Greater Atlantic Region Policy Series
[19-05]

Atlantic Salmon (*Salmo salar*) Climate Scenario Planning Pilot Report

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Contents

Executive Summary

Scenario planning is a structured process that embraces uncertainty and explores plausible alternative future conditions under different assumptions to help manage risk and prioritize actions (Schwartz 1996, Peterson *et al.* 2003). It has been used by a variety of organizations to explore and help prepare for the future, lends itself well to exploring the uncertainty surrounding changing environmental conditions, and is widely applicable to natural resource management issues. The conservation and management of protected resources for example, can be particularly challenging when the rate and magnitude of climate-related changes, and the response of species to those changes, are uncertain (NMFS 2016). The structured process of scenario planning can help resource managers navigate through potentially paralyzing uncertainties, manage risk, and evaluate/prioritize management actions associated with adapting to, and managing for, climate change (Moore *et al.* 2013).

Atlantic salmon (*Salmo salar*) is a species highly vulnerable to climate change in the Northeast Atlantic (Hare *et al.* 2016a). Based on this and the above reasons, a scenario planning initiative was piloted by NOAA Fisheries to explore what the agency can do to improve U.S. Atlantic salmon population resilience to changing climate conditions in riverine, estuarine (transition), and marine environments across its current range (U.S. headwaters to Greenland). Project objectives were: 1) to better understand the challenges of managing Atlantic salmon in a changing climate; 2) to identify and discuss potential management actions and research activities that can be undertaken to increase our understanding of the drivers of Atlantic salmon productivity and resilience; 3) to increase collaborations and coordination related to the species recovery; and 4) to explore how scenario planning can be used to support decisions.

Outcomes from this initiative included, but were not limited to, the identification of high priority research and management actions to further collaborations and efforts to recover this species. The identified high priority actions were those that could be undertaken in the near-term (1-5 years) using current resources and in consideration of potential future conditions. Examples of identified actions by habitat (not in order of priority) included: 1) synthesize and refine range-wide life stage specific quantitative environmental thresholds for temperature, flow, etc.; 2) assess watershed habitat productivity; 3) assess forage fish and survival connection and options for marine migration monitoring; and 4) reduce dam-associated indirect estuarine mortality rate. In addition, a number of high priority climate-related actions were included in the revised Atlantic Salmon Recovery Plan (USFWS and NMFS 2019, Appendix 16) and at least two newly NOAA Fisheries funded projects are now underway (1. conduct range-wide habitat analysis and synthesize life stage specific quantitative thresholds and 2. identify locations of cold water refugia under a changing climate).

This is the first use of the scenario planning process (NPS 2013) by NOAA Fisheries. This report documents an important example of applying scenario planning to marine species/environments and may serve as a useful reference for other case studies.

Introduction

Scenario planning is a structured process used in strategic planning to help organizations generate ideas and test decisions when faced with uncertain conditions (Schwartz 1996, Peterson *et al.* 2003). It is not a prediction or forecast, thus it does not have to be (but can be) data intensive to be useful. Instead, it provides a mechanism for groups to communicate about complex situations through narratives developed using best available science (e.g., models and projections) and encourages "out of the box" thinking to explore a range of possible futures (Schwartz 1996, Peterson *et al.* 2003). The essence of scenario planning is not about accurately predicting the future, but rather identifying a range of relevant futures for which to prepare. This approach embraces uncertainty and explores *plausible alternative conditions under different assumptions* making it an important tool to manage risk and prioritize management actions (Peterson *et al.* 2003).

Scenario planning can be particularly useful in resource management applications where decisions must often be made in the face of uncertain information on any number of issues. A changing climate further complicates resource management, particularly the conservation of protected resources because of the uncertainties surrounding the rate and magnitude of climate-related changes and the response of species to those changes (NMFS 2016). The structured process of scenario planning can help managers navigate through potentially paralyzing uncertainties, manage risk, and evaluate/prioritize management actions associated with adapting to, and managing for, climate change (Moore *et al.* 2013).

Within NOAA Fisheries' current climate-related activities, scenario planning is a plausible "next step" (Figure 1) after a climate vulnerability assessment (e.g., Hare *et al.* 2016a) to improve our understanding of management actions that consider climate, ecological, and other uncertainties. Scenario planning facilitates management actions that are adaptable under changing conditions. Its benefits include: 1) a greater flexibility to react quickly in a changing world through the identification of options; 2) the development of decisions and plans that would be suitable across some or all futures; 3) the generation of innovative ideas; 4) the capability for early and broad risk identification; and 5) the increased alignment towards a common vision (adapted from Appendix 1). A key output of scenario planning is the identification of management options that would be successful across multiple plausible future conditions. Other outcomes include: identification of data gaps, science priorities, and topics in need of more data intensive modeling exercises such as forecasting or management strategy evaluations.

