

## **Fiscal Year 2022 Improving climate understanding and information for Sanctuary management planning**

### **Program Name**

This competition is supported by multiple programs, as contributions to the Climate Program Offices cross-program Marine Ecosystem Climate Risk Area initiative:

Earth System Science and Modeling Division  
Climate Observations and Monitoring (COM) Program  
Modeling, Analysis, Predictions, and Projections (MAPP) Program

Climate and Societal Interactions Division

### **Program Mission**

In support of the Climate Program Office Risk Area Initiative, this multi-program solicitation leverages the strengths of the ESSM programs, increasing the use and value of observations, and enhancing NOAA's ability to model and predict variability and change in the Earth's climate system, as well as CSI programs' tradition of targeting high impact, regionally-scaled, societally relevant interdisciplinary climate and adaptation research and engagement.

The Modeling, Analysis, Predictions, and Projections (MAPP) Program focuses on the development and application of Earth System models and analyses across NOAA, among partner agencies, and with the external research community. Primary objectives include: 1) improving Earth System models; 2) supporting an integrated Earth System analysis capability; 3) improving methodologies for global to regional scale climate analysis, predictions, and projections; and 4) developing climate modeling capabilities and applications relevant to decision makers based on climate analyses, predictions, and projections.

The Climate Observation and Monitoring (COM) Program focuses on supporting work that leverages existing in-situ and satellite-based observations to develop value-added datasets, products, and analyses. Primary objectives are to support work that 1) provides usable and useful datasets that further enable monitoring and modeling efforts and 2) provide authoritative, long-term datasets and analyses for assessment activities.

The Adaptation Science Program focuses on advancing the knowledge, methods and frameworks needed to move society beyond incremental adaptation toward more widespread, connected, adaptive pathways, and resilience strategies with clear economic and societal co-benefits.

MAPP and COM sit within the Earth System Science and Modeling Division (ESSM), and Adaptation Sciences sits within the Climate & Societal Interactions Division of the NOAA Office of Oceanic and Atmospheric Research (OAR) Climate Program Office (CPO).

## Focus for FY 2022

### Improving climate understanding and information for Sanctuary management planning

Improving understanding and information available for climate considerations in Sanctuary condition reports and management planning, including potential short- and long-term implications for water conditions (e.g., temperature, quality, sea level, storms, freshwater input), sediment (e.g., transport, erosion), and ecological assemblages; for ecosystem management approaches that offer co-benefits for adaptation and mitigation; and for the human communities living in close association with these resources and vulnerable to the coastal implications associated with climate change.

## Funding for FY2022

Pending the availability of funds in FY 2022, the COM and MAPP programs and CSI division anticipate a funding allocation of up to \$4,000,000 total for this competition.

Type 1 Proposals may be up to three years, and range from 100K to 175K per year depending on proposed activities outlined in A-E.

Type 2 Proposals may be up to \$250K per year.

## Competition Information

The changing climate and ocean are affecting the nation's valuable living marine resources and the people, businesses, and communities that depend on them<sup>1</sup>. NOAA's National Marine Sanctuary System (NMSS) and the coastal communities it serves are no exception. NMSS sites are contending with rising water temperatures and sea levels, ocean acidification and hypoxia, loss of biodiversity and changing species distributions, and altered weather patterns and storms, which are detailed further in *National Marine Sanctuary (NMS) Climate Change Impacts Profiles*<sup>2</sup>. Likewise, the human communities most closely connected to these sites are experiencing unprecedented changes. Preserving our Nation's coastal heritage and ecosystem services through this time of radical environmental transformation is imperative. Healthy and productive coastal systems also keep our coastal communities safe and provide food for our Nation.

