Work Book

Climate Science Fundamentals for MPA Managers: Understanding and Working with Uncertainty

Knowledge Sharing Session

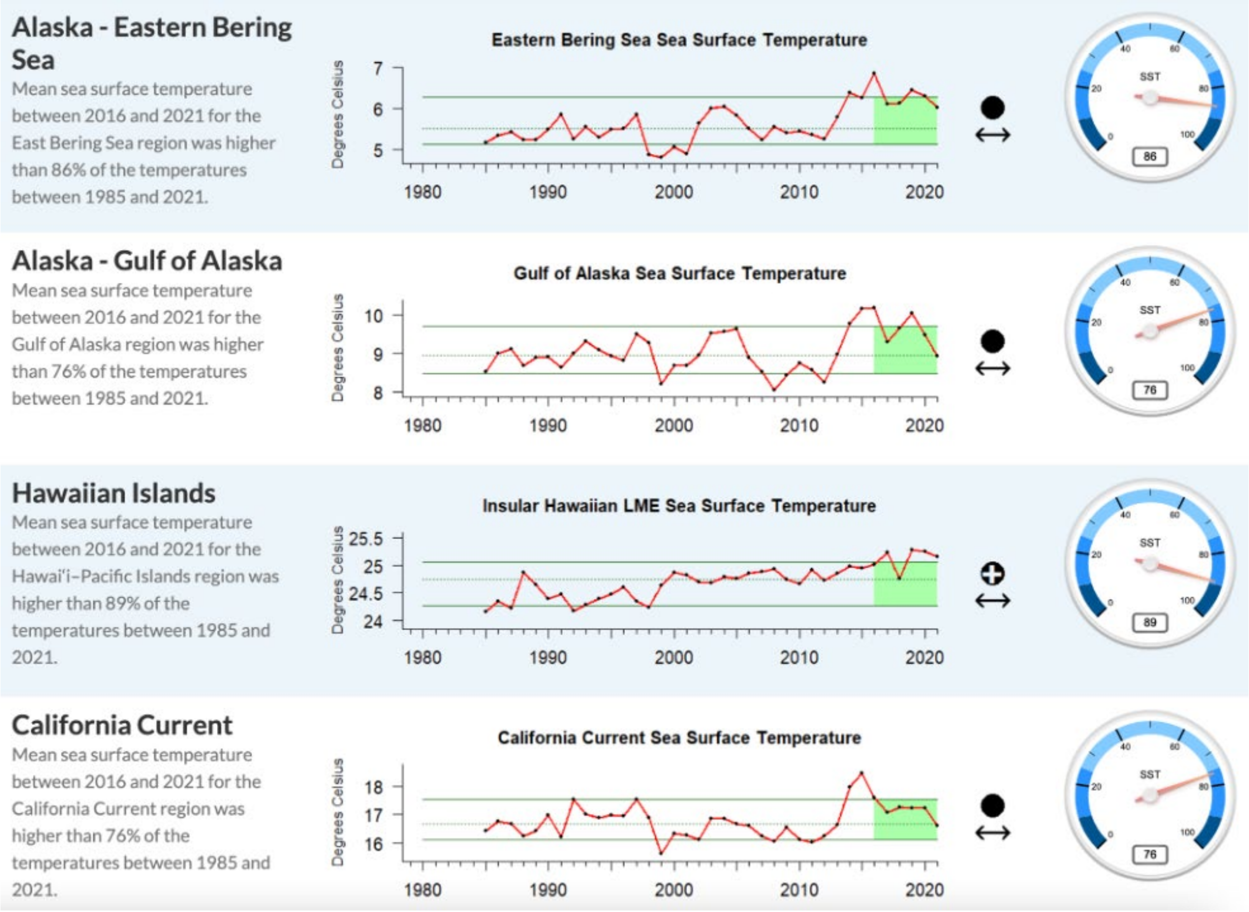
International Marine Protected Areas Congress 5
Vancouver, Canada
February 4, 2023 4:00-5:30pm PT

Climate Change Indicators

What are climate change indicators?

- An indicator is a measurable quantity that helps us understand the status, state, and/or trend of a climate, environmental, or societal condition.
- Climate change indicators describe the changing climate and environment without reducing climate change to just global warming. They can include indicators of climate cycles as well as longer-term, more one-way changes in the system (e.g. Sea Surface Temperature, Sea-Level, Ocean Acidification, etc.).
- Indicators help us to meaningfully track and understand how important things are changing over time and can help us make management decisions.

Climate change indicators simplify the complex nature of climate change in the ocean by breaking it down into trackable variables that represent important changes that affect the resources and processes MPAs protect and manage. Indicators can include physical, chemical, ecological, and socioeconomic variables.



Alaska - Eastern Bering Sea

Mean sea surface temperature between 2016 and 2021 for the East Bering Sea region was higher than 86% of the temperatures between 1985 and 2021.

Alaska - Gulf of Alaska

Mean sea surface temperature between 2016 and 2021 for the Gulf of Alaska region was higher than 76% of the temperatures between 1985 and 2021.

Hawaiian Islands

Mean sea surface temperature between 2016 and 2021 for the Hawai'i–Pacific Islands region was higher than 89% of the temperatures between 1985 and 2021.

California Current

Mean sea surface temperature between 2016 and 2021 for the California Current region was higher than 76% of the temperatures between 1985 and 2021.

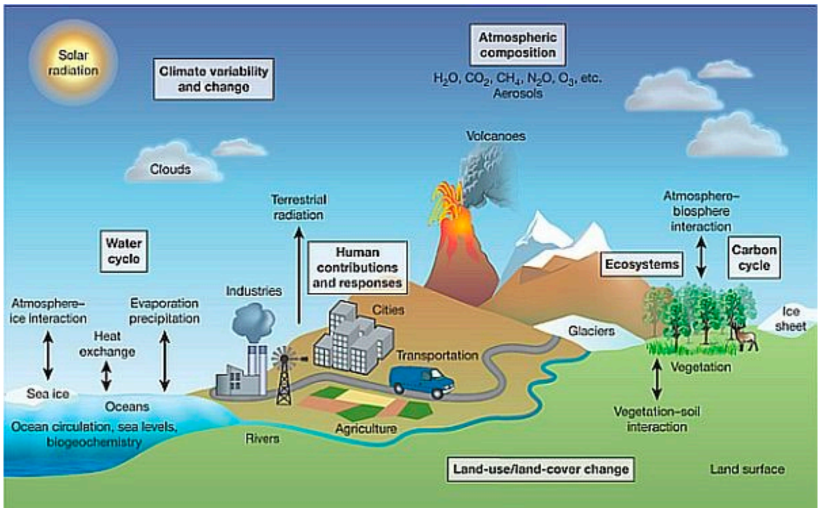
Climate change indicators are often expressed as the change in a variable over a period of time for the location of interest. Sea surface temperature, as displayed above, is a common climate change indicator. Source: [National Marine Ecosystem Status](#).

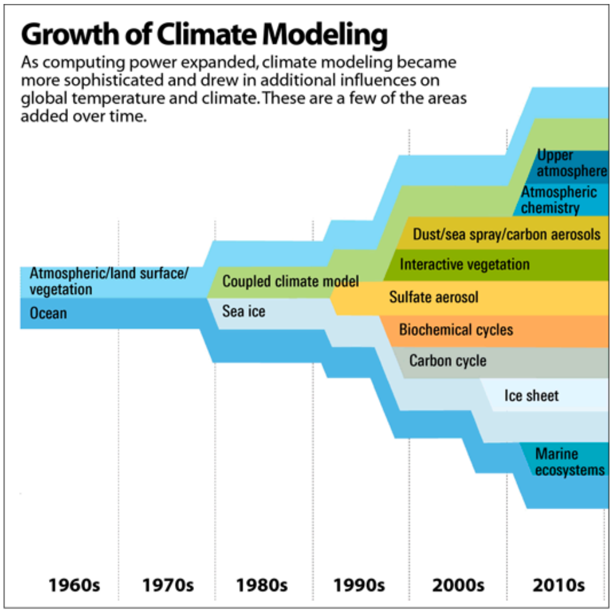
Climate Models

What are climate models?

- Climate models are founded on the basic principles of physics and chemistry.
- They use equations that represent physical, chemical, and biological processes.
- They are run on three-dimensional grids that can cover the globe from deep in the ocean to high in the atmosphere.
- The simulations produced by climate models are compared to observations of real climate and have been shown to reliably reproduce changes and trends in the atmosphere, on land, and in the ocean.

