Climate & Fisheries: forecasts in support of fisheries management and adaptation strategies
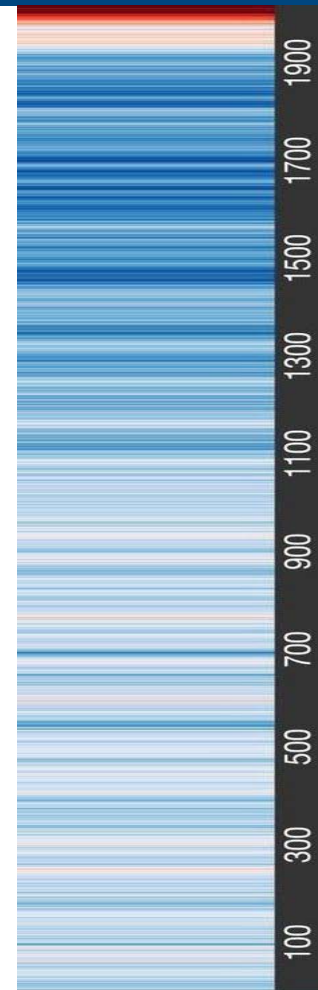
Cisco Werner
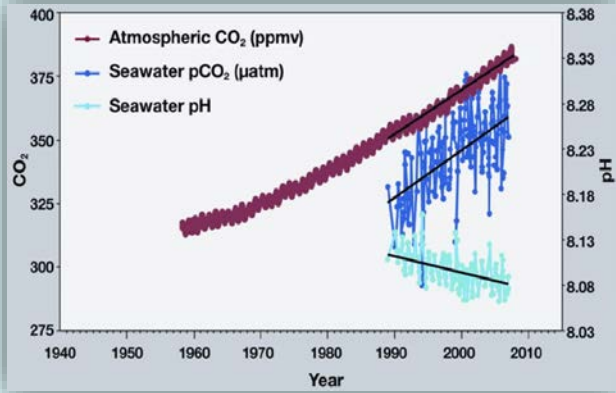**NOAA Fisheries**

(with input and help from **many!**)
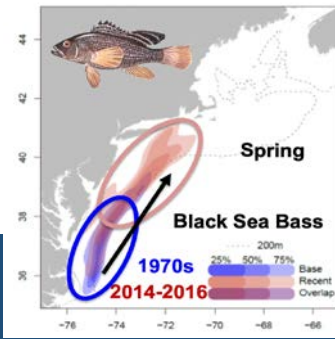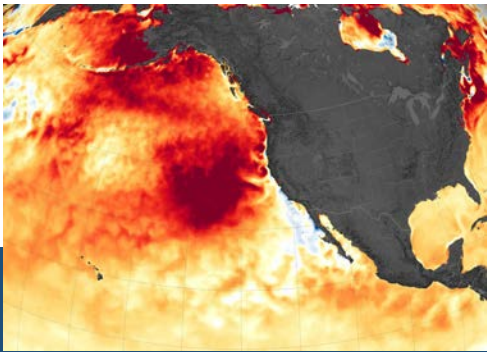
Messages

- **Climate variability and change** is impacting our living marine resources and the communities that depend on them.

  - We have moved from *"nice to know"* to *"need to know"*

- We have made notable **advances in our capacity to predict** these changes

- NOAA's **Climate, Ecosystems & Fisheries Initiative (CEFI)** will provide a national capacity:

  - for the sustained provision of regional ocean and climate information across LMR management time scales, and

  - to translate this information to **improved management and stakeholder decisions**.