A recent Executive Order identified coastal communities as having *an essential role to play in mitigating climate change and strengthening resilience by protecting and restoring coastal ecosystems, such as wetlands, seagrasses, coral and oyster reefs, and mangrove and kelp forests, to protect vulnerable*

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<sup>1</sup> Fourth National Climate Assessment, Oceans and Marine Resources chapter  
<https://nca2018.globalchange.gov/chapter/9/>

<sup>2</sup> Sanctuary Climate Change Impacts Profiles  
<https://sanctuaries.noaa.gov/management/climate/impact-profiles.html>

*coastlines, sequester carbon, and support biodiversity and fisheries.*<sup>3</sup> Sanctuaries and other marine protected areas are a key component of this effort and are increasingly recognized as “nature-based solutions” towards addressing the dual biodiversity and climate crises. This role has been highlighted in the international and national goal of conserving 30% of our lands and waters by 2030.<sup>3</sup> Sanctuaries are charged as stewards of protected ecosystems, and monitor environmental and biological conditions while working with partners. By collaborating closely with coastal communities, sanctuaries play an important role in supporting and celebrating the variety of human connections with our marine environment. Sanctuaries incorporate information into Condition Reports (undertaken every 10 years), and supplement these with Climate Vulnerability Assessments (CVAs), both of which inform Science Needs and mandated *Management* planning.

The need for climate information is emerging as an increasingly pressing issue in the NMSS. Recently, ONMS began considering climate and related impacts in its Condition Report process, where subject matter experts review regional-based information, and make judgment-based ratings (e.g. *Have recent, accelerated changes in climate altered water conditions and how are they changing?*, More detail in Appendix A). Sanctuary sites are also beginning to conduct vulnerability assessments and consider what actions Sanctuaries or Sanctuary partners can take to mitigate climate impacts and build resilience ([ONMS Climate Resilience Plan](#)). Implementing the goals and actions of NOAA’s *Blue Economy Strategic Plan 2021 - 2025*<sup>4</sup>, including expanding and designating new NMS; improving access to coastal recreation areas; supporting accessible, sustainable recreational fishing; and understanding and communicating economic value will also require a better understanding of climate variability and change and its impact on place-based resources and the communities that depend on them.

Despite the increasing need and emerging uses for climate information, a lack of understanding of climate and related impacts and the needs of neighboring communities, and access to information limits the incorporation of climate into sanctuary planning and management. The [Office of National Marine Sanctuaries - Climate Program Office Climate Science for Sanctuaries Workshop Report 2021](#) highlights needs and gaps for more research and synthesis across disciplines<sup>5</sup>. For instance, *incorporating multiple disciplines and perspectives into science, resource assessment, and management* was identified as a cross cutting need and a recent NAS report further stressed the importance of *increased integration of natural and social sciences, improving the balance among physical climate research, ecosystems research, and human systems research*<sup>6</sup>.

To meet these needs, NOAA needs to strengthen climate-related science (including social science) as it relates to the needs of place-based management of marine ecosystems and living resources regionally and nationally.

The Office of Oceanic and Atmospheric Research (OAR) Climate Program Office programs are well-positioned to advance climate science needs in support of the NMSS, and complement research across NOAA at OAR Research Labs, NMFS Fisheries Science Centers, NOS Integrated Ocean Observing System, National Centers for Coastal Ocean Science, National Estuarine Research Reserves, NESDIS CoastWatch/ OceanWatch/ PolarWatch Programs, and Regional Nodes and Sea Grant extensions via the engagement of the broader research community. In FY22, through CPO’s Climate Risk

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<sup>3</sup> Tackling the Climate Crisis at Home and Abroad

<sup>4</sup> [NOAA Blue Economy Strategic Plan](#)

<sup>5</sup> [NOAA ONMS-CPO Climate Science for Sanctuaries Workshop Report](#) (and [Supplemental](#))

<sup>6</sup> [National Academies Global Change Research Needs and Opportunities 2022 - 2031 Report](#)

Area Initiative, COM, MAPP, and CSI division programs are holding a joint competition to address climate-marine ecosystem needs with a focus on applications for Sanctuaries.

