resistance and resilience.

The response to this question will depend largely on changes in biodiversity that have occurred as a result of human activities that cause depletion, extirpation or extinction, illness, contamination, disturbance, and changes in environmental quality. Examples include collection of organisms, excessive visitation (e.g., trampling), industrial activities, coastal development, pollution, activities creating noise in the marine environment, and those that promote the spread of non-indigenous species.

Loss of species or changing relative abundances can be mediated through selective mortality or changing fecundity, either of which can influence ecosystem shifts. Human activities of particular interest in this regard are commercial and recreational harvesting. Both can be highly selective and disruptive activities, with a limited number of targeted species, and often result in the removal of high proportions of the populations, as well as large amounts of untargeted species (bycatch). Extraction removes biomass from the ecosystem, reducing its availability to other consumers. When too much extraction occurs, ecosystem stability can be compromised through long-term disruptions to food web structure, as well as changes in species relationships and related functions and services (e.g. cleaning symbioses). This has been defined as “ecologically unsustainable” extraction (Zabel et al., 2003).

Rating	Status Description
<b>Good</b>	Biodiversity appears to reflect near-pristine conditions and promotes ecological integrity (full community development and function).
<b>Good/Fair</b>	Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.
<b>Fair</b>	Selected biodiversity loss or change has caused measurable but not severe degradation in some attributes of ecological integrity.
<b>Fair/Poor</b>	Selected biodiversity loss or change has caused severe degradation in some but not all attributes of ecological integrity.
<b>Poor</b>	Selected biodiversity loss or change has caused severe degradation in most if not all attributes of ecological integrity.

## ***Maritime Heritage Resources***

### **16. What is the condition of known maritime heritage resources and how is it changing?**

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Maritime heritage resources include archaeological and historical properties, and material evidence of past human activities, including vessels, aircraft, structures, habitation sites, and objects created or modified by humans. The condition of these resources in a marine sanctuary significantly affects their value for science and education, as well as the resource's eligibility for listing in the National Register of Historic Places. The "integrity" of archaeological/historical resources, as defined within the National Register criteria, refers to their ability to help scientists answer questions about the past through archaeological research. Historical significance of an archaeological resource depends on its integrity and/or its representativeness of past events that made a significant contribution to the broad patterns of history, its association with important persons, or its embodiment of a distinctive type or architecture.

Maritime heritage resources also include certain culturally significant resources, locations and viewsheds, the condition of which may change over time. Such resources, often more intangible in nature, may still be central to traditional practices and maintenance of cultural identity. The integrity of both cultural resources and cultural locations are included within the National Register criteria.

Section 110 of the National Historic Preservation Act requires federal agencies to inventory, assess, and nominate appropriate maritime heritage resources ("historic properties") to the National Register. The Maritime Cultural Landscape approach, adopted by the sanctuary system, provides a comprehensive tool for the assessment of archaeological, historical and cultural (maritime heritage) resources.

Assessments of heritage resources include evaluation of the apparent condition, which results from deterioration caused by human and natural forces (unlike questions about water, habitat, and living resources, the non-renewable nature of many heritage resources makes any reduction in integrity and condition, even if caused by natural forces, permanent). While maritime heritage resources have intrinsic value, these values may be diminished by changes to their condition.

Rating	Status Description
Good	Known maritime heritage resources appear to reflect little or no unexpected natural or human disturbance.
Good/Fair	Selected maritime heritage resources exhibit indications of natural or human disturbance, but there appears to have been little or no reduction in aesthetic, cultural, historical, archaeological, scientific, or educational value.
Fair	The diminished condition of selected maritime heritage resources has reduced, to some extent, their aesthetic, cultural, historical, archaeological, scientific, or educational value, and may affect the eligibility of some sites for listing in the National Register of Historic Places.
Fair/Poor	The diminished condition of selected maritime heritage resources has substantially reduced their aesthetic, cultural, historical, archaeological, scientific, or educational value, and is likely to affect their eligibility for listing in the National Register of Historic Places.
Poor	The degraded condition of known maritime heritage resources in general makes them ineffective in terms of aesthetic, cultural, historical, archaeological, scientific, or educational value, and precludes their listing in the National Register of Historic Places.

## Appendix B: Definitions and Rating Scheme for Status and Trends of Ecosystem Services

The following describes the ecosystem services and possible responses that ONMS considers in condition reports for all national marine sanctuaries. ONMS and subject matter experts use this guidance to make judgments about the status and trends of sanctuary ecosystem services.

ONMS defines ecosystem services in a slightly more restrictive way than some other experts. Specifically, ecosystem services are defined herein as the benefits people obtain from nature through use, consumption, enjoyment, and/or simply knowing these resources exist (non-use). The descriptions below reflect this definition, and therefore, only these ecosystem services are evaluated in sanctuary conditions reports. Intermediate services are not evaluated in the Status and Trends of Ecosystem Services chapter of these reports. Intermediate services, while critical to ecosystem function, are not directly used, consumed, or enjoyed by humans and thus do not meet the ONMS condition report definition of ecosystem services. In other words, these intermediate services support ecosystems but are not final ecosystem services in and of themselves. As an example, biodiversity is often considered as an ecosystem service by experts in the field, but ONMS recognizes biodiversity as an intermediate service of the ecosystem on which many final ecosystem services depend (e.g., consumptive and non-consumptive recreation, commercial and subsistence harvest depend on the status and trend of biodiversity). For this reason, biodiversity is considered an intermediate ecosystem service and it is evaluated in the Status and Trends of Sanctuary Resources chapter of the report. Decomposition and carbon storage are examples of other intermediate services.

In addition, ONMS does not consider climate regulation or stabilization as ecosystem services in condition reports. The impacts of climate change on water quality, habitat, and living resources are considered separately in the Status and Trends of Sanctuary Resources chapter of the report. While sanctuaries are not large enough to influence climate stability, they may locally buffer climate-related factors, such as temperature change and ocean acidity; thus, the extent to which they may locally buffer climate-related factors is reflected in resource conditions in the Status and Trends of Sanctuary Resources chapter.

Finally, some ecosystem services may not be assessed by individual sanctuaries because the activities required to achieve them are prohibited (e.g., collection of ornamentals), the sanctuary is not mandated to manage a specific resource that provides a particular service (e.g., management of fisheries), or there is simply no related activity underway or expected (e.g., renewable energy production).

Below are brief descriptions of the ecosystem services that could be considered within each sanctuary condition report (more complete descriptions are provided below the list).

### **Cultural (non-material benefits)**

1. Consumptive recreation — Recreational activities that result in the removal of or harm to natural or cultural resources
2. Non-consumptive recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources
3. Science — The capacity to acquire and contribute information and knowledge
4. Education — The capacity to acquire and provide intellectual enrichment
5. Heritage — Recognition of historical and heritage legacy and cultural practices
6. Sense of Place — Aesthetic attraction, spiritual significance, and location identity

### **Provisioning (material benefits)**

7. Commercial Harvest — The capacity to support commercial market demands for seafood products
8. Subsistence Harvest — The capacity to support non-commercial harvesting of food and utilitarian products
9. Drinking water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash
10. Ornamentals — Resources collected for decorative, aesthetic, ceremonial purposes
11. Biotechnology — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use
12. Renewable energy — Use of ecosystem-derived materials or processes for the production of energy

### **Regulating (buffers to change)**

13. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Sanctuaries vary with regard to the ecosystem services they support. To rate the status and trend for each relevant ecosystem service, the following can be considered:

- the best available indicators for each ecosystem service (e.g., economic, human dimension non-economic, resource, traditional ecological knowledge)
- the status and direction of change of each ecosystem service
- the prioritization of each indicator
- whether economic indicators send a false signal about the status and trend of an ecosystem service (namely, conflicting ecological and economic indicators, suggesting that people are sacrificing natural capital for short-term economic gain)

The steps used to rate ecosystem services were adapted from a multi-year study, *Marine and Estuarine Goal Setting for South Florida*, of three south Florida marine ecosystems, including Florida Keys National Marine Sanctuary (Kelble et al., 2013). The study used integrated conceptual ecosystem models for each ecosystem under the DPSEER Model (Nuttle & Fletcher, 2013) and evaluation of three types of indicators for each ecosystem service: 1) economic; 2) human dimension non-economic (Lovelace et al., 2013); and 3) resource.

The evaluation of ecosystem services should consider whether economic and non-economic indicators yield the same conclusions as resource indicators; this will enable consideration of the sometimes conflicting relationship between economic gain and the preservation of natural capital. For example, economic indicators (e.g., dive operator income) may suggest improving recreational services, while resource indicators (e.g., anchor damage to benthic habitat) suggest that natural resources are being sacrificed for short-term gain, thus making the activity unsustainable.