Blue hues indicate temperatures below the 20th century average and red hues for years when temperatures were above it. *(Ed Hawkins, Warming Stripes)*
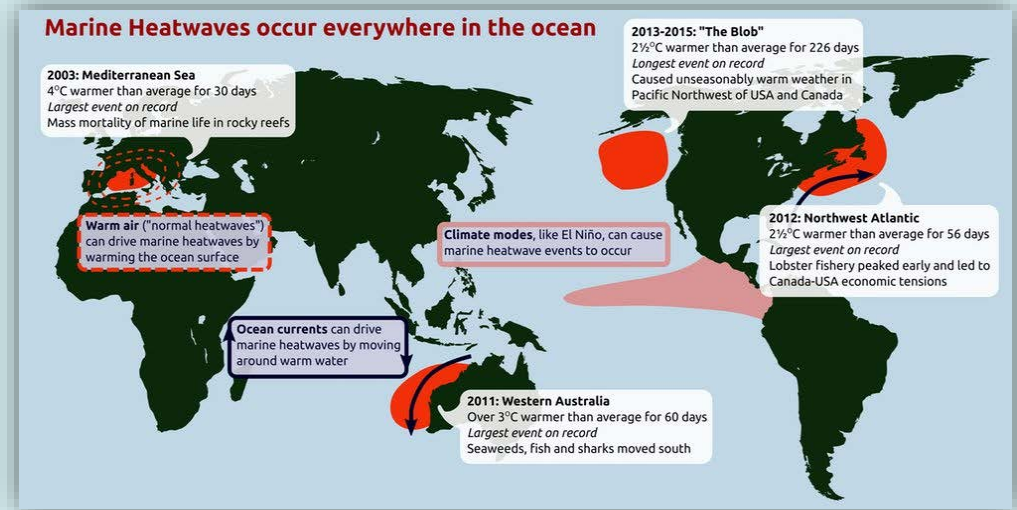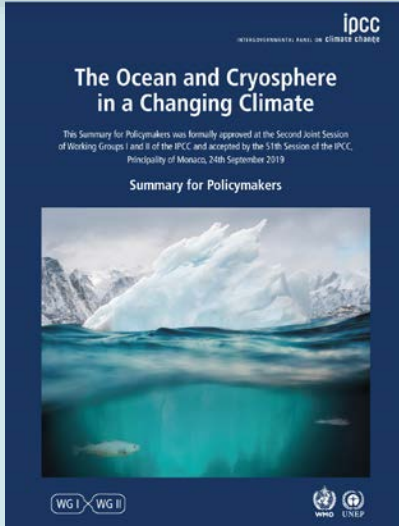
Changing climate is changing our oceans *(more rapidly than we expected)*
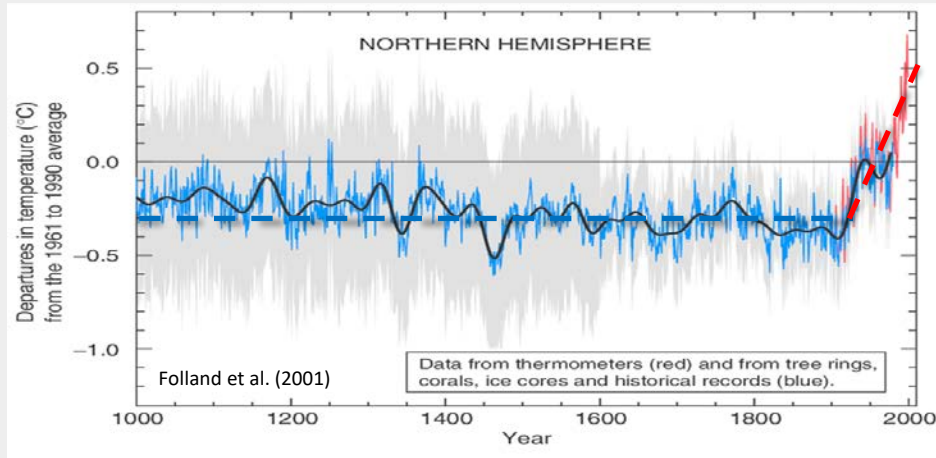
- Secular (gradual) changes: **yes, but...** perhaps more importantly, we need to consider variability in:
- Space: **where?**
- Time: **when and for how long?**
- Frequency: **how often?**
- Variability in intensity: **how extreme?**

3

From *stationarity* to *non-stationarity*

NORTHERN HEMISPHERE

Folland et al. (2001)

Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).

- **Stationarity** – fluctuations within an unchanging envelope of variability.

- **Non-stationarity** – times series whose properties (e.g., mean, variance, etc.) change with time

Folland et al. 2001: Observed Climate Variability and Change. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the 3rd Assessment Report of IPCC [Houghton et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 881pp.

Long-term climate variability

Short-term weather variability (extreme events)

Climate change

Extinction extremes

Survivable extremes

Experienced weather

Interacting (evolving) conditions: long-term, short-term, secular (climate), extreme events

Area of 3 largest features (km^2)

Area of **MHWs** in the **NE Pacific** over time. Colors denote times when there were multiple, spatially separate MHWs on a given day. The horizontal line is for reference at 500,000 km^2, the proposed threshold for the "regional" portion of declaring a MHW.