Climate models use numerical equations that represent known physical, chemical, and biological processes to simulate atmospheric, oceanic, and other large-scale processes in a three-dimensional grid representing the ocean, land, and atmosphere. These models can provide estimates of variables from sea surface temperature and precipitation to ocean currents and biological productivity. By starting these models in the past, scientists have shown that they can reproduce historic changes and trends, providing confidence that they are reasonable representations of our climate system and can provide predictions of the future.




Growth of Climate Modeling

As computing power expanded, climate modeling became more sophisticated and drew in additional influences on global temperature and climate. These are a few of the areas added over time.

SOURCE: University Corporation for Atmospheric Research (UCAR) InsideClimate News

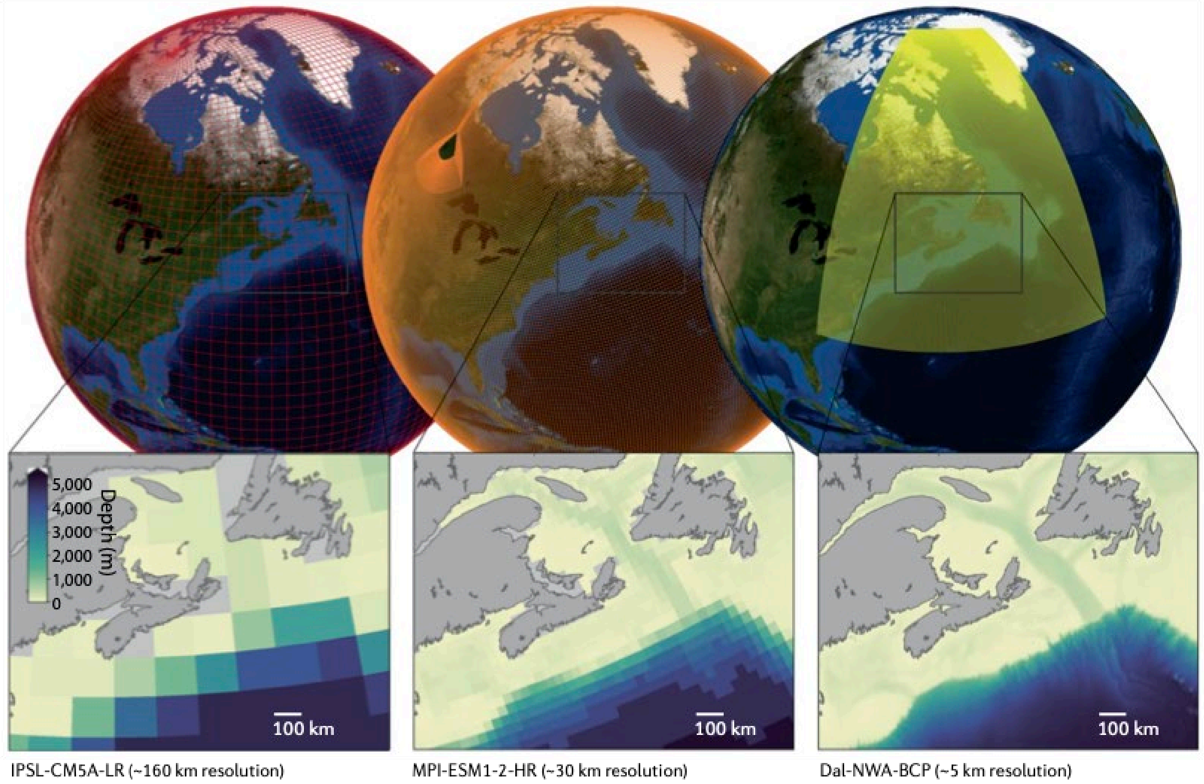
Left: A pictorial representation of the components of a global climate model. Source: climatechangeinaustralia.gov; Right: A timeline of the increasing complexity and sophistication of global climate models. Source: University Corporation for Atmospheric Research (UCAR).

Downscaling

What is downscaling?

- Downscaling can translate large-scale changes produced by global climate models to local scales.
- Downscaling can help represent local physical effects like coastlines, correct biases found in climate models, and consequently make projections more relevant for decisions made by managers and stakeholders.
- Dynamic downscaling uses physical relationships and equations, such as those found in the original climate models.
- Statistical downscaling uses statistical relationships between real world observations and climate model outputs.

Downscaling uses information about climate models and the real world to convert the large-scale information produced by global and regional climate models into local-scale information that can be more useful to stakeholders and decision makers, including MPA managers. Downscaling can accurately reflect local conditions, but does add an additional layer of uncertainty to climate projections. Statistical downscaling may not always appropriately capture climate change trends.

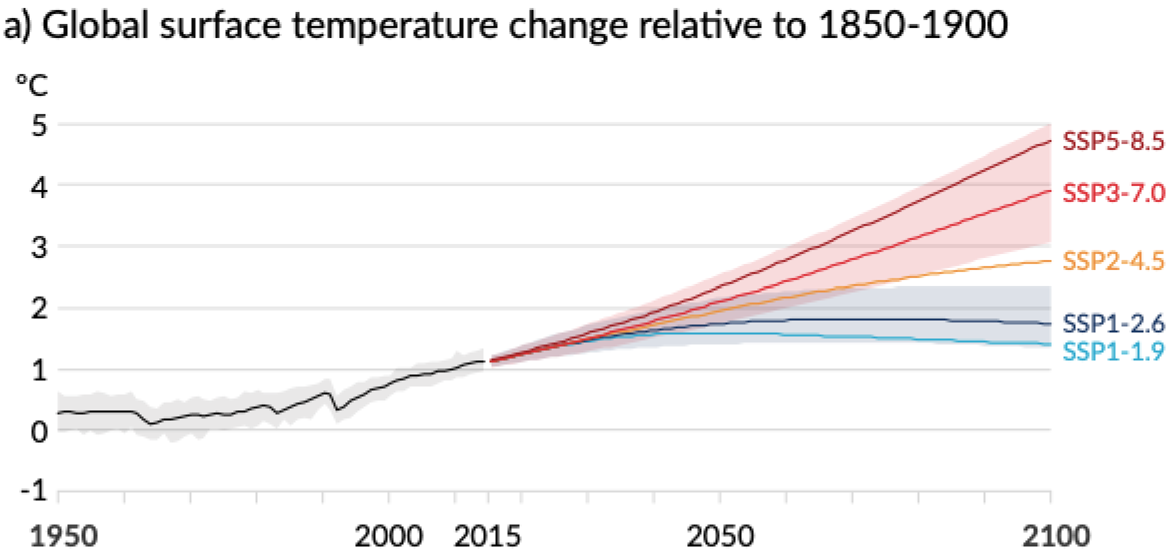


Downscaled climate models can increase the resolution of local-scale processes that may be of interest to management. Source: Fennel et al. (2022)

Climate Projections and Uncertainty

What are climate projections and why are they uncertain?

- The IPCC defines a climate change projection as a simulated response of the climate system to a *scenario* of future emissions of concentrations of greenhouse gas emissions.
- Climate scenarios are plausible alternative futures of *human behavior* often representing the amount of greenhouse gasses we continue to emit.
- Climate models predict how the climate system will react to our decisions (scenarios) creating a projection of future conditions.
- Our future behavior is uncertain leading to many future climate scenarios, resulting in one type of uncertainty.
- Climate models are all slightly different, resulting in different projected futures from other models even under the same scenario, resulting in another type of uncertainty.