ONMS recognizes that the ecosystem services model is intentionally anthropocentric, designed to elicit a selected type of service-oriented rating useful in resource management decision-making. Connections between ecosystems, culture and heritage, and resource management are often complex, beyond the scope of the condition report. Collectively, stakeholders may have multiple worldviews and ecosystem values equally important to consider, and some ecosystem elements may not be appropriate to rate in the ecosystem services approach (e.g., aspects of heritage and sense of place). Sanctuaries may want to consider the option of including a “context-specific perspective” or narrative (as proposed in Diaz et al., 2018), without assigning a status or trend rating, for the purpose of providing appropriate information for management purposes. Cultural (non-material) ecosystem services are particularly intricate and have been undervalued in the past. Evaluators should remember that deliberative processes engaging local stakeholders and subject matter experts are critical, and adherence to the process demands both flexibility and creativity.

During workshops in which status and trends are determined, subject matter experts discuss each ecosystem service and relevant indicators, available data, literature (e.g., published scientific studies, reports), and experience associated with the topic. They then discuss the statements provided (see table below) as options for judgments about status. Once a particular statement is agreed upon, a color code and status rating (e.g., good, fair, poor) is assigned. Experts can also decide that the most appropriate rating is “N/A” (i.e., the ecosystem service does not apply), “undetermined” (i.e., ecosystem service status is undetermined due to a paucity of relevant information), or “mixed” (i.e., variation across indicators prevents the selection of a single status rating). A subsequent discussion is then held about the trend. Conditions are determined to be improving, remaining the same, or worsening in comparison to the results found in the first round of condition reports. Symbols used to indicate trends are the same for all ecosystem services: “▲”—conditions appear to be improving; “—”—conditions do not appear to be changing; “▼”—conditions appear to be worsening; “◆”—conditions appear to be mixed; and “?”—trend is undetermined; “N/A”—the ecosystem service does not apply.

## Rating Scheme for Ecosystem Services

Rating	Status Description
Good	The capacity to provide the ecosystem service has remained unaffected or has been restored.
Good/Fair	The capacity to provide the ecosystem service is compromised, but performance is acceptable.
Fair	The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.
Fair/Poor	The capacity to provide the ecosystem service is compromised, and substantial new or enhanced management is required to restore it.
Poor	The capacity to provide the ecosystem service is compromised, and it is doubtful that new or enhanced management would restore it.

### Cultural (Non-Material Benefits)

**Consumptive recreation** — Recreational activities that result in the removal of or harm to natural or cultural resources

Perhaps the most popular activity that involves consumptive recreation is sport fishing from private boats and for-hire operations. Targeted species and bycatch are removed from the environment, and those that must be released due to regulations and prohibitions (e.g., undersized or out of season) sometimes die due to stress or predation. Nonetheless, fishing for consumptive purposes is a highly valued cultural tradition for many people, as well as a popular recreational activity. Other consumptive recreational activities include beachcombing, clam digs and shell collecting.

Indicators of status and trends for consumptive recreation often include levels of use (direct counts or estimates made from commercial vessel records and catch levels, and fishing license registrations) and production of economic value through job creation, income, spending, and tax revenue. Public polls can also be used to assess non-market indicators, such as importance and satisfaction, social values, willingness to pay, and facility and service availability.

**Non-consumptive recreation** — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources

Recreational activities, including ecotourism and outdoor sports, are often considered a non-consumptive ecosystem service that provides desirable experiential opportunities. Non-consumptive recreational activities include those on shore or from private boats and for-hire operations, such as relaxing, exploring, diving and snorkeling, kayaking, birdwatching, surfing, sailing, and wildlife viewing. Activities that may have unintentional impacts on habitats or

wildlife including catch-and-release fishing and tidepooling which could result in mortality or trampling, respectively, are also considered in this category.

It should be noted that private boating often includes both non-consumptive and consumptive recreational activities (e.g., snorkeling and fishing during a single trip). Thus, field and survey data can be ambiguous, reflecting the heterogeneous preferences of boaters. This also has implications for interpretations of data regarding attitudes and perceptions of management strategies and regulations to protect and restore natural and cultural resources.

Indicators used to assess status and trends in market values for recreation can include direct measures of use (e.g., person-days of use by type of activity) that result in spending, income, jobs, gross regional product, and tax revenues. They can also be non-market economic values (the difference between what people pay to use a good/service and what they would be willing to pay). The data can be used to estimate the value a consumer receives when using a good or service over and above what they pay to obtain the good or service. Indirect measures are also used. For example, populations and per capita incomes at numerous scales influence demand for recreational products and services. Fuel prices can even serve as indirect measures of recreational demand because the levels of use by some recreational users tracks fuel prices.

**Science** – The capacity to acquire and contribute information and knowledge

Sanctuaries serve as natural laboratories that can advance science and education. NOAA provides vessel support, facilities, and information that is valuable to the research community, including academic, corporate, non-governmental and government agency scientists, citizen scientists, and educators that instruct others using research. Sanctuaries serve as long-term monitoring sites, provide minimally disturbed focal areas for many studies, and provide opportunities to restore or maintain natural systems.

Status and trends for science can be assessed by counting and characterizing the number of research permits and tracking the accomplishments and growth of partnerships, activity levels of citizen monitoring, and participation of the research community in sanctuary management. The number and types of research cruises and other expeditions conducted can also provide useful indicators. Indirect indicators, such as per capita income and gross regional or national product, may be helpful as higher incomes and better economic conditions often result in higher investments in research and monitoring.

**Education** – The capacity to acquire and provide intellectual enrichment

As with science, national marine sanctuaries' protected natural systems and cultural resources attract educators at many levels for both formal and informal education. Students and teachers often either visit sanctuaries or use curricula and information provided by sanctuary educators.

The status and trends for education can be tracked by evaluating the number of educators and students visiting the sanctuary and visitor centers, the number of teacher trainings, use of sanctuary-related curricula in the classroom, and levels of activity in volunteer docent programs. The number of outreach offerings provided during sanctuary research and education expeditions can also be a good indicator. Education can also follow trends in populations and

per capita income locally, regionally, and nationally. Populations create demand for services, and higher incomes lead to investment, making these useful indirect indicators.

***Heritage*** — Recognition of historical and heritage legacy and cultural practices

The iconic nature of many national marine sanctuaries or particular places within them generally means that they have long been recognized, used, and valued. Communities developed around them, traveled through them, and depended on their resources. This shared history and heritage creates the unique cultural character of many present-day coastal communities, and can also be an important part of the current economy. Recognition of the past, including exhibits, artifacts, records, stories, songs, and chants provide not only a link to the history of these areas, but a way to better understand the maritime and cultural heritage within the environment itself. Tangible and intangible aspects of heritage blend together to contribute to the history and legacy of the place.

For some marine sanctuaries, vibrant and active indigenous cultures remain a defining and dominant element of the cultural heritage of these places. Not only are they a direct and priceless connection to the past, but they frame and influence modern-day economies, cultural landscapes, and conservation ethics and practices. Their very existence is intrinsic to the heritage of these places.

Given this broad range of cultural expression, benefits of heritage may take many forms. Additionally, cultural heritage resources will often be part of, or overlap with, other ecosystem service categories, and may be understood from multiple perspectives (such as, a living resource keystone species that may also be identified as a “cultural” keystone species, one of exceptional significance to a culture or a people). The Heritage ecosystem service category defines benefits from resources primarily attached to historical and heritage legacy and culture. Heritage resources, including certain living resources and traditional medicines, may also provide other benefits that can be addressed in other ecosystem service categories.

Economic indicators that reflect status and trends for heritage value as an ecosystem service may include spending, income, jobs, and other revenues generated from visitation, whether it is to dive on wreck sites or patronize museums and visitor centers where artifacts are displayed and interpreted. Non-market indicators, such as willingness to pay for protection of resources, activity levels for training and docent interpretation, and changes in threat levels (looting and damage caused by fishing), may also be considered. Sites may determine that some aspects of Heritage may simply not be ratable using the framework of condition reports.

***Sense of place*** — Aesthetic attraction, spiritual significance, and location identity

A wide range of intangible meanings can be attributed to a specific place by people, both individually and collectively. Aesthetic attraction, spiritual significance, and location identity all influence our recognition and appreciation for a place, as well as efforts to protect its iconic elements.

Marine environments serve as places of aesthetic attraction for many people, and inspire works of art, music, architecture, and tradition. Many people also value particular places as sources of therapeutic rejuvenation and to offer a change of perspective. Aesthetic aspects are often

reflected as motifs in books, film, artworks, and folklore and as part of national symbols, architecture, and advertising efforts. These elements of “place attachment” may develop and change over the short and long term.