This builds on recent investments made across CPO programs that focus on:

- improving understanding of the processes that affect ocean variability and change relevant to fisheries (CVP)<sup>7</sup>
- improving the modeling of fisheries and other living marine resources across time scales (MAPP)<sup>8</sup>
- characterizing climate impacts on ecosystem state and processes, and impacts on fisheries and fishing dependent communities, including the assessment of the vulnerabilities of marine resources and coastal communities, and the identification of adaptation opportunities for improved alignment between ecosystem health and human (socio-cultural and economic) well-being in coastal communities (AdSci)<sup>9</sup>
- collaborating with Environmental Protection Agency and U.S. State department to advance blue carbon, including integrating coastal wetlands in the U.S. National Greenhouse Gas Inventory and advancing the NOAA Blue Carbon Inventory Project with the ONMS MPA Center

For over a decade, CPO has supported research on understanding ocean climate variability and change, and socio-economic risk and vulnerabilities of coastal communities. These investments have resulted in social-ecological vulnerability assessment frameworks, adaptation planning assessments by fishing communities, climate-seafood supply chain connections, and improved and integrated modeling capacity that leverages new and existing physical, biological, social and economic data to support prediction and projection of changing ocean habitat and ecological response. The major focus of this work has been fisheries and fishery dependent communities. However, several studies in the last five years have expanded to include co-development of adaptation planning with the conservation community and considered ecosystem services more broadly in the Northeast US region (e.g. fisheries, energy, tourism, recreation, health, etc.). Given ONMS' increased need for climate information and its connection to local coastal communities and living resources, CPO is capitalizing on this opportunity to build on the successes of CPO and NMFS' decade-long applied research collaboration, expand climate work, and apply these multidisciplinary approaches to support planning and adaptive actions under consideration by NOS/ONMS and their local and state partners.

Advancing interdisciplinary climate science to co-develop insights important to ecosystem health and coastal communities (including promoting benefits to coastal communities), in NMS supports recent Executive Orders that 1) call to *bolster resilience to the impacts of climate change; restore and expand our national treasures and monuments*<sup>10</sup> and 2) request agencies to collect input from stakeholders (CPO-ONMS Workshop) on *how to make protected resources more resilient to climate change, including changes in management and conservation measures and improvements in science, monitoring, and cooperative research*<sup>11</sup>. This effort aligns with OAR's Research Strategy 2020 - 2026 Goals: 1.2; 1.3; 2.3; 3.1; 3.3.<sup>12</sup>

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<sup>7</sup> [Climate and Changing Ocean Conditions: Research and Modeling to Support NOAA Fisheries](#)

<sup>8</sup> [MAPP Marine Ecosystem Taskforce 2020 - 2023](#)

<sup>9</sup> [Understanding Climate Impacts on Fish Stocks to Inform Sustainable Management](#)

<sup>10</sup> [Executive Order: Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis](#)

<sup>11</sup> [Executive Order: Tackling the Climate Crisis at Home and Abroad](#)

<sup>12</sup> [OAR Research Strategy 2020 - 2026](#)

**In FY22, programs participating in the marine ecosystem risk area initiative, MAPP, COM, and the CSI division, solicit proposals for research to improve understanding of long-term variability and change of physical or biogeochemical conditions in place-based managed ecosystems; climate-related impacts on biological/ecologically-relevant physical processes; and/or the consequential impacts to outcomes desired by the communities that Sanctuaries serve and potential solutions with co-benefits to coastal community resilience and ecosystem conservation. Type 1 proposals are project-based. Type 2 proposals should include a team plan to organize and lead Task Force activities.**

**Type 1** Proposals are strongly encouraged to work with Sanctuaries throughout the project (find POC information in *General Guidelines* section), to ensure that project outcomes are relevant to Sanctuary applications (e.g. Condition Reports, Climate Vulnerability Assessments, improved understanding for research and monitoring, or applicable to other regional or site-specific Sanctuary needs, such as their partnerships with local communities or local, regional, tribal, and/or state entities). Proposals may focus on scientific research and development projects that target an individual sanctuary, a region, or consider the entire National Marine Sanctuary System. Where relevant, applicants are encouraged to consider how methods, approaches, and/or products scale to other Sanctuaries, Regions, or the broader system. Proposals are encouraged to focus on one or more of the following (A through E). Note proposals that focus on one of A through E will be equally considered with those proposals that focus on more than one.