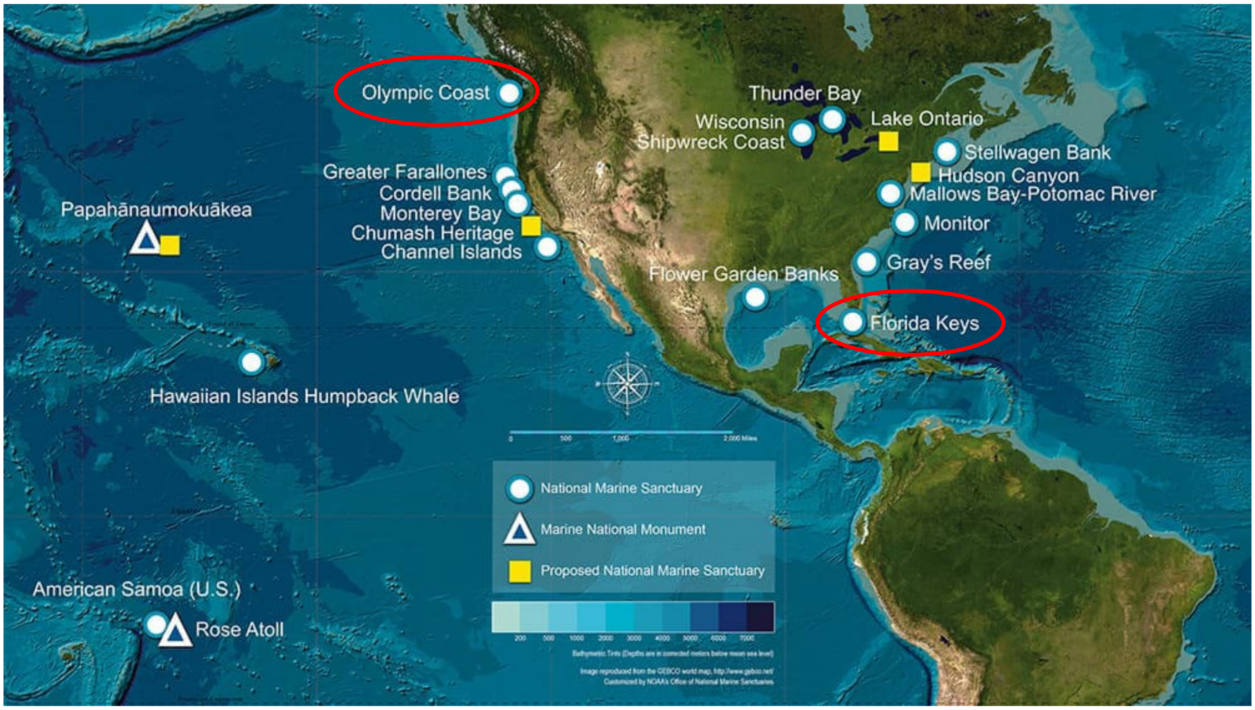


Example of different climate scenarios representing future uncertainties in human behavior. Note that there is even uncertainty within scenarios as the solid line represents the average projected temperature change while the shaded areas represent error around those averages. Source: IPCC

Activities

The following pages contain activities designed to introduce you to making management decisions when presented with climate data that contains uncertainty. These activities are intended to serve as a climate-focused learning experience. While they represent real management challenges being faced by managers in the focal MPAs, they do not introduce the full range management and policy considerations and limitations that are incorporated into management decisions.

The National Marine Sanctuary System includes 17 marine protected areas, 15 national marine sanctuaries and two marine national monuments, encompassing more than 620,000 square miles of marine and Great Lakes waters from Washington state to the Florida Keys, and from Lake Huron to American Samoa. These federal MPAs are managed by the United States National Oceanic and Atmospheric Administration's (NOAA) Office of National Marine Sanctuaries (ONMS). Two of these sanctuaries, Florida Keys and Olympic Coast, are the focus of the activities in this workbook and represent only a small portion of the ecological, geographic, and cultural diversity of the National Marine Sanctuary System.

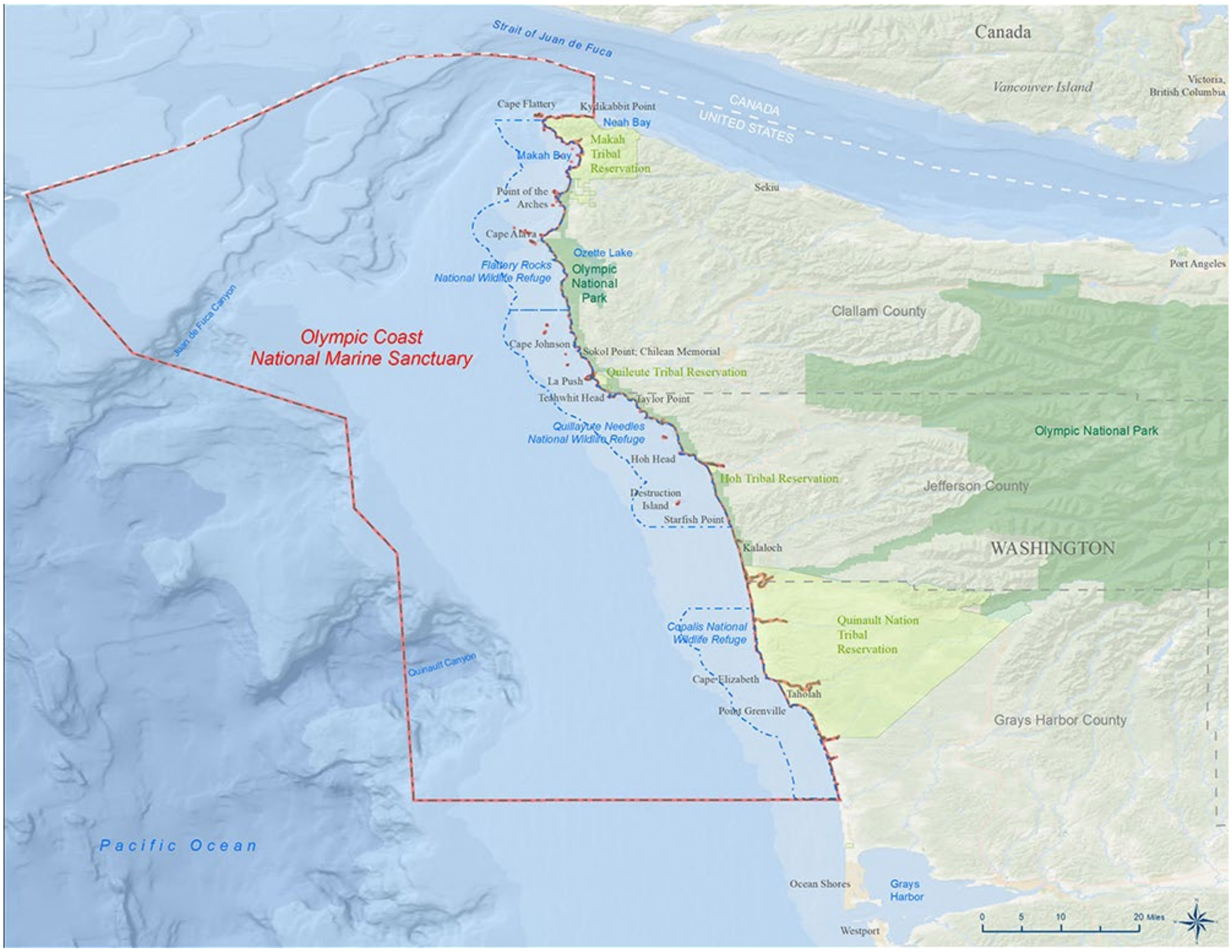


Map of the National Marine Sanctuary System. Olympic Coast National Marine Sanctuary and Florida Keys National Marine Sanctuary (both circled) are the focus of the following activities. Source: NOAA

Dungeness in Danger

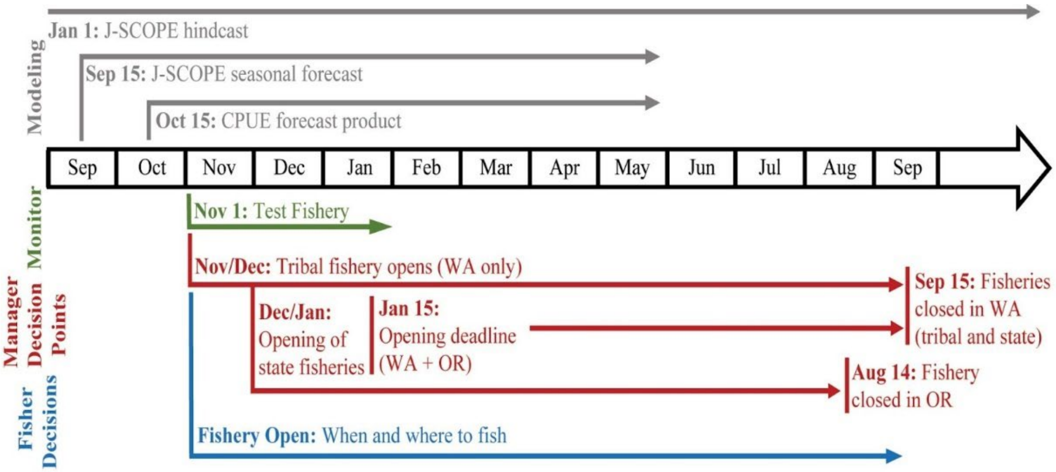
Climate Change and Dungeness Crab in Olympic Coast National Marine Sanctuary