Many people, families, and communities consider places as defining parts of their “self identity,” especially if they have lived there during or since childhood. The relationship between self/family/community and place can run very deep, particularly where lineage is place-based, with genealogy going back many generations. “Place identity” develops over the long term, and is often expressed in reciprocal human-ecosystem relationships, and locations associated with spiritual significance. The recognition of very long term place-based stewardship, sometimes in excess of 10,000 years, provides a unique aspect of place identity.

Many people even incorporate water or water-related activities as habitual or significant parts of their lives and cultures. Different factors are considered to measure/assess sense of place, including level of uniqueness, recognition, reputation, reliance, and appreciation for a place. Accounting for sense of place can provide strong incentives for conservation, preservation, and restoration efforts.

Despite its value as a cultural ecosystem service, it is difficult to quantify sense of place with direct measures. Examples of indicators may include the quality and availability of opportunities to support rituals, ceremonies and narratives and the level of satisfaction knowing that a place exists. Polls or surveys are often used to evaluate public opinions regarding economic and non-economic values of a place. Non-economic values may include existence or bequest value, which use surveys to estimate the value people would be willing to pay for resources to stay in a certain condition even though they may never actually use them. To comprehensively evaluate sense of place, sites may find it useful to consider subcategories such as place attachment and place identity. Furthermore, sites may determine that some aspects of Sense of Place may simply not be ratable using the framework of condition reports.

### **Provisioning (Material Benefits)**

**Commercial harvest** — The capacity to support commercial market demands for seafood products

Humans consume a large variety and abundance of products originating from the oceans and Great Lakes for nutrition or for use in other sectors. This includes fish, shellfish, other invertebrates, roe, and algae. Seafood is one of the largest traded food commodities in the world. Commercial fishing provides food for domestic and export markets, sold as wholesale and retail for household, restaurant and institutional meals. Seafood based industries include those that fish and harvest directly from wild capture and cultivated resources, as well as other businesses with functions throughout the supply chain including production of commercial gear, processors, storage facilities, buyers, transport and market outlets.

Within this category we also include what many call artisanal fishing, which can include commercial sale, but is also conducted by individuals or small groups who live near their harvest sites and use small scale, low technology, low cost fishing practices. Their catch is usually not processed (although it may be smoked or canned), and is mainly for local consumption or sale.

Artisanal fishing uses traditional fishing techniques such as rod and tackle, fishing arrows and harpoons, cast nets, and sometimes small traditional fishing boats.

Fisheries located in national marine sanctuaries are usually encompassed by larger regional fisheries that are regulated by fisheries management plans. Fisheries management plans may include sanctuary-specific restrictions to protect sanctuary habitats, living resources, and archaeological resources, and to fulfill treaty obligations. Data that can be used to assess status and trends for this ecosystem service include: catch levels by species and species groups; and economic contributions in the form of sector-related jobs, income, sales, and tax revenue. Indirect measures include data on licensing, fleet size, fishing vessel types and sizes, days at sea, and commodity prices.

***Subsistence harvest*** — The capacity to support non-commercial harvesting of food and utilitarian products

Subsistence harvesting is the practice of collecting marine resources (e.g., fish, shellfish, marine mammals, seabirds, roe, and algae) either for food or for creating products that are utilitarian in nature (e.g., traditional medicine, shelter, clothing, fuel and tools) that are not for sale or income generation. Subsistence is conducted principally for personal and family use, and sometimes for community use, and may be distributed through ceremony, sharing, gifting, and bartering. Some people depend on subsistence fishing for food security and may have few other sources of income to provision their food and nutrition needs. Harvesting for subsistence is also a cultural or traditional practice for some people. It typically operates on a smaller and more local scale than commercial fishing. Natural resources that support subsistence harvest may also be used as ceremonial regalia or for cultural traditions, and therefore support other ecosystem services, including Heritage, Sense of Place, and Ornamentals. Data from surveys, tribal and indigenous knowledge and the status of fishery stocks can be used to assess the status and trends of this service.

***Drinking water*** — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash

Clean water is considered a final ecosystem service when the natural environment is improving water quality for human consumption or other direct use (e.g., irrigation). Although sanctuary ecosystems often function to improve water quality, most do not result in the final ecosystem service of clean water for human use. For most natural resources, improving water quality in a sanctuary is a supporting or intermediate ecosystem service that may, for example, result in better water quality for fish species that are then enjoyed by commercial or recreational anglers, safer water in which to swim, or improved water clarity for diving. These are aspects of other final ecosystem services and the water quality itself is an indicator that is inherently important to them; however, ONMS does not include this aspect of clean water in condition reports because it would result in a double counting of its ecosystem service value. Instead, ONMS evaluates clean water as a final ecosystem service, where the natural environment is improving water for human consumption, such as drinking water, or for irrigation (e.g., through filtration or suitability for desalination). In this way, the benefits of management policies and actions that improve water quality are captured separately, but in relation to the relevant final ecosystem services they support.

**Ornamentals** — Resources collected for decorative, aesthetic, or ceremonial purposes

In sanctuaries where the collection of ornamental products is not prohibited or is allowed under permit, they are taken for their aesthetic or material value for artwork, souvenirs, fashion, handicrafts, jewelry, or display. This includes live animals for aquaria and trade, pearls, shells, corals, sea stars, furs, feathers, ivory, and more. Some, particularly animals for the aquarium trade, are sold commercially and can be valued like other commodities; others cannot. Some products may be decorative and relatively non-functional, others culturally significant and specifically functional, such as ceremonial regalia. Status and trends for the use of ornamentals can also be evaluated using indicators such as the number of permitted or other collectors, frequency and intensity of collection operations, and sales.

**Biotechnology** — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use

Biochemical and genetic resources, medicines, chemical models, and test organisms are all potential products that can be derived or sourced from national marine sanctuaries. Biochemical resources include compounds extracted from marine animals and plants and used to develop or manufacture foods, pharmaceuticals, cosmetics, and other products (e.g., omega-3 fatty acids from fish oil, or microbes for spill or waste bioremediation). Genetic resources are the genetic content of marine organisms used for animal and plant breeding and for biotechnology. Natural resources can also be used as a model for new products (e.g., the development of fiber optic technology, based on the properties of sponge spicules). Items harvested for food consumption are evaluated in Commercial and Subsistence Harvest.

Collections of products for biotechnology applications may be allowed under permit, and sanctuary permit databases can also be used to gauge demand and collection activity within a given national marine sanctuary. The value of commercially sold products associated with biotechnology may also be available.

**Renewable energy** — Use of ecosystem-derived materials or processes for the production of energy

In the offshore environment, energy production sources are considered to be either non-renewable (oil and gas) or renewable (wind, solar, tidal, wave, or thermal). While oil and gas technically are ecosystem-sourced and may be renewable over a time frame measured in millions of years, as an ecosystem service, they are not subject to management decisions in human time frames; therefore, they are not considered an ecosystem service in this section. The activities and management actions related to hydrocarbon production are, however, considered elsewhere in condition reports, primarily with regard to resource threats, impacts, and protection measures.

In contrast, “renewable” forms of energy that depend on ecosystem materials and processes operating over shorter time periods are evaluated. Indicators of status and trends for these energy sources include the types and number of permitted or licensed experimental or permanent operations, energy production, revenues generated, and jobs created. Indirect indicators that inform trends and provide some predictive value include social and market trends, energy costs, and expected demand based on service market populations trends.

## ***Regulating (Buffers to Change)***

**Coastal protection** — Natural features that control water movement and/or wind energy, thus protecting habitat, property, heritage resources and coastlines

Coastal and estuarine ecosystems can buffer the potentially destructive energy of environmental disturbances, such as floods, tidal surges and storm waves, and wind. Wetlands, kelp forests, mangroves, seagrass beds, and reefs of various types all absorb some of the energy of local disturbances, protecting themselves, submerged habitats closer to shore, intertidal ecosystems, and emergent land masses. They also can trap sediments and promote future protection through shoaling. They can also become sources of sediments for coastal dunes and beaches that control flooding and protect coastal properties from wave energy and the impacts of sea-level rise.

The value of coastal protection can be estimated by evaluating the basis of the value of vulnerable coastal properties and infrastructure and modeled estimates of losses expected under different qualities of coastal ecosystems (replacement cost). Levels of historical change under different energy scenarios can be used to support these estimates. Public polls can also reveal information on willingness to pay that is used to value this service.