- A) Develop or analyze physical and biogeochemical datasets or products to improve the understanding of linkages between physical and biological parameters for Sanctuary applications. Proposals should have a strong focus on existing observational data and are *encouraged (but not required)* to incorporate additional existing biological/ecological data (species or ecosystems of economic, ecological, or cultural relevance to one or more sanctuaries) and consider multiple data types (e.g. integrate observation and modeled data). Proposals will achieve one or more of the following:
- enable monitoring of physical or biogeochemical conditions, or climate impacts to place-based managed ecosystems;
  - enable the incorporation of underutilized or emerging types of observational data into models to inform place-based management;
  - advance the improvement or development of new, experimental satellite products or the improvement or development of new applications that leverage existing satellite data products to address Sanctuaries' needs.
- B) Develop new, model-based monitoring approaches or model-based experimental products. Model-based approaches should include either artificial intelligence methods, reanalysis datasets, or data assimilation techniques. Proposals are encouraged to consider innovative ways to capture conditions in observation-limited areas, such as subsurface and benthic conditions, to support observing and monitoring gaps in Sanctuaries. Such proposals should include either a pathway toward operational maintenance of the monitoring product(s) or a plan for transition into operational or real-time maintenance during the term of the project.
- C) Use data from the Coupled Model Intercomparison Project (CMIP6) and constituent MIPs (e.g., HighResMIP, OMIP), or other model forecast or projection datasets to consider one or more of the following:
- improved understanding of drivers of marine and coastal extremes relevant to Sanctuaries sites, model performance and capacity to simulate these drivers and

responses undergirding confidence in projections, and how they are projected to change in the future on space and time scales relevant to NMS.

- applications of model-based data or experiments to Sanctuary designation, expansion, and location based on ecosystem characteristics and physical conditions relevant to unique features of the NMSS.
- evaluation of changes (on-going and future) in the ability of a Sanctuary site or the NMSS to meet its mission (e.g. target species will shift out of proposed areas) or identify areas where sanctuary protection could have outsized benefits (e.g., blue carbon ecosystems and climate refugia).

D) Explore the effects of changing climate conditions on the social and cultural aspects of (and economic implications for), local sanctuary adjacent communities, including vulnerabilities and prospective adaptation options. Consider one or more:

- impacts to culturally-relevant resources, including methods that incorporate traditional local knowledge (TLK) into understanding climate extremes and impacts to cultural and other resources
- perspectives on benefits of and threats to sanctuaries, particularly in relation to building climate resilience
- impacts to local culture, economies, and small businesses, including tourism, recreation and natural resource use
- impacts to public health, public safety (lives, livelihoods, property), and/or food security

E) Through an integrated risk framing approach, considering the risks to human and natural systems posed by climate variability and change, investigate Sanctuary-relevant climate adaptation or management frameworks and their co-benefits (such as blue carbon). Proposals should examine co-benefits to BOTH conservation of Marine Protected Areas, Sanctuaries, ecosystems AND to the health, safety, socio-cultural interests, economic security, and/or food security of related coastal communities. Projects are encouraged to:

- Examine all aspects to support the needs of decision makers in planning and preparing for multiple climate stressors to ecosystems and coasts in the context of overall social and economic development objectives of focal coastal communities.
- Integrate climate, ecological, and socio-economic behavioral (SEB) research and modeling efforts to evaluate adaptive strategies under different climate and ocean scenarios to inform adaptation and management, inclusive of local community interests.
- Examine legal and policy mechanisms impacting the ability of sanctuaries and partners to pursue adaptive management actions
- Promote regional collaboration across science and management communities to provide information on future conditions, risks, compound impacts (e.g. on biological resources important to food systems and security), and management strategies for use in planning and policy making.
- Pursue innovative, applicable and transferable approaches for managing/planning/decision making (within the realm of possibilities available to sanctuaries/partners), especially for risk characterization in the context of a variable and changing climate.
- Engage communities adjacent to sanctuaries, particularly those with limited interaction with their neighboring sanctuary, in collective inquiry, reflection, and collaborative discussion around sanctuaries including but not limited to non-economic benefits as well

as their own social maritime history, interactions with the marine environment, and/or experiences with climate-related environmental transformation.

Proposed work plans should also account for time spent on participation in a *NOAA Climate Program Office Science for Sanctuaries Task Force* that will be constituted of the investigators funded as a result of this solicitation. In addition to project primary investigators, postdoctoral fellows and graduate students are also welcome to participate in Task Force activities. Task Forces enable collaboration between funded investigators, CPO, ONMS, and other relevant programs via monthly teleconferences and through constructive, collaborative activities. In the past, Task Forces have produced fact sheets, knowledge statements, collaborative analysis products, and group journal articles; and have organized meeting sessions, special collections, or other activities.