NOAA FISHERIES
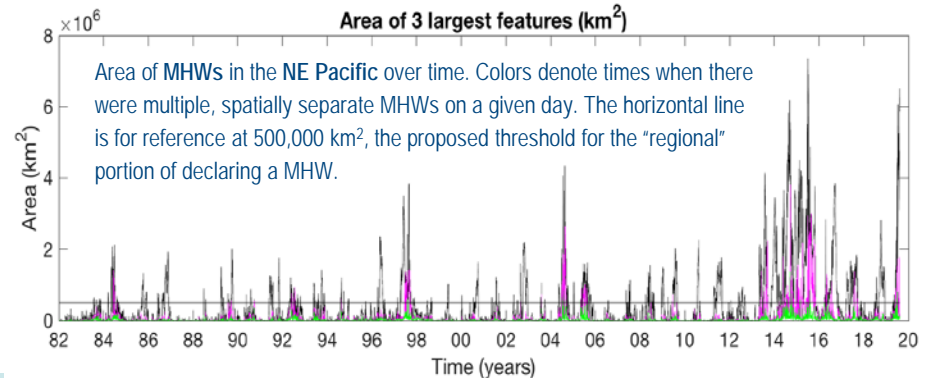
Climate impacts on living marine resources

Pacific Cod (kg/ha)
- no catch
- > 0 - 1
- > 1 - 10
- > 10 - 20
- > 20 - 30
- > 30 - 40
- > 40

Bottom Temperature (BT) < 0° C   Min. BT = 1.6° C

2010   2017   2018
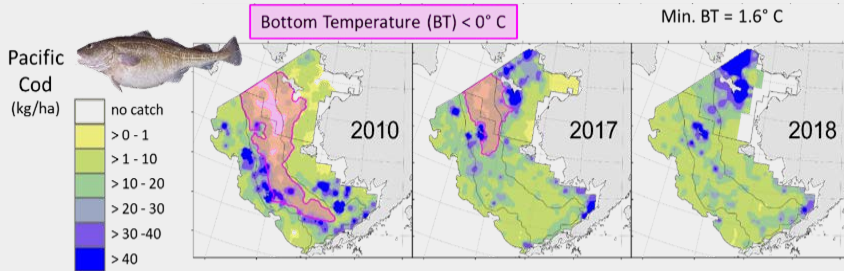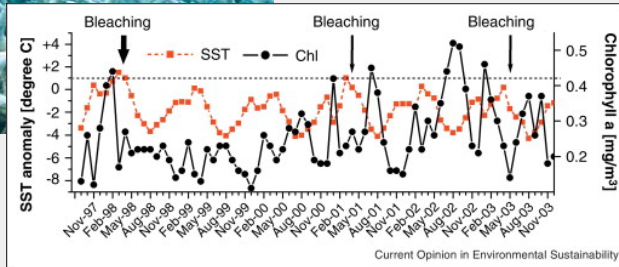
Pacific cod and pollock distribution moved shoreward and northward 100's of kms as the cold pool (<2°C) was reduced.

- Right whales feed on a small zooplankton – Calanus finmarchicus

- Warming temperature related to fewer *C. finmarchicus* in the Gulf of Maine

- NA right whales move to Gulf of Saint Lawrence as *C. finmarchicus* in Gulf of Maine decrease

Gulf of St. Lawrence
CANADA
Prince Edward Island
Bay of Fundy
Gulf of Maine
North Atlantic Ocean
UNITED STATES

Right whale habitats
- Primary range
- Occasional range
- Calving area
- New sightings since 2015

0   500 Km
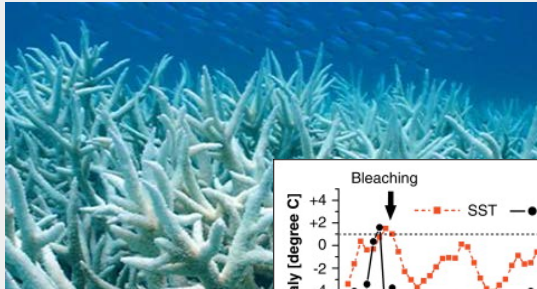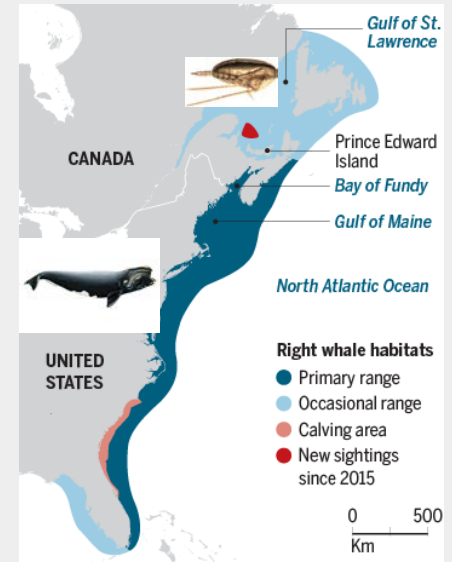
Coral bleaching / habitat