## Appendix C: Methods for Report Development

The process for preparing national marine sanctuary condition reports involves a combination of accepted techniques for collecting and interpreting information gathered from subject matter experts. The approach varies somewhat from sanctuary to sanctuary to accommodate different styles for working with partners; however, all include the evaluation of ecosystem indicators, which is a well-established method for tracking ecosystem conditions and trends with the purpose of informing ecosystem-based management. The assessment of sanctuary resources and ecosystem services include quantitative measures of ecosystem indicators derived from regional and local monitoring data, supplemented by qualitative interpretations derived from expert opinions and local knowledge. This approach allows for a transparent and repeatable process.

The first step to assess an ecosystem's condition and health (see Appendices A and B) is to select indicators that reflect the status and trends of key components of the ecosystem. These indicators should be representative of the entire socio-ecological system, including individual components like biophysical indices, human activity, and community vulnerability. Indicators should meet certain criteria to be considered usable and appropriate for the condition report. This includes long-term data availability, importance to the ecosystem and culture, responsiveness to changes in environmental conditions, measurability, relevance to sanctuary condition report questions, and responsiveness to management actions. The indicator selection process for the GRNMS condition report began with sanctuary staff conducting a literature review of previous work focused on indicators in the region. Sanctuary staff then reviewed and prioritized each indicator based on the criteria previously described. For some questions, a select group of subject matter experts were consulted to aid in indicator prioritization.

Next, ONMS selected and consulted subject matter experts familiar with water quality, habitat, living resources, maritime heritage resources, and socioeconomics in the sanctuary. A list of experts who participated in the GRNMS condition report process is available in the Acknowledgements section of this report. A series of hybrid and virtual workshops were held with these subject matter experts in March and April of 2023 to discuss and evaluate each resource question (relating to human activities, water quality, habitat, and living resources) and ecosystem service (consumptive recreation, non-consumptive recreation, science, education, heritage, and sense of place). During the virtual workshops, experts were first introduced to the questions and ecosystem services (see Appendices A and B). Next, the indicators for each topic were presented, accompanied by data sets ONMS had collected prior to the meeting.

Attendees were then asked to review the indicators and data sets, identify data gaps or misrepresentations, and suggest any additional data sets that may be relevant. Once all data were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. GRNMS's approach in working with workshop experts was closely related to the Delphi Method, a technique designed to organize group communication among a panel of geographically dispersed experts by using questionnaires, ultimately facilitating the formation of a group judgment. This method can be applied when it is necessary for decision

makers to combine the testimony of a group of experts, whether in the form of facts, informed opinion, or both, into a single useful statement. The Delphi Method requires experts to respond to questions with a limited number of choices to arrive at the best-supported answers. Feedback to the experts allows them to refine their views, gradually moving the group toward the most agreeable judgment. In order to ensure consistency with the Delphi Method, a critical role of the facilitator was to minimize dominance of the discussion by a single individual or opinion (which often leads to “follow the leader” tendencies in group meetings) and to encourage the expression of honest differences of opinion. As discussions progressed, the group converged on an opinion for each rating that most accurately described the resource or ecosystem service condition. After an appropriate amount of time, the facilitator asked whether the group could agree on a rating for the question or ecosystem service, as defined by specific language linked to each rating (see Appendices A and B). If an agreement was reached, the result was recorded and the group moved on to consider the trend in the same manner. If agreement was not reached, the facilitator recorded the vote of individuals for each rating category and that information helped to inform the confidence scoring process.

After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the sources of information they used to make judgments; and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence ratings, as described in the three steps outlined below.

**Step 1: Rate Evidence**

Consider three categories of evidence typically used to make status or trend ratings: (1) data, (2) published information, and (3) personal experience.

Limited	Medium	Robust
Limited data or published information, and little or no substantive personal experience.	Data available, some peer reviewed published information, or direct personal experience.	Considerable data, extensive record of publication, or extensive personal experience.

**Step 2: Rate Agreement**

Rate agreement among those participating in determining the status and trend rating, or if possible, within the broader scientific community. Levels of agreement can be characterized as “low,” “medium,” or “high.”

### Step 3: Rate Confidence

Using the matrix below, combine ratings for both evidence and agreement to identify a level of confidence. Levels of confidence can be characterized as “very low,” “low,” “medium,” “high,” or “very high.”

Agreement →	“Medium” High agreement Limited evidence	“High” High agreement Medium evidence	“Very High” High agreement Robust evidence
	“Low” Medium agreement Limited evidence	“Medium” Medium agreement Medium evidence	“High” Medium agreement Robust evidence
	“Very Low” Low agreement Limited evidence	“Low” Low agreement Medium evidence	“Medium” Low agreement Robust evidence
	Evidence (type, amount, quality, consistency) →		

An initial draft of the report, written by ONMS, summarized information, expert opinions, and levels of confidence expressed by the experts. Comments, data, and citations received from the experts were included, as appropriate, in text supporting the ratings. This initial draft was made available to contributing experts and data providers, which allowed them to review the content and determine if the report accurately reflected their input, identify information gaps, provide comments, or suggest revisions to the ratings and text.

Following the expert review, the document was sent to representatives of partner agencies for a second review. These representatives were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors. Upon receiving reviewer comments, ONMS revised the text and ratings as appropriate.

In 2024, a draft final report was sent to three regional experts for a required external peer review. External peer review became a requirement when the White House Office of Management and Budget issued a Final Information Quality Bulletin for Peer Review (OMB Bulletin) that established peer review standards to enhance the quality and credibility of the federal government’s scientific information (White House Office of Management and Budget, 2004). Along with other information, these standards apply to “influential scientific information,” which is information that can reasonably be determined to have a “clear and substantial impact on important public policies or private sector decisions” (White House Office of Management and Budget, 2004, p. 11). Condition reports are considered influential scientific information and are subject to the review requirements of both the Information Quality Act and the OMB Bulletin guidelines; therefore, every condition report is reviewed by a minimum of three individuals who are considered to be experts in their field, were not involved in the development of the report, and are not ONMS employees. Comments and recommendations of the peer reviewers were considered and incorporated, as appropriate, into the final text of this report. Furthermore, OMB Bulletin guidelines require that reviewer comments, names, and affiliations be posted on the agency website (<http://www.cio.noaa.gov/>). Reviewer comments,

however, are not attributed to specific individuals. Comments by the external peer reviewers are posted at the same time as the formatted final document.

In all steps of the review process, experts were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors; however, the interpretation, ratings, and text in the condition report are the responsibility of, and receive final approval by, ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report.

### Gray’s Reef National Marine Sanctuary Confidence Ratings from March and April, 2023 Expert Workshops

**Table App.C.1.** A summary of confidence levels for GRNMS condition report resource ratings.

Resource Question	Workshop Date and Format	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Human Activities/Water Quality	March 23 (Hybrid)	Status: Good	Medium	High	High
		Trend: Not Changing	Limited	Medium	Low
Human Activities/Habitat	March 23 (Hybrid)	Status: Good/Fair	Medium	Medium	Medium
		Trend: Not Changing	Medium	High	High
Human Activities/Living Resources <sup>23</sup>	March 23 (Hybrid)	Status: Good/Fair	Medium	Low	Low
		Trend: Not Changing	Medium	High	High
Water Quality/Eutrophication	March 22 (Hybrid)	Status: Good	Medium	High	High
		Trend: Not Changing	Medium	High	High

<sup>23</sup> Due to time constraints, a status rating for this question was not determined during the expert workshop. This status rating was determined later by GRNMS staff, who reevaluated the indicators, data sets, and expert input provided during the workshop.