**Type 2** The team proposal should address the research areas described above and advance key objectives of this solicitation. The Task Force lead team proposal should also describe plans for how to integrate results and activities of the individual projects in a Task Force collectively and synergistically, addressing the core objectives of this solicitation and potential for incorporation into planning processes, building a community of practice among funded PIs and participating Sanctuaries. These will include a vision for collaborative activities to unify participating researchers, support for integration of datasets or products into Sanctuary applications, and plans for publications, documentation, or other outputs that can synthesize and disseminate the work of the Task Force and lead to increased community awareness and utility of the competition outputs. Team proposals should also include support for the integration of data, information, knowledge from research teams funded outside of this solicitation, depending on relevance, and should be sufficiently inter-disciplinary so as to be able to lead a diverse set of investigators funded through the type 1 opportunity. Team proposals should include contributions from multiple institutions and may request up to \$75k/year for non-NOAA collaborators and up to an additional \$50k/year for activities at or affiliated with NOAA laboratories for a total of 750K per project. Only one team proposal would be funded, if successful.

**All proposals are encouraged (but not required) to**

- Work collaboratively with the NOAA community including ONMS Sanctuaries, OAR Laboratories, Cooperative Institutes, Sea Grant, IOOS Regional Associations and Marine Biodiversity Observation Network, NOAA CoastWatch (including Regional Nodes), and/or Regional Fishery Science Centers. Proposals should integrate NOAA science, services, and stewardship where possible to further enhance the uptake of NOAA research and climate information into Sanctuary and coastal management, and should engage and leverage existing service structures for the transition of real-time or other products and information. Applicants interested in working with the above mentioned NOAA programs should reach out to programs when developing their LOIs. POCs for ONMS, MBON, and CoastWatch programs are listed below.
  - Office of National Marine Sanctuaries: Zachary Cannizzo, ONMS Climate Coordinator ([zac.cannizzo@noaa.gov](mailto:zac.cannizzo@noaa.gov))
  - Marine Biodiversity Observation Network: Gabrielle Canonico, MBON Program Manager ([Gabrielle.Canonico@noaa.gov](mailto:Gabrielle.Canonico@noaa.gov))
  - NOAA CoastWatch Program Manager, Veronica Lance ([Veronica.Lance@noaa.gov](mailto:Veronica.Lance@noaa.gov))
  - Applicants interested in working with IOOS RAs should reach out to the corresponding RA Director when developing their LOIs.
- Generate insight and long-term networks that could support partnerships with communities to better understand their interests and goals as they anticipate planning for climate change. (e.g. partnering with at least one sanctuary that is new to formalized climate change planning, or



working with local/regional associated tribal, indigenous, rural, or socioeconomically disadvantaged areas and/or communities)

- Where relevant, consider how methods, approaches, products, and knowledge will scale to other sanctuary sites, and across the NMSS
- Promote the transfer of climate knowledge, assessment tools, products, and services within NOAA, to NOAA partners, across the federal government, nationally, and internationally.

**Proposals that pursue the development of a non-static dataset/product (which is not required) must include a statement (1 page or less) on the potential for the data product/set to be produced/maintained past the duration of the product (exclude from page count).** In these cases, *applicants must demonstrate that the NOAA or NOAA partner operational host is integrated (aware, supportive of, committed to planning for) into transition activities. Guidance for collaborating with operational hosts (not limited to below):*

- *IOOS RA: Proposals must include at least one IOOS Regional association partner to qualify, and must contact them at least 30 days prior to application deadline.*
- *NOAA CoastWatch: Proposals must include at least one CoastWatch collaborator.*

Competition Contact Information: Virginia Selz, [virginia.selz@noaa.gov](mailto:virginia.selz@noaa.gov), competition manager

#### **General Guidelines for FY 2021 COM/MAPP/CSI proposal submission:**

- Principal investigators submitting a proposal in response to this COM/MAPP/CSI Announcement are required to follow the Letters of Intent (LOI) and Proposal preparation and submission guidelines described in the Climate Program Office FY 2021 Notice of Federal Funding Opportunity announcement.
- Investigators are strongly encouraged to submit an LOI prior to developing and submitting a full proposal. LOIs can be submitted to Virginia Selz ([Virginia.Selz@noaa.gov](mailto:Virginia.Selz@noaa.gov)). Investigators will be notified by the COM Program Competition Manager as to whether a full proposal is encouraged based on the LOI within four weeks of the LOI due date.
- Administrative questions regarding the Notice of Federal Funding Opportunity (e.g. proposal formatting or submission guidelines) should be directed to Diane Brown ([diane.brown@noaa.gov](mailto:diane.brown@noaa.gov)).