Background



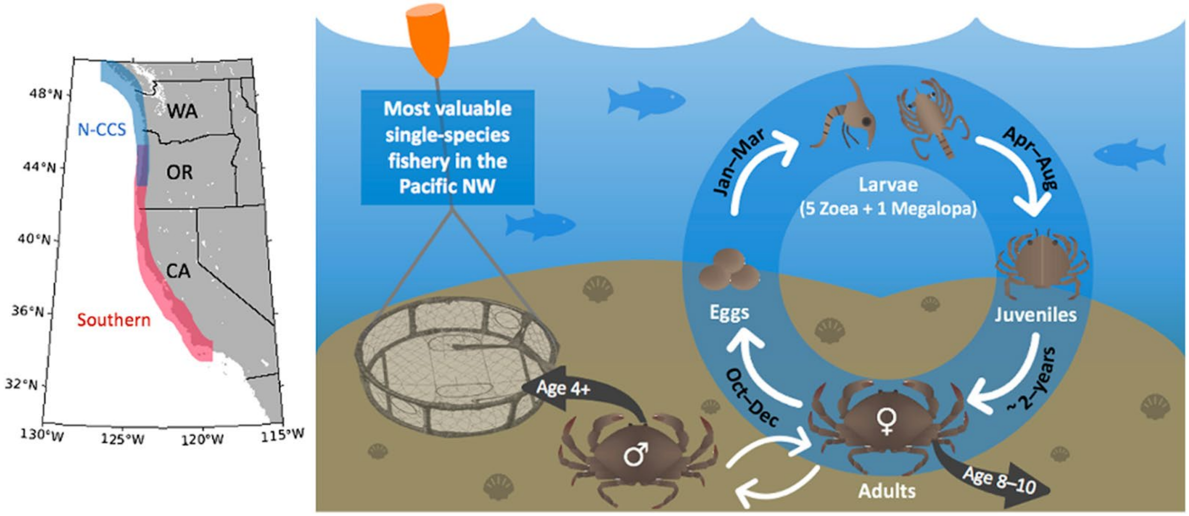
Map of Olympic Coast National Marine Sanctuary. Source: NOAA.

Dungeness crab (*Metacarcinus magister*) inhabit the California Current System (CCS) from Vancouver Island, British Columbia, to Santa Barbara, California, and are an economically and culturally important species within Olympic Coast National Marine Sanctuary (OCNMS) and throughout the region. Under the Stevens Treaties, the tribes in Washington are guaranteed the right to harvest fifty percent of the shellfish in their traditional fishing grounds. Thus, the state and tribal governments in Washington co-manage this fishery within the treaty areas, and the timing of opening dates in co-managed areas must strive toward equal sharing of the crab catch among the state and tribal fishermen. While OCNMS does not manage the fishery, many of the co-managed areas are found within the sanctuary, and the Dungeness crab population is of management interest due to its ecological and cultural importance. The tribal fishery opens first in the co-managed areas to allow tribal fishers the opportunity to harvest half of the legal crab, with the state fishery opening later. If managers open the state fishery too early or too late, equal sharing will not be attained. Dungeness crab are managed within the “3S” framework (i.e., “season”, “size”, and “sex”), by which managers adjust the season opening dates, set minimum size limits, and restrict retained catch to males only. This relatively simple management system has been successful in coping with strong interannual fluctuations in landings of this short-lived species. However, climate change threatens to upset this balance.

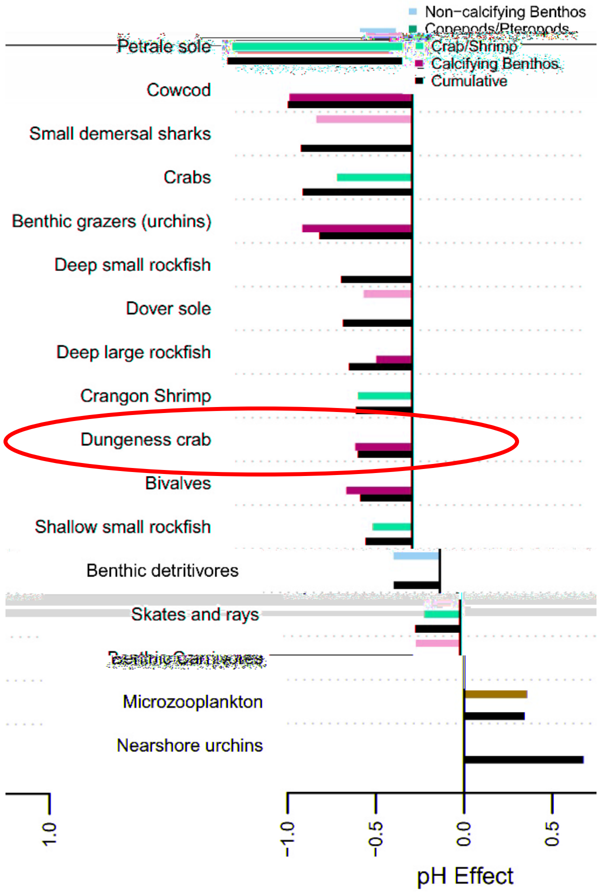


Timing of the Dungeness crab fishery in Washington and Pregon. Source: Norton et al. (accepted).

Like many marine invertebrates, Dungeness crabs exhibit a biphasic life history, living in the water column and on the seafloor over the course of their development. In the fall, bottom-dwelling adult females release fertilized eggs that hatch into planktonic larvae and grow through five stages before settling back to the benthic environment as juvenile crabs. During these larval stages, crabs have been shown to be susceptible to a number of environmental factors, including temperature, oxygen, and pH. Crabs continue to grow, reaching sexual maturity at approximately two or three years of age and legal catch size at age four or five.



Left: N. California Current and Southern Dungeness crab population geographic ranges. Right: Life cycle and timings for Washington and Oregon Dungeness crabs. Source: Berger et al. (2021)



Projected effect of future pH on multiple organisms. A negative pH effect signifies a negative impact on the species. Dungeness crab is circled. Source: Adapted from Marshall et al. (2017).

Crab abundance, often estimated by catch rate, is influenced by population-level drivers as well as both large-scale oceanographic features and local ocean conditions that affect movement and response of adult crabs. Adult crabs have been shown to prefer certain environmental conditions. For example, there is strong evidence that adult crabs are unable to withstand exposure to severe low-oxygen (hypoxia) events and in Puget Sound, hypoxia can compress habitat for adult populations. Further, a study examining the vulnerability of Dungeness crab to climate-driven changes found that the population will be vulnerable to low pH, low oxygen, and high temperature in the future (2100) as a result of the impacts of these parameters on both larval and adult crabs. Thus, the stability of the Dungeness crab population in OCNMS, and the associated fishery, may be compromised by changing ocean conditions, and management may need to consider these conditions in future decision-making.

Activity

Several dynamically downscaled projections exist for the California Current system and are included as figures below. They all project the region will be lower in both pH (i.e. higher ocean acidification, Figure 1) and oxygen (Figure 2 and 3), as well as warmer (Figure 3) and higher in pCO2 (which is often correlated with higher ocean acidification; Figure 3). These models represent a range of ecosystem model structures and resolutions. In general, they all agree on the direction of the trends in the system, but the magnitudes of the projected change differ. All of the results below represent the most severe emissions scenario. Figure 4 is the result of a regional vulnerability assessment project in the OCNMS region targeting Dungeness crab. It represents areas in the Dungeness crab habitat where climate parameters are currently, and are projected to be, at levels that are stressful to adult and larval crabs respectively.

Given the vulnerabilities described above, and climate projections included below, please respond to and discuss the questions following the climate projections.