## Appendix C: Methods for Report Development

Resource Question	Workshop Date and Format	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Water Quality/Risk to Human Health	April 7 (Virtual)	Status: Good/Fair	Limited	High	Medium
		Trend: Undetermined	Limited	Medium	Low
Water Quality/Climate Change	April 14 (Virtual)	Status: Good/Fair	Medium	High	High
		Trend: Worsening	Medium	High	High
Water Quality/Other Stressors	April 17 (Virtual)	Status: Good/Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
Habitat/Integrity	March 22 (Hybrid)	Status: Good	Medium	High	High
		Trend: Not Changing	Medium	High	High
Habitat/Contaminants	March 22 (Hybrid)	Status: Good/Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
Living Resources/Other Focal Species <sup>24</sup>	March 22 (Hybrid)	Status: Mixed	Medium	High	High
		Trend: Mixed	Medium	High	High

<sup>24</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

Resource Question	Workshop Date and Format	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Living Resources/Non-indigenous Species	March 21 (Hybrid)	Status: Good/Fair	Limited	High	Medium
		Trend: Not Changing	Limited	High	Medium
Living Resources/Biodiversity	March 22 (Hybrid)	Status: Good/Fair	Medium	Low	Low
		Trend: Not Changing	Medium	Low	Low

**Table App.C.2.** A summary of confidence levels for GRNMS condition report ecosystem service ratings.

Ecosystem Services	Virtual Workshop Date	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Consumptive Recreation	March 23 (Hybrid)	Status: Good/Fair	Medium	Medium	Medium
		Trend: Not Changing	Medium	Medium	Medium
Non-Consumptive Recreation	March 23 (Hybrid)	Status: Good/Fair	Medium	High	High
		Trend: Improving	Limited	Medium	Low
Science <sup>25</sup>	March 21 (Hybrid)	Status: Good/Fair	Medium	Low	Low
		Trend: Not Changing	Medium	Medium	Medium
Education	March 21 (Hybrid)	Status: Fair	Medium	Medium	Medium
		Trend: Improving	Robust	High	Very High

<sup>25</sup> Due to time constraints, a trend rating and associated confidence score for this question were not determined during the expert workshop. This trend rating and associated confidence score were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

Appendix C: Methods for Report Development

<b>Ecosystem Services</b>	<b>Virtual Workshop Date</b>	<b>Rating</b>	<b>Evidence (Limited, Medium, Robust)</b>	<b>Agreement (Low, Medium, High)</b>	<b>Confidence (Very Low, Low, Medium, High, Very High)</b>
Heritage	March 21 (Hybrid)	Status: Good/Fair	Medium	High	High
		Trend: Improving	Medium	Medium	Medium
Sense of Place <sup>26</sup>	March 21 (Hybrid)	Status: Fair	Medium	High	High
		Trend: Improving	Medium	High	High

<sup>26</sup> Due to time constraints, status and trend ratings and associated confidence scores for this question were not determined during the expert workshop. They were determined later by GRNMS staff who reevaluated the indicators, data sets, and expert input provided during the workshop.

## Appendix D: Comparison of the Previous and Current Condition Reports

**Table App.D.1.** Resource question ratings from the 2008 condition report (ONMS, 2008), 2012 addendum (ONMS, 2012), and 2008–2022 condition report for GRNMS.

2008 and 2012 Condition Report Questions	2008 Rating	2012 Rating	2008–2022 Condition Report Questions	2008–2022 Condition Report Rating
Human activities and water quality	—	N/A	Human activities and water quality	Good
Human activities and habitat	?	▲	Human activities and habitat	Good/Fair
Human activities and living resources	?	▲	Human activities and living resources	Good/Fair
Eutrophic condition	?	N/A	Eutrophic condition	Good
Human health risks	—	N/A	Human health risks	Good/Fair
Multiple stressors (including climate)	?	—	Climate drivers	Good/Fair
			Other stressors	Good/Fair
Habitat abundance/distribution	?	?	Integrity of major habitats	Good
Condition of biologically structured habitat	?	?		
Contaminants	—	N/A	Contaminants	Good/Fair
Status of key species	▼	▲	Other focal species	Mixed
Non-indigenous species	▼	N/A	Non-indigenous species	Good/Fair
Biodiversity	?	—	Biodiversity	Good/Fair

## Appendix E: Indicator Tables

The following are the indicator tables presented at the hybrid and virtual status and trend workshops. The tables summarize each indicator that was presented during the workshop; these indicators and supporting data sets are also presented and described in greater detail in the narrative of this report. Each indicator table was edited for clarity and grammar following the workshop.

**Table App.E.1.** Summaries for the key indicators related to human activities that may adversely influence water quality that were discussed during the March 23, 2023 workshop.

Indicator	Source	Summary
Coastal development	U.S. Geological Survey, 2022	<p>Status: Regulations have limited the loss of salt marshes in coastal Georgia. Impervious surface cover in coastal Georgia was slightly higher in 2019 compared to 2001.</p> <p>Trend: Coastal salt marsh spatial cover remained stable; however, impervious surface cover increased 0.24% from 2001–2019.</p>
Waste disposal and pollution via vessel registrations, transit and spill threats	Georgia Department of Natural Resources, 2022; U.S. Coast Guard, 2022; Office of Response and Restoration, 2022	<p>Status: Around 90% of registered vessels are an average of 26 feet, with no marine toilet. 1,635 vessels transited 9,783 nautical miles in GRNMS (2015–2021); traffic was concentrated over live-bottom areas. Eleven significant spill threat incidents occurred in coastal Georgia from 2008–2021, but did not directly affect GRNMS.</p> <p>Trend: Annual vessel registrations in coastal Georgia increased, and vessel transits also appeared to increase over time. There was no change in major spill threats to GRNMS between 2008 and 2022.</p>
Data gaps	Updated time-series data are needed regarding locations within the sanctuary where vessels stop or drift, and the time spent at those locations.	

## Appendix E: Indicator Tables

**Table App.E.2.** Summaries for the key indicators related to human activities that may adversely influence habitat quality that were discussed during the March 23, 2023 workshop.

Indicator	Source	Summary
Recreational fishing	Kendall et al., 2020; NOAA Marine Recreational Information Program, 2022	<p>Status: Data on fishing within GRNMS were limited; however, one study found that most visitors to the sanctuary in 2019 engaged in fishing.</p> <p>Trend: More recreational angler trips occurred during the study period than in the preceding two decades; however, there was no trend in angler trips during the study period. Registrations of Class 1 vessels (16 to &lt;26 feet in length) increased statewide during the study period. However, no recreational fishing trend data specific to GRNMS were available.</p>
Research activities	ONMS, 2023	<p>Status: Research activities are ongoing, with 4–7 permits active at any given time. Research activities that may negatively impact GRNMS habitats are limited.</p> <p>Trend: There was no apparent trend in the number of permits issued during the study period.</p>
Scuba diving	K. Hunnicutt, personal communication, February 10, 2023	<p>Status: Approximately 20 recreational scuba diving charter trips to GRNMS have occurred each year from 2018 to 2022.</p> <p>Trend: Anecdotal observations suggest that the number of recreational dive trips to GRNMS likely remained stable during the study period.</p>
Data gaps	Site-specific, quantitative data on recreational fishing activity and prevalence of fishing debris within GRNMS are lacking. Lack of detailed statistics on non-GRNMS dive activity (including diving from private vessels).	

**Table App.E.3.** Summaries for the key indicators related to human activities that may adversely influence living resources that were discussed during the March 23, 2023 workshop.

Indicator	Source	Summary
Vessel activity	Ozburn, 2023; Kendall et al., 2020; Stanley et al., 2021; U.S. Coast Guard Navigation Center, 2022	<p>Status: The number of vessel registrations in coastal Georgia and vessel visitation to GRNMS are higher than in past years. Acoustic detections of vessels are higher in summer months.</p> <p>Trend: Vessel activity increased during the study period.</p>
Recreational fishing	NOAA Marine Recreational Information Program, 2022; GADNR, 2022	<p>Status: The average number of recreational fishing trips per year, number of fish harvested, and number of fish released in offshore GA waters were greater from 2012 to 2021 than for 1990 to 2011. Enforcement detections were low throughout the study period, regardless of effort.</p> <p>Trend: Recreational fishing trips, number of fish harvested, and enforcement detections were stable from 2012 to 2021, while the number of fish released increased during the same period.</p>

## Appendix E: Indicator Tables

Indicator	Source	Summary
Data gaps		Activity levels for vessels without AIS; additional acoustic monitoring data; recreational fishing data within GRNMS specifically; fishery-independent data within GRNMS; connectivity between coastal Georgia and GRNMS living resources, and the associated effect of coastal development

**Table App.E.4.** Summaries for the key indicators related to eutrophic condition of sanctuary waters that were discussed during the March 22, 2023 workshop.

Indicator	Source	Summary
Chlorophyll <i>a</i> anomalies and concentration	NOAA CoastWatch, 2023	Status: Chlorophyll <i>a</i> followed a seasonal pattern, and was highest in 2020.  Trend: The trend was stable, with limited variability from 2008 to 2022.
Dissolved oxygen	Noakes, 2023	Status: Surface dissolved oxygen followed a seasonal pattern, peaking in winter and spring and declining in summer. Surface dissolved oxygen reached near hypoxic levels (2–5 mg/l) in 2013 and 2022. Hypoxia occurred at the seafloor on one occasion in 2014.  Trend: No trend could be determined due to data gaps.
Inorganic nutrients	Craig et al., 2021	Status: Nutrient levels were higher at the bottom than at the surface.  Trend: No conclusive trend could be determined due to data gaps; however, total nitrogen increased in all river outlets.
Turbidity (Kd490)	NOAA CoastWatch, 2023	Status: Turbidity varied seasonally, with periodic peaks in 2013, 2016, 2019, 2020, and 2022.  Trend: No trend was apparent.
Altamaha River discharge	U.S. Geological Survey, 2023	Status: Discharge varied seasonally, with peaks in 2009, 2016, and 2020. The highest discharge level, observed in 2020, was likely due to storms.  Trend: The trend was stable from 2008 to 2022.