A webinar will be recorded and made available to potential applicants for background on the participating programs and this solicitation soon after publication of this announcement. The webinar will be posted on the [CPO Marine Ecosystem Risk Team webpage](#) and participating program webpages. Please contact the competition manager with questions.

#### **Diversity and Inclusion**

Participating programs recognize that they have a particular and unique opportunity and responsibility to support NOAA's and the community's commitment to diversity and inclusion by taking an intentional step that encourages program applicants to consider diversity and inclusion as part of their scientific projects. Programs support the goal of increasing the inclusion of underrepresented groups in NOAA-relevant modeling science. This action has the potential to make an impact on not only the diversity and inclusion



in science at NOAA, but also beyond the agency. In your proposal, we encourage you to think about how your project can broaden the participation of underrepresented groups (e.g., gender, race, ethnicity, disability, geographic, etc.). Examples could include, but are not limited to, full participation of women, persons with disabilities, and other underrepresented minorities in science, technology, engineering, and mathematics (STEM). Opportunities that may engage students or early career scientists from underrepresented groups at different or earlier ages (e.g., even secondary) in the context of your proposed research are encouraged.

## Data Archiving and Computational Resources

### Computational Resources

Computational resources on NOAA's high-performance computing platforms may be requested for research sponsored as a result of this solicitation. Proposals should indicate the availability of alternative computing resources should NOAA resources not be available for the project. Proposers who choose to request computational allocations on NOAA's platforms must include in their proposal a request describing the computational resources and data storage required, as well as a description of how they will port their methodology to the NOAA platforms. Proposers must submit an HPC Request Form<sup>13</sup> with their proposal in order to apply for computational resources.

Questions regarding the use of NOAA's high-performance computing platforms should be directed to Dan Barrie ([daniel.barrie@noaa.gov](mailto:daniel.barrie@noaa.gov)).

### Data Management Guidance

The MAPP Program requires that all products and deliverables produced via solicitation will reside in the open access / open source domain, freely available to the public.

Public access to grant/contract-produced data will be enabled in one of the following ways (select one):

- Funding recipients are planning to submit data to NOAA National Centers for Environmental Information (NCEI), which will provide public access and archiving<sup>14</sup>. Point of Contact for NCEI is Nancy Ritchey ([Nancy.Ritchey@noaa.gov](mailto:Nancy.Ritchey@noaa.gov))
- Data are to be submitted to an International Council for Science (ICSU) World Data System facility: <https://www.icsu-wds.org/community/membership/regular-members>
- An existing publicly accessible online data server at the funded institution is to be used to host these data (describe in proposal).
- An existing publicly accessible online "cloud" service is to be used to host the data (describe in the proposal).
- The Competition Manager (above) is the responsible NOAA Official for questions regarding this guidance and for verifying accessibility of data produced by funding recipients.

## Appendix

### Appendix A - Example of Questions Related to Climate from Sanctuary Condition Report

<sup>13</sup> [https://cpo.noaa.gov/Portals/0/MAPP\\_FY22\\_HPC\\_Request\\_Form.docx](https://cpo.noaa.gov/Portals/0/MAPP_FY22_HPC_Request_Form.docx)

<sup>14</sup> NCEI supports the creation of adequate metadata and data ingest into long term repository holdings using tools such as Send2NCEI ([www.nodc.noaa.gov/s2n](http://www.nodc.noaa.gov/s2n)), for small volume, one-time only data collections) and Advanced Tracking and Resource tool for Archive Collections or ATRAC (<https://www.ncdc.noaa.gov/atrac/index.html>), for recurring and/or large volume data collections).

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.

- **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