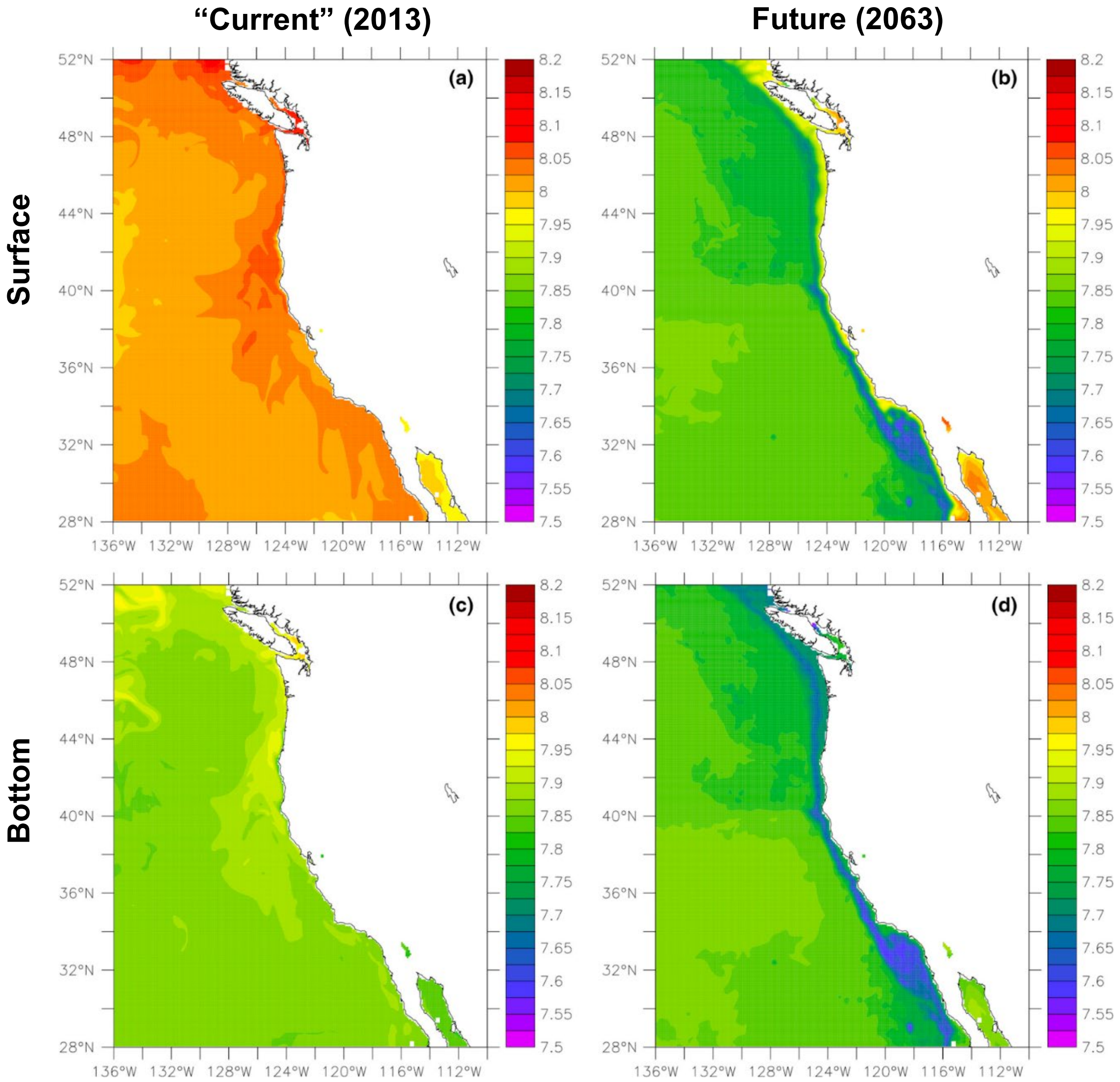


*Figure 1: projections of pH (lower pH = higher acidity) in August 2013 (a, b) and August 2063 (c, d), at the surface (a, c) and bottom (b, d). Models represent the IPCC RCP 8.5 scenario. Source: Adapted from [Figure 3 of Marshall et al. (2017)](). *

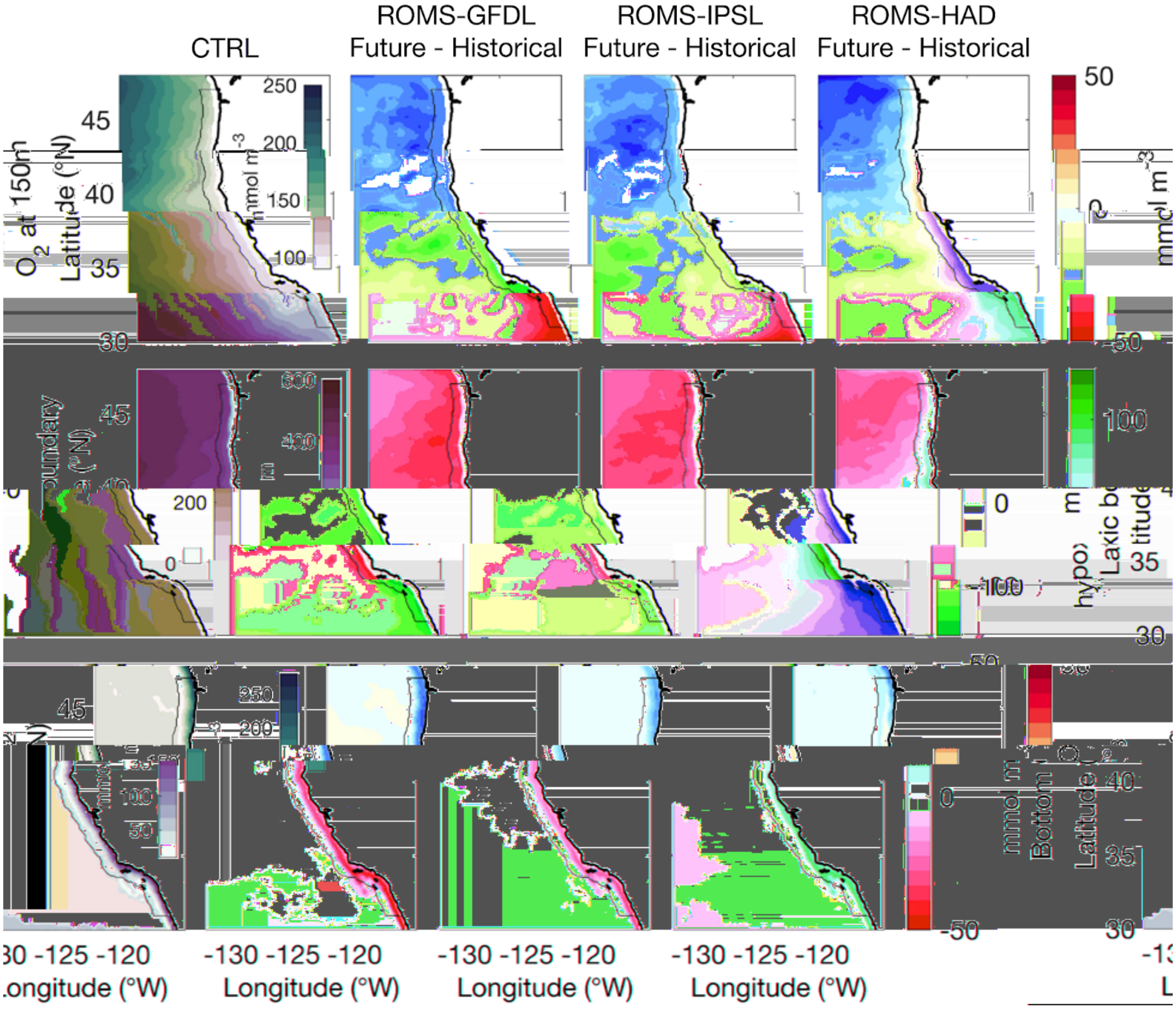


*Figure 2: Downscaled projections using three different climate models (ROMS-GFDL, ROMS-IPSL, and ROMS-HAD). The left column represents a control (CTRL) using the time period 1980–2010. The following columns represent mean and future changes (Future-Historical) by comparing each model output for the timeframe of 2070–2100 to the control time period for dissolved oxygen (O_2) at 150 m depth (top row), the depth of the hypoxic boundary (middle row), and dissolved oxygen at the bottom (bottom row). The black contour marks 100 km from shore. Source: Adapted from [Pozo Buli et al. (2021)](). *

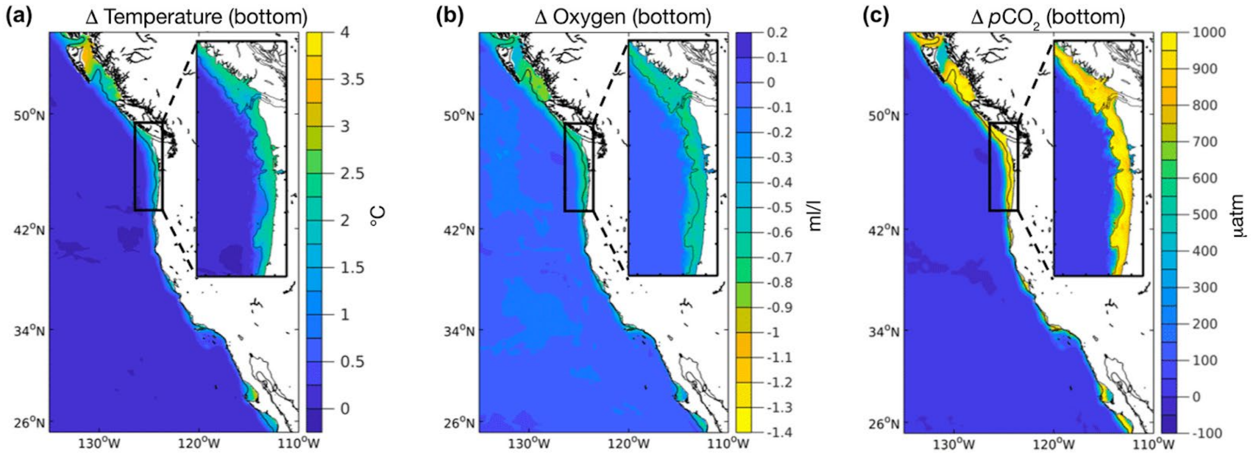


Figure 3: Downscaled physical model outputs for the Pacific coast of North America from British Columbia to Baja California. Each panel shows results for the large California Current Marine Ecosystem and an inset of the smaller Cascadia region, which includes OCNMS. Each model uses a different biogeochemical/ecosystem model. Colors indicate differences between year 2100 and modern conditions, in the bottom (benthic) zone, for (a, left) temperature (^{o}C), (b, middle) dissolved oxygen (ml/L O_2), and (c, right) pCO2 (µatm). Source: Siedlecki et al. (2021) and Sunday et al. (2022).