- Including red tide index improves stock assessment fit

- Red tide explains declines of ~8 million grouper (gag and red combined) in 2005

model
data
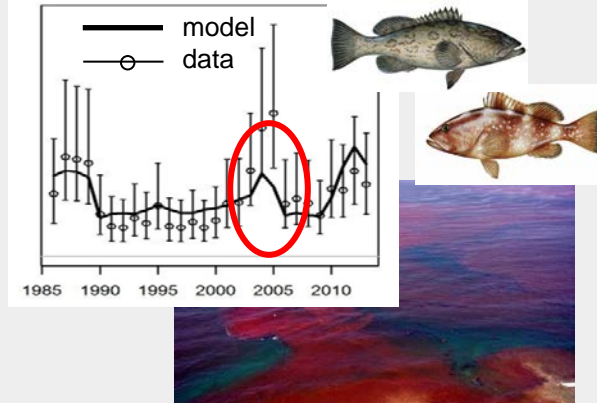
Generation of Advice under Non-stationarity: Uncertainty, and Scenario Planning
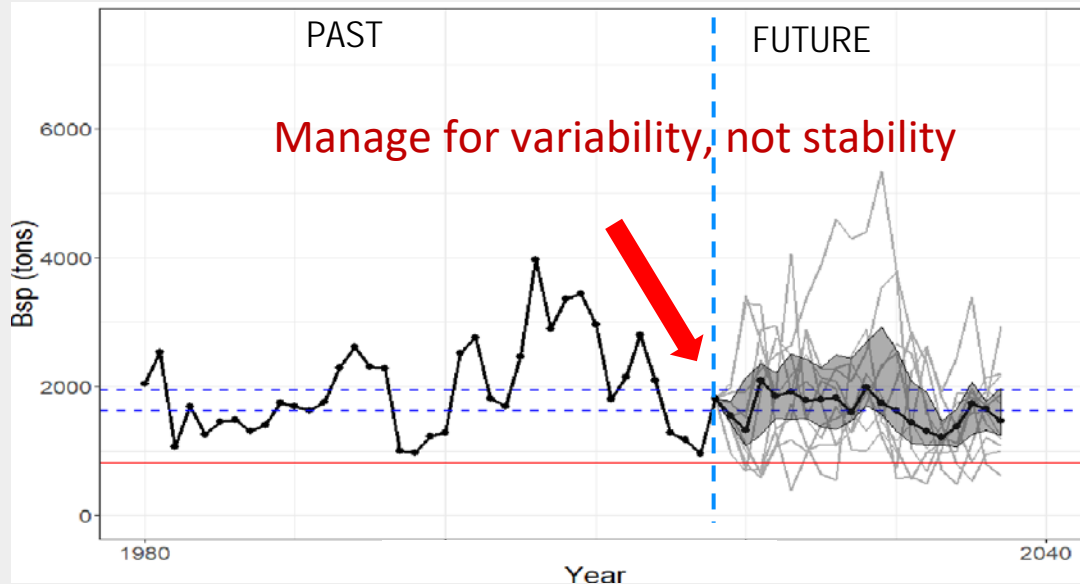
(Adapted from Éva Plagányi, 2019)

NOAA Fisheries' Climate Information Requirements

Modified from Tommasi et al., Progress in Oceanography, 2017

Forecasts, predictions, and projections
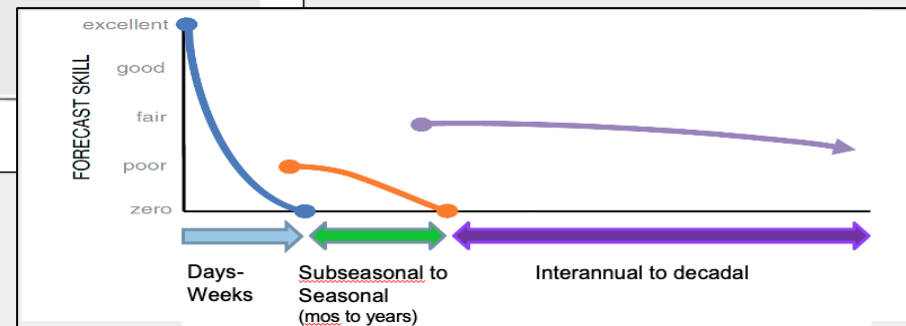
Adapted from White et al. (2017); in *Meteorological Applications*.