**Table App.E.5.** Summaries for the key indicators related to whether sanctuary waters pose risks to human health that were discussed during the April 7, 2023 workshop.

Indicator	Source	Summary
Mercury bioaccumulation	GADNR, 2021	Status: Some mercury advisories exist for GA Atlantic offshore waters and estuaries leading to GA Atlantic offshore waters.  Trend: Cannot determine- only one advisory issued during timeline.

## Appendix E: Indicator Tables

Indicator	Source	Summary
Ciguatera fish poisoning	NCCOS, 2015; U.S. Centers for Disease Control and Prevention, 2022	Status: No cases have been documented in Georgia from fish caught in sanctuary waters.  Trend: Conditions do not appear to be changing, since there are no documented cases.
Harmful algal blooms	NCCOS, 2023	Status: No “bloom” in sanctuary waters, but “common” and “present” ratings given for HAB species in sanctuary.  Trend: Declining trend of “present +” occurrences of HABs since 2010.
Conditions suitable for <i>Vibrio</i> spp.	NOAA CoastWatch, 2023	Status: Only 2 observations of <i>Vibrio</i> occurring in sanctuary waters.  Trend: Both observations in 2017, none after.
Contaminant levels in biota	Balthis et al., 2015	Status: No contaminant levels in 2012/2013 biota samples exceeded FDA human health guideline values, but EPA human-health risk values were exceeded in 2 of 10 ark clam samples.  Trend: No trend data available.

**Table App.E.6.** Summaries for the key indicators related to climate change that were discussed during the April 14, 2023 workshop.

Indicator	Source	Summary
SST	National Data Buoy Center & Southwest Fisheries Science Center, 2023; NOAA Fisheries, 2022; O'Brien & Oakes, 2020	Status: The recent mean for SST was within $\pm 1.0$ standard deviation of the long-term mean.  Trend: SST increased during the study period.
Marine heatwaves	Physical Sciences Laboratory, 2022	Status: Marine heatwaves were more frequent in the last 10 years compared to historic data.  Trend: No clear trend was apparent.
Wind and waves	National Data Buoy Center & Southwest Fisheries Science Center, 2023	Status: Recent means for wind speed, wave height, and wave period were within $\pm 1.0$ standard deviation of the long-term mean.  Trend: Wind speed and wave period were stable during the study period, while wave height increased.

## Appendix E: Indicator Tables

Indicator	Source	Summary
Tropical cyclone intensity and frequency	Noakes, 2022b; National Weather Service, 2023	<p>Status: Within the study period, storm frequency was highest in 2020. The study period fell within a high activity era, as designated by the Accumulated Cyclone Energy index.</p> <p>Trend: Storm frequency and the Accumulated Cyclone Energy index appear to have increased during the study period.</p>
Ocean acidification	Pacific Marine Environmental Laboratory, 2022; Noakes, 2022a	<p>Status: The recent mean seawater CO<sub>2</sub> concentration was within <math>\pm 1.0</math> standard deviation of the long-term mean. Aragonite saturation was above the threshold for sub-lethal effects on organisms, except in the spring of 2011, 2013, and 2015.</p> <p>Trend: Seawater CO<sub>2</sub> concentration was stable during the study period. Trends for pH and aragonite saturation could not be determined due to data gaps.</p>
Salinity	Noakes, 2022a; O'Brien & Oakes, 2020	<p>Status: A seasonal pattern of lower salinity in winter and spring and higher salinity in summer was detected. The recent mean was within <math>\pm 1.0</math> standard deviation of the long-term mean.</p> <p>Trend: An apparent decreasing trend was observed; however, data gaps preclude a statistical assessment of trend.</p>
Dissolved oxygen	Noakes, 2023	<p>Status: Surface dissolved oxygen peaked in winter and spring and was lowest in summer, reaching the upper hypoxia threshold of 2–5 mg/l in 2013 and 2022. Bottom dissolved oxygen reached hypoxic levels in 2014.</p> <p>Trend: A trend could not be determined due to data gaps.</p>
Mixed layer depth and Altamaha River input	U.S. Geological Survey, 2023	<p>Status: Mixed layer depth was greatest in 2019 and 2020. Altamaha River discharge in 2016 and 2020 was the highest in the last 10 years.</p> <p>Trend: Mixed layer depth appears to be increasing. No clear trend in Altamaha River daily maximum discharge was apparent.</p>
Data and analysis gaps	Consistent data on sea surface (i.e., pH, salinity) and seafloor parameters (i.e. temperature, pH, salinity, pCO <sub>2</sub> ) would aid in assessment of status and trends; existing gaps in data resulted from equipment challenges, weather, etc.	

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**Table App.E.7.** Summaries for the key indicators related to other stressors that may affect water quality that were discussed during the April 17, 2023 workshop.

Indicator	Source	Summary
Contaminant releases from vessels	Office of Response and Restoration, 2022; U.S. Coast Guard, 2022	<p>Status: No releases of contaminants from vessels occurred in GRNMS during the study period. Contaminants, primarily petroleum, were released within 100 km of GRNMS and may be affecting water quality in the sanctuary.</p> <p>Trend: No apparent trend in any metric of contaminant releases from vessels within 100 km of GRNMS.</p>
Data gaps	Contaminant loads within sanctuary habitats, including those associated with vessel releases, pharmaceutical contaminants, per- and polyfluoroalkyl substances, as well as time-series data on microplastics.	

**Table App.E.8.** Summaries for the key indicators related to habitat integrity that were discussed during the March 22, 2023 workshop.

Indicator	Source	Summary
Benthic habitat distribution	Kendall et al., 2005	<p>Status: The most recent assessment data (2001) indicate GRNMS is composed of 75% unconsolidated sediment and 25% colonized live bottom.</p> <p>Trend: No trend data were available; no apparent changes based on in situ observations.</p>
Unconsolidated sediment	Alexander et al., 2020; Balthis et al., 2015	<p>Status: Unconsolidated sediment habitats in GRNMS were characterized by relatively coarse grain size and a healthy infaunal community.</p> <p>Trend: No trend data were available.</p>
Ledge height/undercut depth	Kendall et al., 2008, 2009; Muñoz, 2019; Muñoz et al., 2020	<p>Status: While these habitats comprise a relatively small proportion of GRNMS by area, they provide key habitat for a variety of biota and some also contain biodiversity hot spots.</p> <p>Trend: No trend data were available.</p>
Benthic invertebrate cover	Gleason et al., 2022	<p>Status: Key benthic invertebrate species were abundant in sanctuary live bottom habitats. Resilience is high among benthic invertebrates in GRNMS.</p> <p>Trend: Benthic invertebrate cover was stable during the study period.</p>
Macroalgae	Aumack & Cohen, 2021	<p>Status: Over 55 species of macroalgae were sampled in GRNMS.</p> <p>Trend: No trend data were available.</p>

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Indicator	Source	Summary
Soundscape/acoustic environment	Integrated Ocean Observing System, 2023; Stanley et al., 2021; Kendall et al., 2020; ONMS & U.S. Navy, 2021	Status: Baseline data illustrated seasonal patterns in the sanctuary soundscape. Anthropogenic sound was relatively low in GRNMS.  Trend: No trend data were available.
Data gaps	No new benthic habitat map has been created since 2005. Although updated bathymetry data have been collected, there is an analysis gap for these data that should be addressed to better understand changes in habitat structure over time. No new unconsolidated sediment sampling has occurred since 2013. Trend data on macroalgae and soundscape metrics were not available. Seasonal data were not available for most indicators.	

**Table App.E.9.** Summaries for the key indicators related to contaminants in sanctuary habitats that were discussed during the March 22, 2023 workshop.

Indicator	Source	Summary
Contaminant levels in sediment	Balthis et al., 2015; Geiger, 2021	Status: Contaminant levels in sediment samples were low and did not exceed Effects Range Low thresholds in 2012–2013. Microplastics were present in sediment samples in 2021.  Trend: No trend data were available.
Contaminant levels in biota	Balthis et al., 2015	Status: Contaminant levels in biota samples did not exceed U.S. Food and Drug Administration levels of concern. However, arsenic and cadmium levels in some samples met or exceeded U.S. Environmental Protection Agency thresholds for recommended limited human consumption.  Trend: No trend data were available.
Data gaps	No data on contaminant levels in sanctuary habitats or biota were available from 2013–2022. No data on microplastic presence in sanctuary habitats were available prior to 2021.	