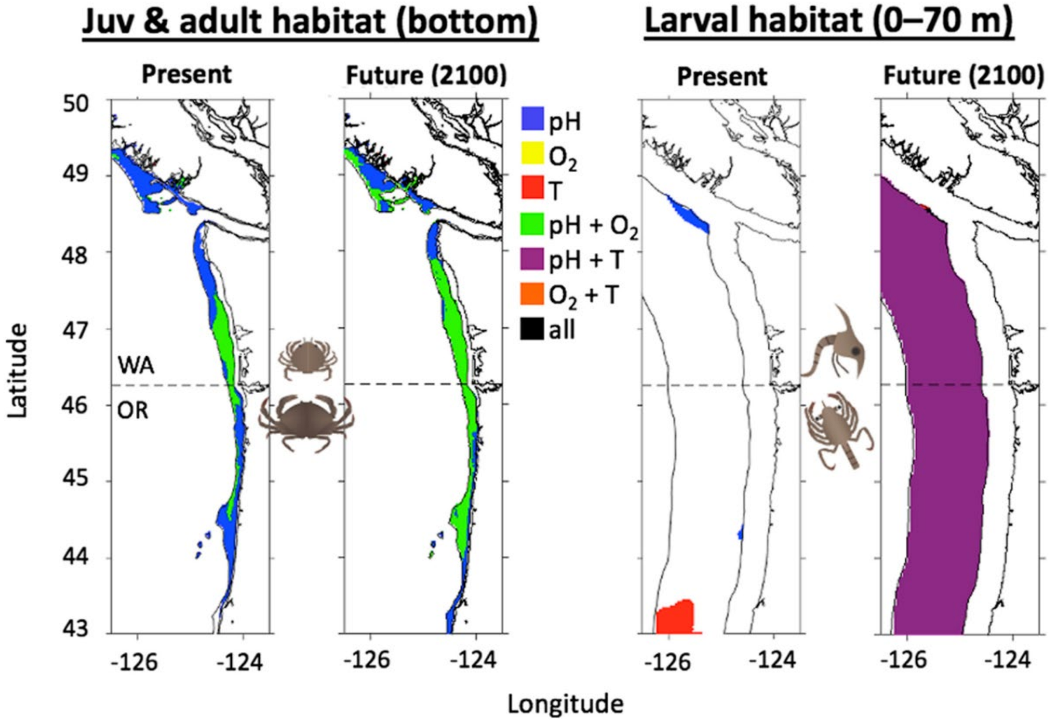


Figure 4: Multi-stressor hotspots for the juvenile and adult habitat and larval habitat in the summer (Jul–Sep). Areas where colors appear represent areas where the identified parameter or parameters (pH, dissolved oxygen (O_2), temperature (T)) cross the threshold to cause stress on Dungeness crab (i.e. become stressors. Maps created according to stressor exposure in the present and future estimated using the distribution map method from Berger et al. (2021) and the 1.5km resolution projection under RCP 8.5 detailed in Siedlecki et al. (2021). For the larval habitat, low pH and low dissolved oxygen are mapped at 70 m depth, while the high temperature is mapped at the surface. The only area where all three stressors overlap (black) is along the northeast edge of the larval habitat near the outskirts of the Juan de Fuca eddy (~48.5°N) under future conditions. Source: Berger et al. (2021).

Given the vulnerabilities described and climate projections above, please respond to and discuss the following questions:

Q1: What management actions can you recommend to be taken within OCNMS to help Dungeness crabs be sustained and how will you quantify success?

Q2: What management actions could you take now that would be beneficial under any scenario (no regrets)?

Q3: Do you have the right level of information to take action?

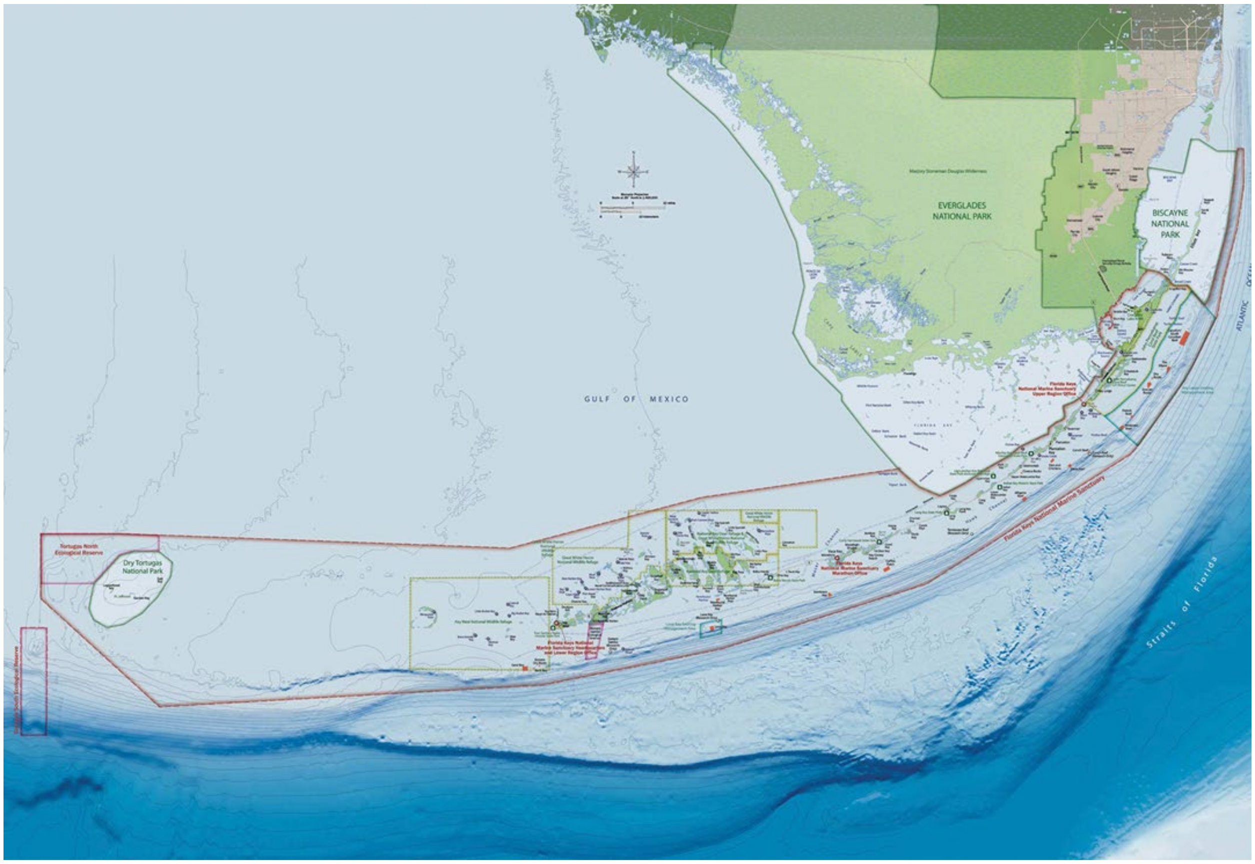
- Are additional observations are needed?

- What additional information would you need?