Example of model forecast skill at S2S scales
[need for consideration of Earth System Modeling (ESM) approaches]

ESMs: T, S, pH, nutrients, biogeochemistry (models' initialization and data assimilation)
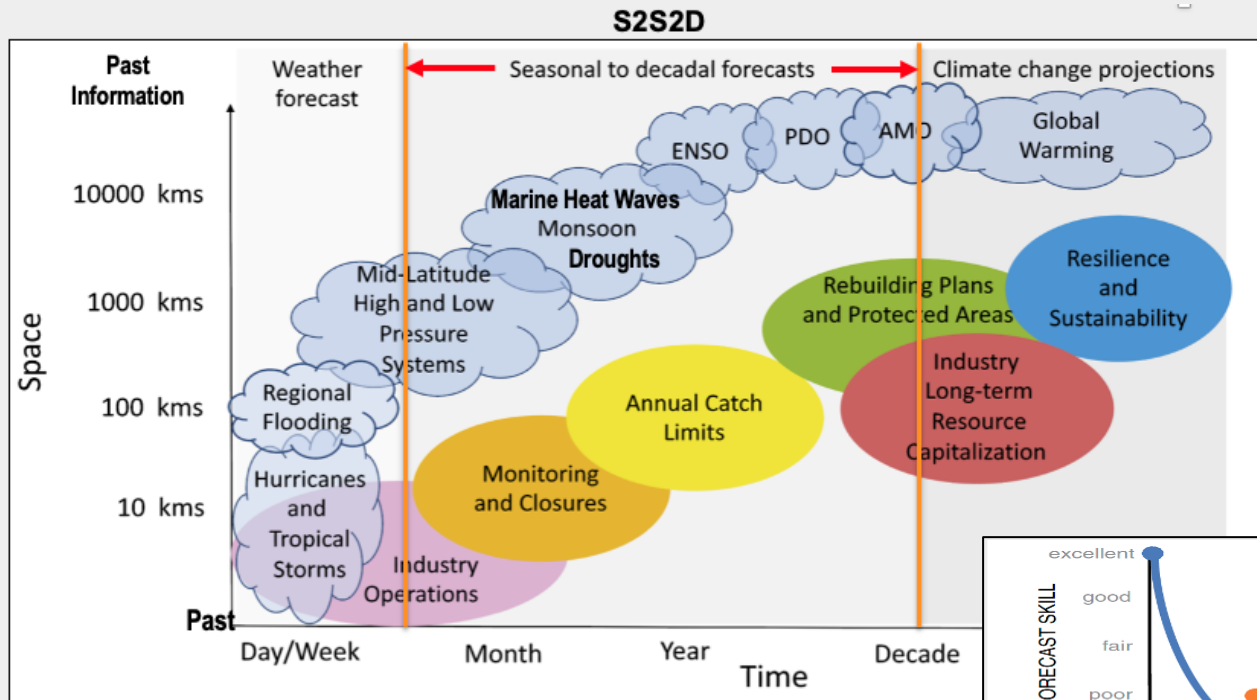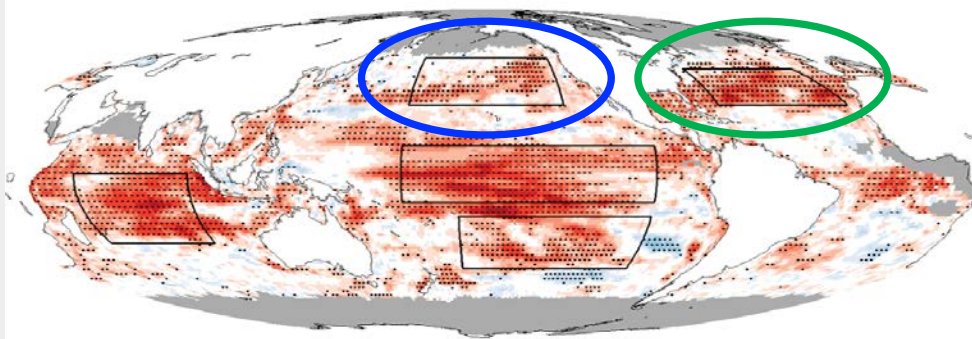
Chlorophyll prediction skill (1-3 months lead time)

Global marine biogeochemical prediction system produces skillful chlorophyll predictions one season in advance in many ocean regions.