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**Table App.E.10.** Summaries for the key indicators related to the status of other focal species that were discussed during the March 22, 2023 workshop.

Indicator	Source	Summary
Loggerhead sea turtle	GRNMS, 2021a	<p>Status: Loggerhead sea turtles were present in the sanctuary during the study period; however, their presence was recorded opportunistically and no focused monitoring has occurred to date.</p> <p>Trend: No trend could be determined due to limited data availability.</p>
North Atlantic right whale	GRNMS, 2021b	<p>Status: North Atlantic right whales were recorded on hydrophones in the sanctuary. They are believed to be present seasonally during migration.</p> <p>Trend: No trend could be determined due to limited data availability.</p>
Sand tiger shark	Williams et al., 2019	<p>Status: Six individuals were present for two or fewer days from 2012 to 2017. They are believed to be present seasonally during migration.</p> <p>Trend: No trend could be determined due to limited data availability.</p>
Red snapper	Muñoz et al., 2019	<p>Status: Red snapper were consistently present in the sanctuary during the study period.</p> <p>Trend: Red snapper biomass increased in the sanctuary from 2010 to 2019.</p>
Tomtate	Muñoz et al., 2019	<p>Status: Tomtate were abundant in GRNMS throughout the study period.</p> <p>Trend: Biomass was stable over time.</p>
Black sea bass	Muñoz et al., 2019	<p>Status: Black sea bass were abundant in GRNMS throughout the study period.</p> <p>Trend: Biomass was stable over time.</p>
King mackerel	SEDAR, 2020	<p>Status: According to a 2020 stock assessment, king mackerel were not overfished and were not subject to overfishing in the South Atlantic region (which includes GRNMS).</p> <p>Trend: Estimated biomass increased from 2013 to 2017. Landings increased or remained stable depending on fishing method.</p>
<i>Oculina arbuscula</i>	Gleason et al., 2022	<p>Status: <i>O. arbuscula</i> is the only structurally complex stony coral present in abundance in the sanctuary.</p> <p>Trend: Cover was stable during the study period.</p>
<i>Halymenia</i> spp. algae	Aumack & Cohen, 2021	<p>Status: <i>Halymenia</i> spp. were present at all 21 sites visited in 2021.</p> <p>Trend: No trend data were available.</p>

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**Table App.E.11.** Summaries for the key indicators related to non-indigenous species that were discussed during the March 21, 2023 workshop.

Indicator	Source	Summary
Lionfish ( <i>Pterois volitans</i> and <i>P. miles</i> )	GRNMS, 2023a; Muñoz et al., 2019	Status: Lionfish were present in the sanctuary during the study period.  Trend: Limited trend data were available.
Titan acorn barnacle ( <i>Megabalanus coccopoma</i> )	Gleason et al., 2022; Reigel, 2015	Status: Titan acorn barnacles were present in the sanctuary during the study period, but only on human-made structures.  Trend: No trend data were available.
Orange cup coral ( <i>Tubastraea coccinea</i> )	Gleason et al., 2022	Status: Orange cup coral has not been observed in the sanctuary since 2012.  Trend: No trend data were available.
Branching vase sponge ( <i>Callyspongia vaginalis</i> )	Gleason et al., 2022	Status: Branching vase sponges were present in the sanctuary during the study period.  Trend: Limited trend data were available.
Red algae ( <i>Platoma gelatinosum</i> )	Aumack & Cohen, 2021	Status: <i>P. gelatinosum</i> was present in the sanctuary during the study period.  Trend: Limited trend data were available.
Data gaps	Data on abundance, density, and trends of most non-indigenous species were limited.	

**Table App.E.12.** Summaries for the key indicators related to biodiversity that were discussed during the March 22, 2023 workshop.

Indicator	Source	Summary
Benthic infaunal diversity	Balthis et al., 2015	Status: An estimated 900 benthic taxa are present in GRNMS.  Trend: Trend data were not available for the present study period. Historically, benthic infaunal diversity was stable to decreasing.
Fish biodiversity	Muñoz et al., 2020	Status: The top five dominant fish species were documented over time using two transect methods.  Trend: Fish community composition was stable.
Sessile and mobile invertebrate biodiversity	Daniel & Gleason, 2021	Status: Sessile and mobile invertebrate biodiversity is high.  Trend: Diversity has remained stable.
Algal biodiversity	Aumack & Cohen, 2021	Status: No major differences in macroalgae species richness were apparent between recent and historical inventory studies.  Trend: Trend data were not available.

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Indicator	Source	Summary
Shifts in species distribution related to temperature	Muñoz et al., 2021	Status: Tropical species have been observed in GRNMS for the first time in recent years.  Trend: Sightings of tropical species have increased.
Data and analysis gaps	Analysis of acoustic monitoring data is necessary to assess the diversity of biogenic sounds.	

**Table App.E.13.** Summaries for the key indicators related to science that were discussed during the March 21, 2023 workshop.

Indicator	Source	Summary
Research activity	GRNMS	Status: Activities are ongoing, with an average of 14 activities and 4–7 active permits per year.  Trend: There was no statistically significant trend in research activity during the study period.
Research partner feedback	Botta et al., 2024	Status: The status of GRNMS as a sanctuary, management needs/requests, boat/dive support, and biodiversity were the top reasons researchers chose to work at GRNMS.  Trend: No trend data were available.
GRNMS small boat days at sea	GRNMS	Status: Two small boats were used for sanctuary research during the study period.  Trend: The number of days at sea decreased over time for <i>Joe Ferguson</i> and remained stable for <i>Sam Gray</i> .
NOAA ship time	GRNMS	Status: Expeditions to GRNMS, typically aboard the NOAA ship <i>Nancy Foster</i> , occurred consistently during the study period.  Trend: NOAA ship time remained stable during the study period.
Research Area designation	Roberson et al., 2020	Status: The Research Area was established in 2011 to allow for improved understanding of natural and human-induced changes in sanctuary resources.  Trend: No trend data were available.
Monitoring programs	GRNMS	Status: During the study period, there were 8–20 active monitoring projects underway per year.  Trend: Monitoring activity was stable during the study period.

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Indicator	Source	Summary
Science publications	GRNMS; Google Scholar	<p>Status: A total of 231 peer-reviewed publications were produced during the study period.</p> <p>Trend: There was no statistically significant trend in the number of peer-reviewed publications during the study period.</p>
Volunteer hours	GRNMS	<p>Status: Volunteers contributed to GRNMS science throughout the study period.</p> <p>Trend: There was no trend in volunteer hours throughout the study period; however, volunteer hours were markedly low in 2020 and remained relatively low in 2021 and 2022 as a result of the COVID-19 pandemic.</p>
Public support/value for research	Samonte et al., 2023	<p>Status: In 2020, 65% of GRNMS users placed a high or extremely high value on scientific research as an ecosystem service provided by GRNMS.</p> <p>Trend: The level of public support for scientific research at GRNMS was consistent between surveys conducted in 2010 and 2020.</p>

**Table App.E.14.** Summaries for the key indicators related to education that were discussed during the March 21, 2023 workshop.

Indicator	Source	Summary
Virtual engagement	Google; Meta; Twitter	<p>Status: GRNMS engages with the public via its website and social media accounts on Facebook and Twitter. A website redesign in 2023 increased mobile device accessibility.</p> <p>Trend: The number of views and time spent on the GRNMS webpage were stable from 2015 to 2023. There was no apparent trend in new Facebook followers or engagement, but the number of new Twitter followers declined from 2019 to 2022.</p>
Exhibits	NOAA, 2018; Hamline University Center for Global Environmental Education, 2023	<p>Status: Attendance at partner institutions featuring GRNMS exhibits ranged from 32,000 to over 1,100,000 per year from 2014 to 2022. From 2018 to 2022, the number of user sessions with kiosks featuring GRNMS content ranged from 1,181 to 10,133. Each session lasted an average of 6 minutes.</p> <p>Trend: The number of kiosk sessions increased from 2013–2018, but time per session declined during the same period.</p>