Corals on the move

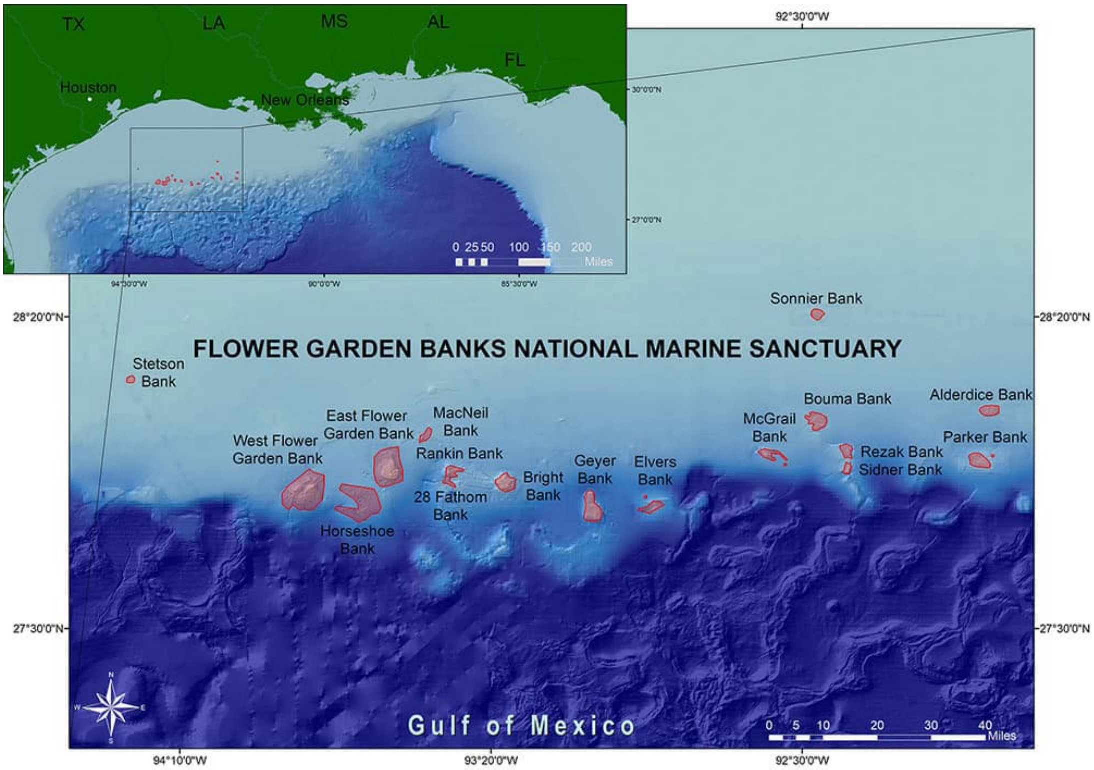
Changing benthic species distributions in Southeast USA National Marine Sanctuaries

Background



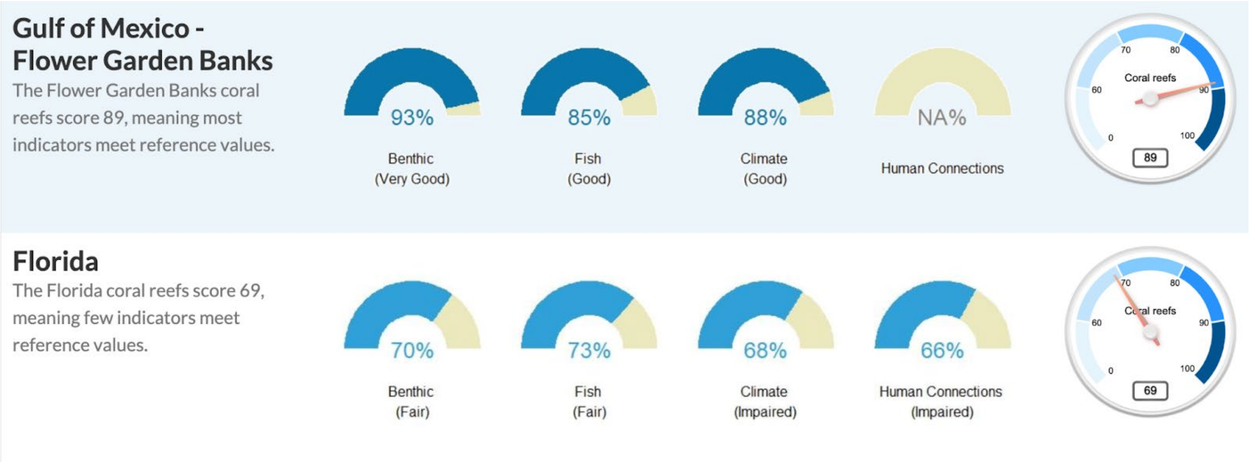
Map of Florida Keys National Marine Sanctuary. Source: NOAA.

Coral reef ecosystems are biodiversity hotspots that are ecologically and economically important. The status of whether a coral reef is growing or shrinking is based on the difference between accretional and erosional processes. Healthy reefs under minimal stress are net accretional (growing), while reefs that are under significant stress are net erosional (dissolving). Most coral reefs globally are either already net erosional or are predicted to be net erosional in the coming decades. This is in large part due to climate change stressors that are already being felt. This stress will continue to increase as many coral reefs are predicted to undergo annual severe bleaching in the coming decades due to increasing seawater temperatures.



Map of Flower Garden Banks National Marine Sanctuary. Source: NOAA.

Two current Marine Protected Areas designated to protect coral reefs in the southeast USA are Florida Keys National Marine Sanctuary (FKNMS) and Flower Garden Banks National Marine Sanctuary (FGBNMS). Corals in FGBNMS, located in the northern Gulf of Mexico, are currently under minimal stress due to climate change, because the reefs are deeper and at higher latitudes. However, most coral reefs within FKNMS are predicted to have annual severe bleaching by 2050 and are already under significant climate stress.



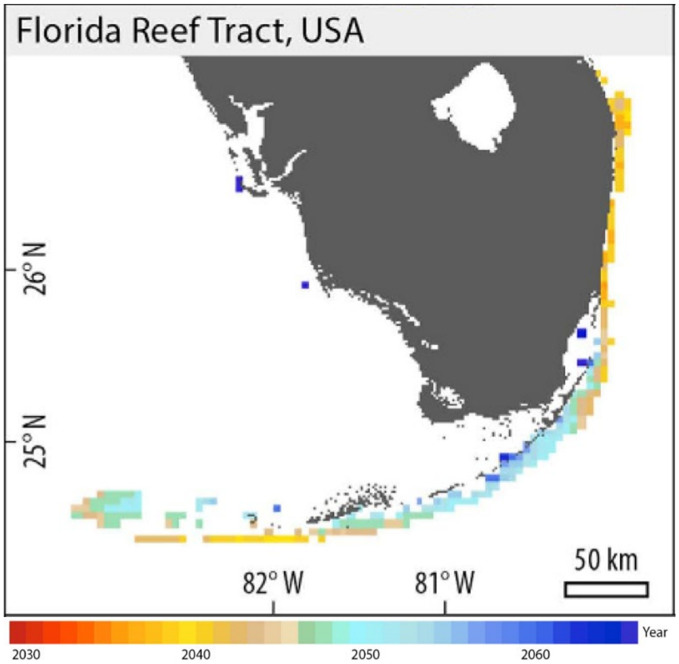
Gulf of Mexico - Flower Garden Banks

The Flower Garden Banks coral reefs score 89, meaning most indicators meet reference values.