- Interannual **fisheries variations** in some large marine ecosystems can be anticipated from predicted **chlorophyll and sea surface temperature** anomalies.

- This suggests a role for **ESM-based marine biogeochemical predictions** in dynamic marine resource management efforts.

- **Significant chlorophyll prediction skill** in some regions (more intense red regions in the plot)

- **Skill varies by region and other factors.** For example, in the N. Pacific, prediction skill is weaker and limited in spatial extent, perhaps reflecting a greater **role of atmospheric iron deposition in the North Pacific.**

Park et al. (2019) Seasonal to multiannual marine ecosystem prediction with a global Earth System Model. *Science.*

U.S. Regional Fishery Management Councils

ADAPTING FISHERIES MANAGEMENT TO A CHANGING ECOSYSTEM

Melissa Haltuch
PFMC

Kristin Marshall
PFMC

Frank Camacho
WPFMC

Erik Frank
WPFMC

Courtesy Dr. Diana Stram
(North Pacific Fishery Management Council)

The North Pacific Fishery Management Council hosted the 7th national meeting of the Scientific Coordination Subcommittee (SCS7) in Sitka, Alaska August 15-17th. The meeting addressed challenging and timely fishery management issues and was well attended by SSC delegates and staff from all eight Regional Fishery Management Council SSCs, as well as NMFS Headquarters.

KEY FINDINGS

① Councils need to start preparing now for increasingly complex management decisions due to climate change

② Investment is needed in the development of new data collection and analysis tools that are responsive to changing conditions

③ SSCs and Councils need to be prepared to transition toward a more sophisticated toolbox

④ Stakeholder engagement will be critical for adaptive management to be successful

- Need pathways to sustain fisheries in a **future non-stationary marine environment**
  - abrupt shifts in distribution or abundance
  - changes in ecosystem structure and function

- RFMCs need to consider … regional differences
  - Models with **ecosystem linkages**
  - Climate-informed **risk assessments**
  - Performance of **management strategies**

- SSCs need to **prepare to transition**
  - from reliance on indicators derived from observations
  - to informed dynamic simulations of marine ecosystem change, tuned to observations

- **Begin scenario planning now** to avoid reactive responses

What does the CEFI propose to do?

- **BUILD** *the end-to-end operational ocean modeling & decision support system we need for climate-ready fisheries*

- **PROVIDE** *NMFS and other decision-makers with the forecasts, risk assessments & management options essential to EBFM*

- **ENABLE** *climate-informed living marine resource management.*

National Marine Fisheries Service | NOAA CLIMATE, ECOSYSTEMS, AND FISHERIES INITIATIVE

CEFI Integrated Ocean Modeling and Decision Support System

▶ Advancing Climate, Ocean, and Ecosystem Understanding

▶ Operational Climate, Ocean, and Ecosystem Decision Support Systems

▶ Climate Ready Decision Making

SCIENCE AND DEVELOPMENT
Drives Innovation and Skill

OPERATIONS AND INFRASTRUCTURE
Drives Dissemination and Decision Support

EXTENSION AND ENGAGEMENT
Drives Service Delivery and Knowledge Transfer

NOAA FISHERIES

Regional modeling capacity built into OAR's GFDL Global Modular Ocean Model 6 (MOM6)
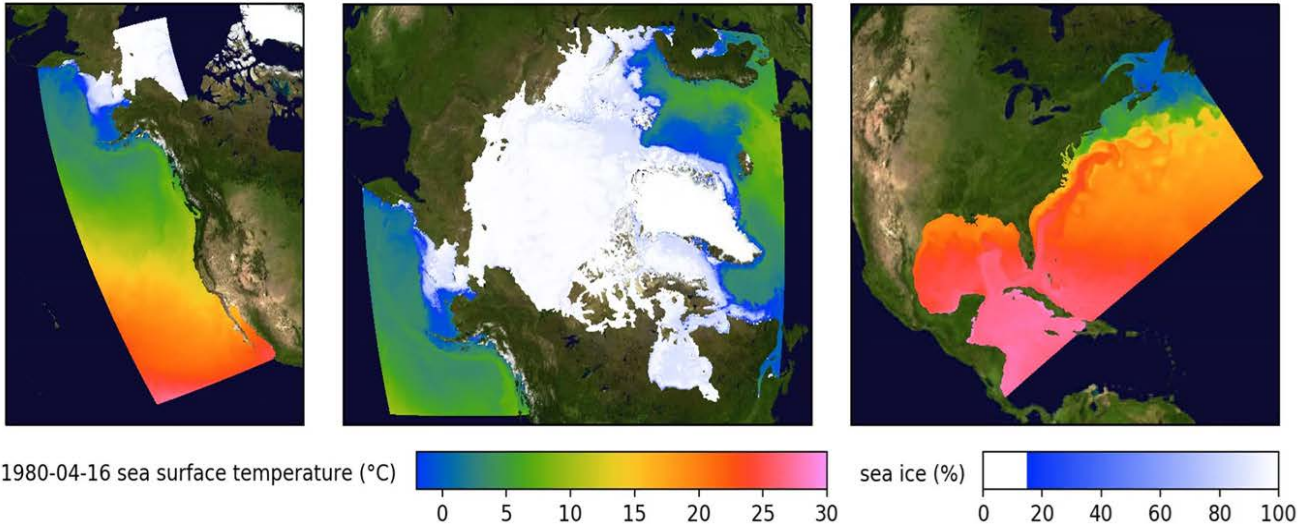