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Indicator	Source	Summary
Community outreach events	Gray's Reef National Marine Sanctuary Foundation, 2023	<p>Status: During the condition report study period, GRNMS led events, supported partner-led events, and participated in public speaking engagements to bring sanctuary messaging to the community.</p> <p>Trend: A shift in outreach approach resulted in a cessation of GRNMS-led events and a reliance on partner-led events beginning in 2018. Participation in the MATE ROV program peaked in 2018, but has been lower in recent years.</p>
K–12 education	Georgia Public Broadcasting, 2017	<p>Status: GRNMS has not had a site education coordinator since 2015, hindering its ability to offer K–12 programs; however, programs led by partners (e.g., the Gray's Reef National Marine Sanctuary Foundation) helped to fill this gap during the study period. Approximately 45,000 Georgia students participated in the virtual Live Exploration of Gray's Reef event in partnership with Georgia Public Broadcasting.</p> <p>Trend: No trend data were available.</p>
Investment into education	GRNMS	<p>Status: GRNMS invested in education during the study period by forming new partnerships. Education staffing was low, with 0.3 dedicated full time employees from 2016 to 2022. The education program budget ranged from \$250 to \$83,000 from 2017 to 2022 (with a median of \$21,622).</p> <p>Trend: The number of educational partners increased during the study period. Education staffing was stable from 2016 to 2022. The education budget varied from 2017 to 2022 with no clear trend.</p>
Volunteer engagement	GRNMS	<p>Status: Volunteers contributed 13,016 hours toward GRNMS projects from 2013–2022 for an in-kind value of \$374,410.</p> <p>Trend: Volunteer hours steadily increased between 2014–2018 and declined significantly between 2019–2022</p>

**Table App.E.15.** Summaries for the key indicators related to heritage that were discussed during the March 21, 2023 workshop.

Indicator	Source	Summary
Paleolandscape and archaeological resources	Garrison et al., 2016	<p>Status: Foundational research has occurred on the GRNMS paleolandscape. Archaeological evidence of past human activities exists.</p> <p>Trend: Although key findings were published during the study period, the level of research activity has decreased in recent years.</p>

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Indicator	Source	Summary
Fishing heritage	Hoskins, 2015; Sakas & Caglayan, 2018; Sweeney-Tookes & Fluech, 2018, 2022	<p>Status: Fishing is a strong component of heritage in coastal Georgia.</p> <p>Trend: Recognition of fishing heritage has increased; new oral histories that describe the importance of fishing heritage were recorded during the study period.</p>
Science heritage	GRNMS, 2023; Roberson et al., 2020; Whittle, 2019	<p>Status: Public recognition of GRNMS was spurred by the scientific research of Sam Gray. Today, GRNMS remains a living laboratory.</p> <p>Trend: Science heritage in GRNMS has remained strong over time. The designation of a research area in 2011 highlighted the importance of the sanctuary for generating scientific information.</p>
Associated Gullah/Geechee heritage	Gullah Geechee Cultural Heritage Corridor Commission, 2012; Hoskins, 2015; Hoskins-Brown, 2020	<p>Status: Georgia's coastal and ocean waters have deep connections to Gullah/Geechee heritage.</p> <p>Trend: Although connections to coastal waters remain a strong cultural component of some Gullah/Geechee communities, participation in fishing livelihoods has declined over time.</p>
Data gaps	No information on possible heritage connections between modern Indigenous cultures and GRNMS was available.	

**Table App.E.16.** Summaries for the key indicators related to sense of place that were discussed during the March 21, 2023 workshop (no trends, service not previously evaluated).

Indicator	Source	Data Summary
Site awareness	ONMS	<p>Status: A total of 316 news clips have featured GRNMS over 10 years. Exhibits and information about the sanctuary are present at multiple public venues. New outreach was initiated at the Georgia Aquarium and Ocean Discovery Center.</p> <p>Trend: News attention has remained steady throughout the study period, with the exception of a slight decline during the COVID-19 pandemic. Social media mentions of and searches for GRNMS were also consistent over time.</p>
Modern fishing destination	ONMS; GRNMS; GADNR	<p>Status: GRNMS has been identified as a hotspot for fishing tournaments. Anglers valued GRNMS, but did not necessarily know its correct location.</p> <p>Trend: In all Georgia waters (including but not specific to the sanctuary), there was a net decline in commercial fishing and increase in recreational fishing.</p>

## Appendix E: Indicator Tables

Indicator	Source	Data Summary
Gullah/Geechee sense of place	Hoskins- Brown, 2020	<p>Status: The ocean has spiritual and practical value to many Gullah/Geechee communities, such as Hog Hammock and Sapelo Island. Connection to the water is a large part of Gullah/Geechee identity and heritage, and preservation of ocean ecosystems is important to these communities.</p> <p>Trend: No trend data were available.</p>
Iconic species	ONMS; NOAA Fisheries; GADNR	<p>Status: Selected species are considered iconic due to one or more of the following: high public awareness and close association with place and regional identity; cultural history; species scarcity and a public desire for conservation; abundance and local familiarity; and integral association with specific human activities.</p> <p>Trend: Public interest in red snapper has been particularly strong over time; however, interest has remained consistent for all iconic species identified</p>
Modern diving destination	ONMS; GRNMS; AP News; Google	<p>Status: GRNMS has developed a reputation as a special but remote and difficult-to-access dive destination. Scuba diving at GRNMS was mentioned 7,780 times on web pages and in 114 articles.</p> <p>Trend: Views of the GRNMS web page on scuba diving have remained consistent. Nationwide Google searches for “diving Georgia” were steady over time.</p>

**Table App.E.17.** Summaries for the key indicators related to consumptive recreation that were discussed during the March 23, 2023 workshop.

Indicator	Source	Summary
Days spent at sea	Burns et al., 2022	<p>Status: Georgia SIP permit holders spent 35 days at sea annually, and an average of one day in GRNMS. 48.3% of permit holders’ time was spent inshore on open water for fishing.</p> <p>Trend: No trend data were available.</p>
Boat counts	Kendall et al., 2020	<p>Status: The majority of boats observed within GRNMS were center console or other vessels likely used for ocean recreation and fishing.</p> <p>Trend: No trend data were available.</p>
Vessel registrations	Ozburn, 2022, 2023	<p>Status: Annual boat registrations peaked in 2020 at over 6,000 for vessels 16–26 ft and 4,000 for vessels less than 16 ft.</p> <p>Trend: Registrations of vessels under 26 ft increased from 2015 to 2021.</p>

## Appendix E: Indicator Tables

Indicator	Source	Summary
Georgia angler landings	NOAA Marine Recreational Information Program, 2022	<p>Status: Black sea bass and vermilion snapper are the top species landed by charter boats. Herring and black sea bass are top species landed by private/rental boats.</p> <p>Trend: Landings appeared to be steady, with some highs and lows, but no clear trend.</p>
Expenditures and economic contributions	Burns et al., 2022; Lovell et al., 2020; Frimpong, 2023	<p>Status: Expenditures per angler-day in Georgia were \$50 for private/rental boats and \$352 for for-hire boats in 2017. In 2020, an average fishing trip to GRNMS cost \$152. The two years of data were not comparable due to differences in methods.</p> <p>Trend: No trend data were available.</p>
Attitudes and perceptions	Burns et al., 2022; Samonte et al., 2023	<p>Status: Recreation activities, seafood, scientific research, and support for education were positively valued inside and outside of GRNMS. Non-users of GRNMS were more concerned with threats to the sanctuary than users.</p> <p>Trend: Most users felt that bottom fish populations, live bottom habitat, and diversity of fish populations were getting better, while invasive species and ocean acidification were getting worse.</p>

**Table App.E.18.** Summaries for the key indicators related to non-consumptive recreation that were discussed during the March 23, 2023 workshop.

Indicator	Source	Summary
Days spent at sea	Burns et al., 2022	<p>Status: Georgia SIP permit holders spent 35 days at sea and one day in GRNMS annually.</p> <p>Trend: No trend data were available.</p>
Vessel traffic	U.S. Coast Guard Navigation Center, 2022	<p>Status: Several different types of boats use the sanctuary, including pleasure craft, dive vessels, and passenger vessels.</p> <p>Trend: The total number of unique pleasure craft and the distance traveled within the sanctuary has increased since 2015.</p>
For-hire diving	K. Hunnicutt/ Latitude 31, personal communication, February 10, 2023	<p>Status: Roughly 20 charter dive trips to GRNMS were taken annually since 2018; each trip took six divers to the sanctuary.</p> <p>Trend: The number of dive trips has remained stable since 2018.</p>

## Appendix F: List of Acronyms

AIS	automatic identification system
DPSEER	Driving forces-Pressures-State-Ecosystem services-Response
GADNR	Georgia Department of Natural Resources
GDP	gross domestic product
GRNMS	Gray's Reef National Marine Sanctuary
HAB	harmful algal bloom
MSD	marine sanitation device
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
ONMS	Office of National Marine Sanctuaries
SAFMC	South Atlantic Fishery Management Council
SIP	Saltwater Information Program
SST	sea surface temperature



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