Florida

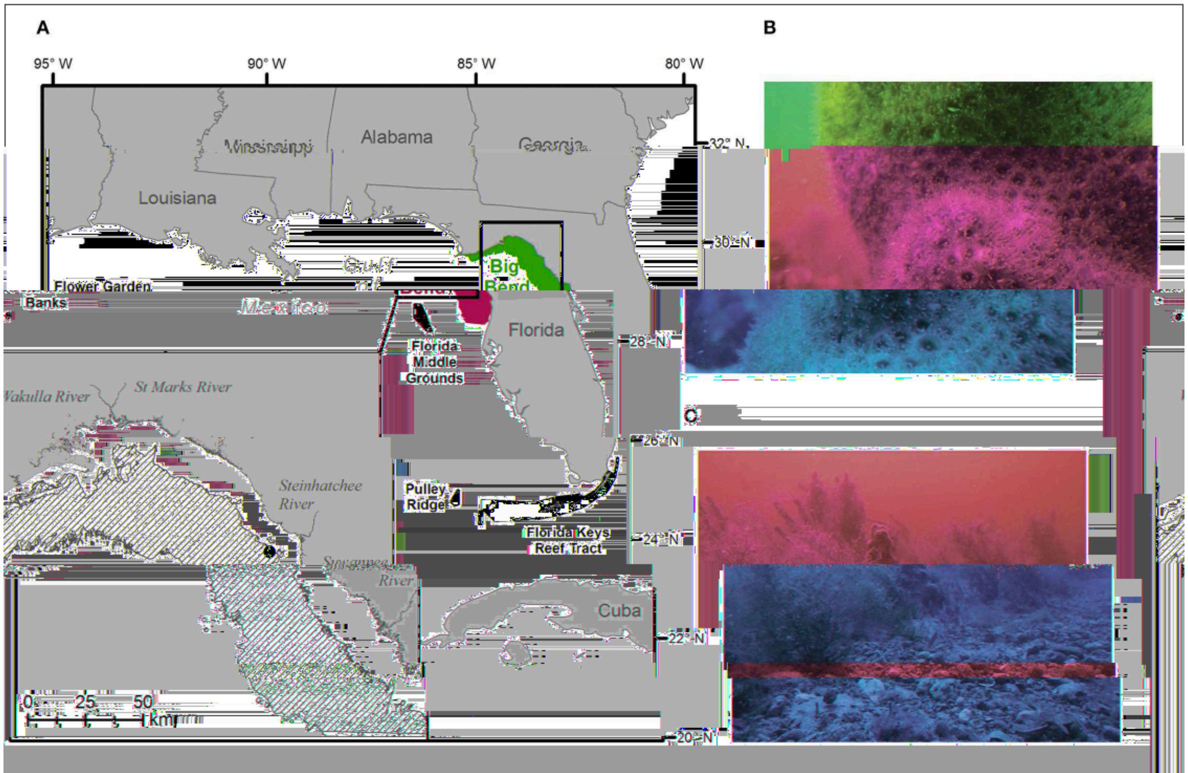
The Florida coral reefs score 69, meaning few indicators meet reference values.

Coral reef status in the Southeast USA. Source: NOAA's National Coral Reef monitoring Program and www.ecowatch.noaa.gov.



Projections of the onset of Annual Severe Bleaching using the RCP8.5 (most severe) scenario. Source: [vanHooidonk et al. (2016)](#).

[On the flip side, climate and ecological projections suggest that the Big Bend region of Florida could potentially support the coral reefs in the near future](#). This area is currently too cold, with winter temperatures below the 18℃ threshold for corals, and experiences river discharges high in nutrients and other materials that are stressful to corals. However, as waters warm, tropical species including corals and fishes typically associated with coral reefs are moving further into the Northern Gulf of Mexico, closer to this area. [Moreover, future predictions are for up to 4℃ of warming by 2100](#) and reduced discharge of freshwater via rivers and groundwater. These changes could make this region a high-quality habitat for corals in the future.



GURE 1 | The 0–20 m (**A**: blue polygon) and 5.5–18 m (**A** inset: black diagonal bars) depth bands of Big Bend region of Florida, USA in the northern Gulf of Mexico. ack polygons denote potential larval sources of hermatypic coral species to the area—in decreasing order of importance: the Florida Middle Grounds, Pulley Ridge, orida Keys Reef Tract, and the Flower Garden Banks. Scenes of current hard-bottom communities dominated by **(B)** cold-tolerant scleractinian corals (shown: *lenastrea* sp.), and **(C)** soft corals and attached macroalgae (shown: *Sargassum* sp. and *Caulerpa* spp.), were taken at 6.7 m depth off Steinhatchee, Florida on rill 13, 2018 (**A** inset; black circle).

Map depicting potential future coral reef habitat in Big Bend, FL with pictures of the current benthic habitat. Source: [Furman et al. (2020)](#).

There are, however, some unknowns. First, there has been minimal oceanic monitoring in the Big Bend area and we do not have well defined benthic temperature distributions. We do have predictions for the future that range from 2℃ to 4℃ of warming. Another unknown is whether coral larvae are currently being delivered to this area, or if they will be in the future. Oceanographic circulation suggests that reefs in the Florida Keys, Florida Middle Grounds, and Flower Garden Banks might be sources of coral larvae.

Activity

Given these projections, what management decisions would you make to protect coral reefs in the Southeast USA? In other words, how would you create climate ready MPAs for coral reefs in Southeast Florida?

Potential solutions:

Do you resist the change and try to keep existing MPAs?

- *Keep current MPAs*
- *Enhance restoration efforts*
- *Selective breeding and outplanting of stress (temperature, OA, etc.) resistant genotypes*
    - *Epigenetic programming*
    - *Coral microbiome manipulation*
    - *Assisted evolution to more heat and acidification tolerant genotypes*

Do accept the change and establish new MPAs where corals are likely to be in the future?

- *Forward looking MPA designations for new coral ecosystems*

Do you direct the change to attempt to achieve a desired MPA configuration?

- *Assisted migration/seeding of Big Bend and other future coral MPAs*
- *Assisted evolution*

Do you still have too much uncertainty to take action? If so, what information do you need?

- *More research on key uncertainties.*
- *More robust modeling to better confine the demise of existing coral reefs in the Florida Keys and the likely rise of coral reefs in Big Bend and elsewhere.*

These possible responses follow the Resist-Accept-Direct (RAD) Framework for climate adaptation. More information on the framework can be found here.

Adaptation Resources

Once you understand how climate conditions may change in your MPA, it is important to begin the process of adapting to those projected changes to ensure that the resources under your management have the best opportunity to persist and thrive. Climate change adaptation can mean many different things. The IPCC defines climate change adaptation as “the process of adjustment to actual or expected climate and its effects”. For the purposes of MPAs, it can be useful to think of climate change adaptation as any policy or management action that is intended to allow resources, services, communities, or infrastructure to adjust to current or future changes in climate by reducing their vulnerability and/or increasing their resilience or adaptive capacity to the impacts of climate change. As such, many management actions can be thought of as adaptation. What makes them *climate change* adaptation is the intention inclusion of adaptation to climate change hazards and impacts as a driving goal of the action. Acting with intentionality is important to managing MPAs and the resources they protect in a changing environment.

- Some resources that can help guide the adaptation planning process are listed below.
- CAKE MPA Climate Adaptation Toolkit (https://www.cakex.org/MPAToolkit) - EcoAdapt
- U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) - US Climate.gov
- Panorama (https://panorama.solutions/en)
- Resist-Accept-Direct (RAD)—A Decision Framework for the 21st-century Natural Resource Manage (https://irma.nps.gov/DataStore/DownloadFile/654543) - US National Park Service (2020)
- Planning For a Changing Climate (https://irma.nps.gov/DataStore/Reference/Profile/2279647) - US National Park Service (2021)
- Marine Protected Areas and Climate Change (https://portals.iucn.org/library/sites/library/files/documents/2016-067.pdf) - IUCN (2016)
- Coastal Adaptation Strategies Handbook (https://www.nps.gov/subjects/climatechange/coastalhandbook.htm) - US National Park Service (2016)
- National Fish, Wildlife and Plants Adaptation Strategy (https://www.st.nmfs.noaa.gov/Assets/ecosystems/documents/NFWPCAS-Final.pdf) - US Fish and Wildlife service (2012)
- Climate Change Adaptation in National Marine Sanctuaries (https://sanctuaries.noaa.gov/management/climate/climate-change-adaptation.html) – US NOAA Office of National Marine Sanctuaries

Climate Information and Assessment Resources

Understanding how climate conditions may change in your MPA is critical to beginning to take meaningful, climate-informed management actions. Useful information to inform management actions can include data that directly describes projected changes to activities that allow you to directly assess the potential vulnerability of the resources you manage.

Some resources that can help you better understand projected climate changes in your MPA and assess the impacts of those changes on the resources under your management include:

- KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi) - World Meteorological Organization
- NOAA's Climate Change Web Portal: CMIP5 (https://psl.noaa.gov/ipcc/cmip5/) – US NOAA
- PSL Marine Heatwaves Tool (https://psl.noaa.gov/marine-heatwaves/) - US NOAA
- NOAA Sea Level Rise Viewer (https://coast.noaa.gov/slr/) - US NOAA
- NOAA Distribution Mapping and Analysis Portal (https://apps-st.fisheries.noaa.gov/dismap/DisMAP.html) - US NOAA
- Marine Protected Area Climate Vulnerability Assessment Guide (https://sanctuaries.noaa.gov/media/docs/2023-mpa-climate-vulnerability-assessment-guide.pdf) - US NOAA Office of National Marine Sanctuaries and National Marine Protected Areas Center
- North American Marine Protected Areas Rapid Vulnerability Assessment Tool (https://www.cakex.org/MPAToolkit/rapid-vulnerability-assessment-tool) - Commission for Environmental Cooperation