1980-04-16 sea surface temperature (°C)

sea ice (%)

Figure from Andrew Ross (NOAA/GFDL)

Prototype MOM6 coast-wide domains for seasons to decades (Great Lakes, Pacific Islands in progress)

- Builds on NOAA ocean forecast and Prediction Systems
- Regional Ocean Modeling Teams customize products for NMFS uses
- Holistic ocean/biogeochemical predictions, expandable to Earth system as needed
- NOAA High Performance Computing powers predictions spanning the range of ocean futures
- Robust dissemination through CFI Information Hub & national data standards

https://www.gfdl.noaa.gov/improving-ocean-habitat-forecasts-for-the-northeast-u-s/

ACLIM
Alaska Climate Integrated Modeling

Climate scenarios

Global General Circulation Models (GCM)
- CESM
- GFDL
- MIROC

Carbon Scenarios:
- Hindcast (1970-2021)
- (high CO_2 mitigation)
  - CMIP6 SSP1 2.6
- (med CO_2 mitigation)
  - CMIP5 RCP 4.5
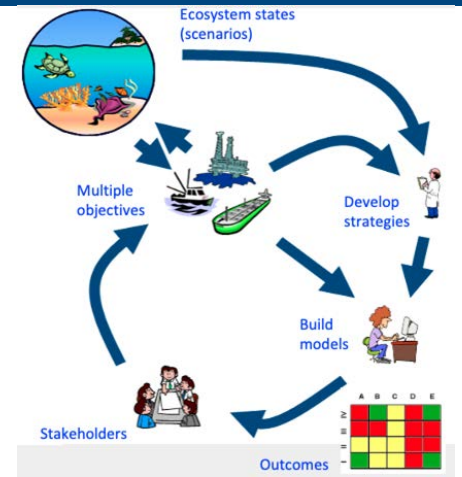- low CO_2 mitigation)
  - CMIP5 RCP 8.5
  - CMIP6 SSP5 8.5

Physical downscaling

ROMS

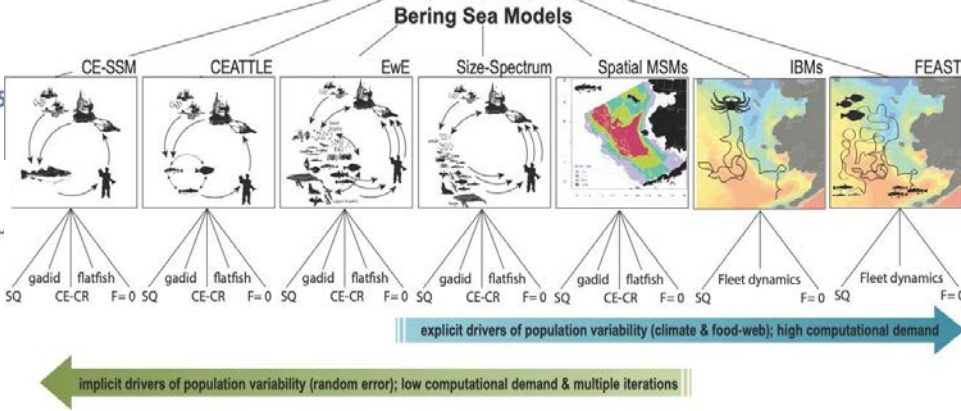Biological downscaling
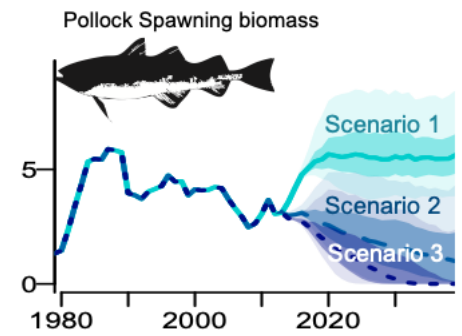
NPZ

Bering Sea 10K Model

Ocean scenarios

Ecosystem and stock scenarios

Climate Enhanced Biological models (x 5
- CE- single-spp assessment models
- CE- multi-spp model (CEATTLE)
- CE - Size spectrum model
- CE- Ecopath with Ecosim
- End-to-End model (FEAST)
- CE- spatial MICE model
- CE - IBM (crab)

Social & economic

Bering Sea Models

| CE-SSM | CEATTLE | EwE | Size-Spectrum | Spatial MSMs | IBMs | FEAST |

| gadid | flatfish | gadid | flatfish | gadid | flatfish | gadid | flatfish | gadid | flatfish | Fleet dynamics | Fleet dynamics |
| SQ | CE-CR | F=0 | SQ | CE-CR | F=0 | SQ | CE-CR | F=0 | SQ | CE-CR | F=0 | SQ | CE-CR | F=0 | SQ | F=0 | SQ | F=0 |

explicit drivers of population variability (climate & food-web); high computational demand

implicit drivers of population variability (random error); low computational demand & multiple iterations

Ecosystem states (scenarios)

Multiple objectives

Develop strategies

Build models

Stakeholders

Outcomes

Fishery and Management scenarios

Pollock Spawning biomass

Scenario 1
Scenario 2
Scenario 3

1980   2000   2020

Climate, Ecosystems, and Fisheries Initiative (CEFI): forecasts in support of fisheries management and adaptation strategies
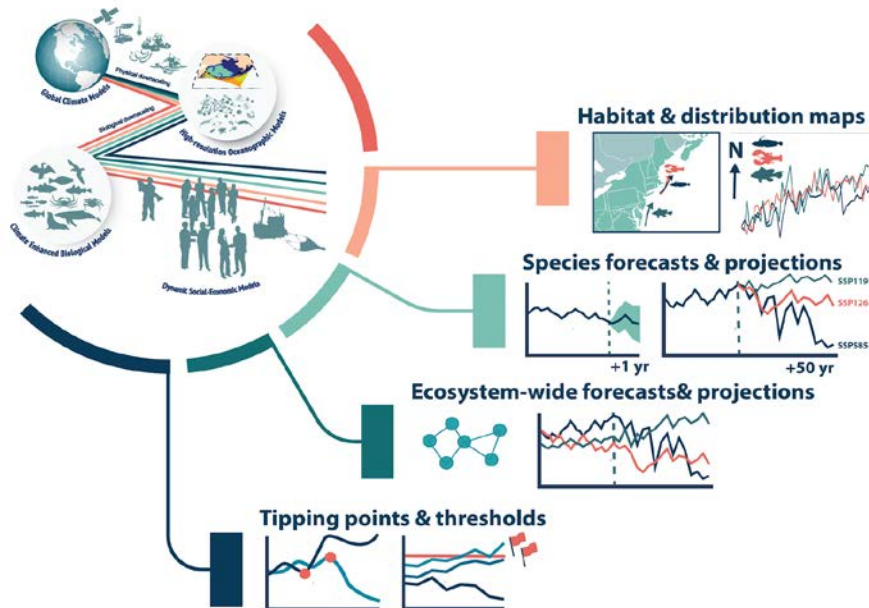
- Provide a national capacity for sustained provision of regional ocean and climate information **across LMR management time scales**.

Ocean Predictions

Decision Support Teams

Habitat & distribution maps

Species forecasts & projections

Ecosystem-wide forecasts & projections

Tipping points & thresholds

Advice Pathways
- Population Modelers
- Stock Assessors
- Risk Assessors
- Ecosystem Assessors
- EFH Assessors
- Impact Assessors
- Strategy Evaluators

Applications
- Scenario Planning
- Risk Assessments
- Rapid Responses
- Consultations
- Management Strategies
- Rebuilding & Recovery Plans

Summarizing, the CEFI …

- **Non-stationarity**
- **Need to know**
- **Need to evolve our advice**
- **Climate Ecosystem and Fisheries Initiative (CEFI)**