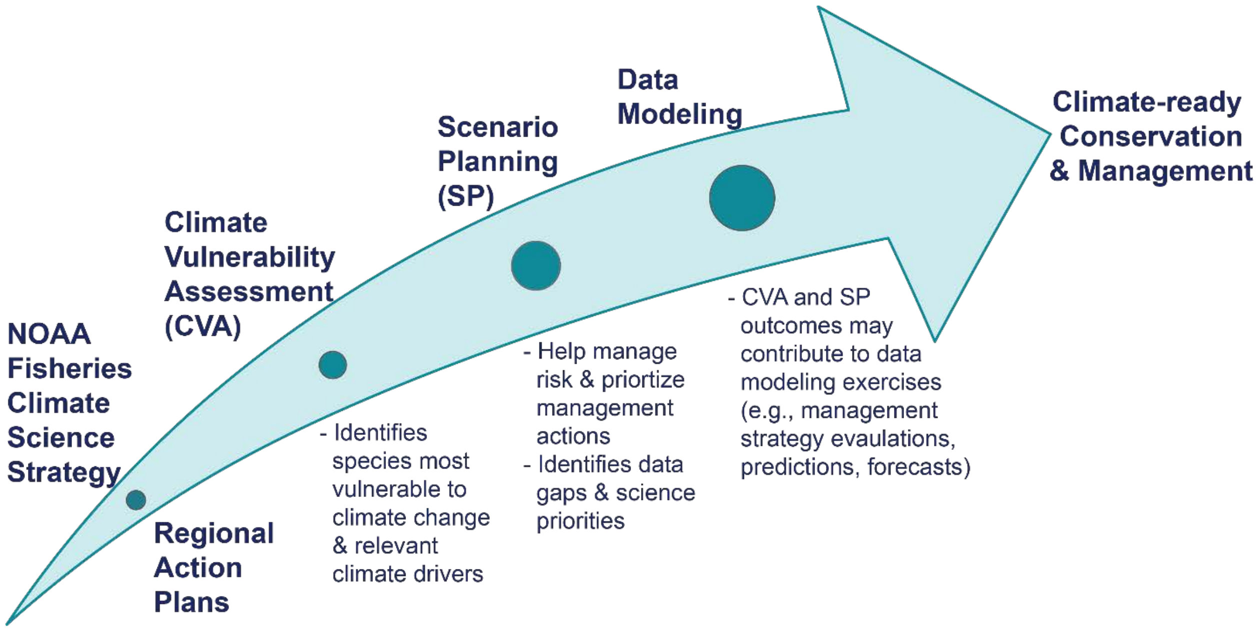


Figure 1. An example trajectory of a NOAA Fisheries climate-ready approach and where scenario planning can fit. In some circumstances, not all items would be needed or the order of items might change.

Previous resource management applications of scenario planning focus primarily on the terrestrial environment. A few examples from estuarine and marine systems exist; however, they rarely focus at the species level (Appendix 2). This pilot applies scenario planning to the critically endangered Atlantic Salmon (*Salmo salar*) Gulf of Maine (GOM) Distinct Population Segment (DPS) [hereafter referred to as Atlantic salmon] – a population highly vulnerable to climate change in freshwater, estuarine, and marine habitats (Hare *et al.* 2016a). Our purpose was to apply the scenario planning process to explore what the agency can do to improve U.S. Atlantic salmon population resilience to changing climate conditions in riverine, estuarine (transition), and marine environments across its current range (U.S. headwaters to Greenland). Specific project objectives were: 1) to better understand the challenges of managing Atlantic salmon in a changing climate; 2) to identify and discuss potential management actions and research activities that can be undertaken to increase our understanding of the drivers of salmon productivity and resilience; 3) to increase collaboration and coordination related to the species recovery; and 4) to explore how scenario planning can be used to support decisions. The pilot furthered discussion on the management and science of Atlantic salmon, a NOAA Fisheries Species in the Spotlight[1].

[1] https://www.fisheries.noaa.gov/topic/endangered-species-conservation#species-in-the-spotlight

Atlantic Salmon Overview

In the United States, remaining populations of Atlantic salmon constitute the GOM DPS. This DPS was originally listed as endangered under the Endangered Species Act (ESA) in 2000 (65 FR 69459, November 17, 2000) and encompassed populations found only in small coastal river systems of Maine. Based on new data, the GOM DPS was revised in 2009 to include populations found in larger river systems covering a broader geographic area (74 FR 29344, June 19, 2009; Figure 2). To recover viable populations, monitoring of population size is often used but parameters such as population growth rate, spatial structure on the landscape, and genetic diversity are essential to long-term resilience (McElhany *et al.* 2000).

Considered one of the most vulnerable species to climate change on the Northeast U.S. continental shelf (Hare *et al.* 2016a), and a species for which focused, climate-related efforts should continue (Hare *et al.* 2016b), there is a critical need to consider how climate-related changes may affect the Atlantic Salmon GOM DPS and the riverine, estuarine, and marine habitats upon which it depends. The effects of climate operate on variable scales from ocean circulation patterns to river temperature phenology and relation to elevation. Scenario planning was considered an appropriate next step to address climate impacts and possible management actions across all scales.

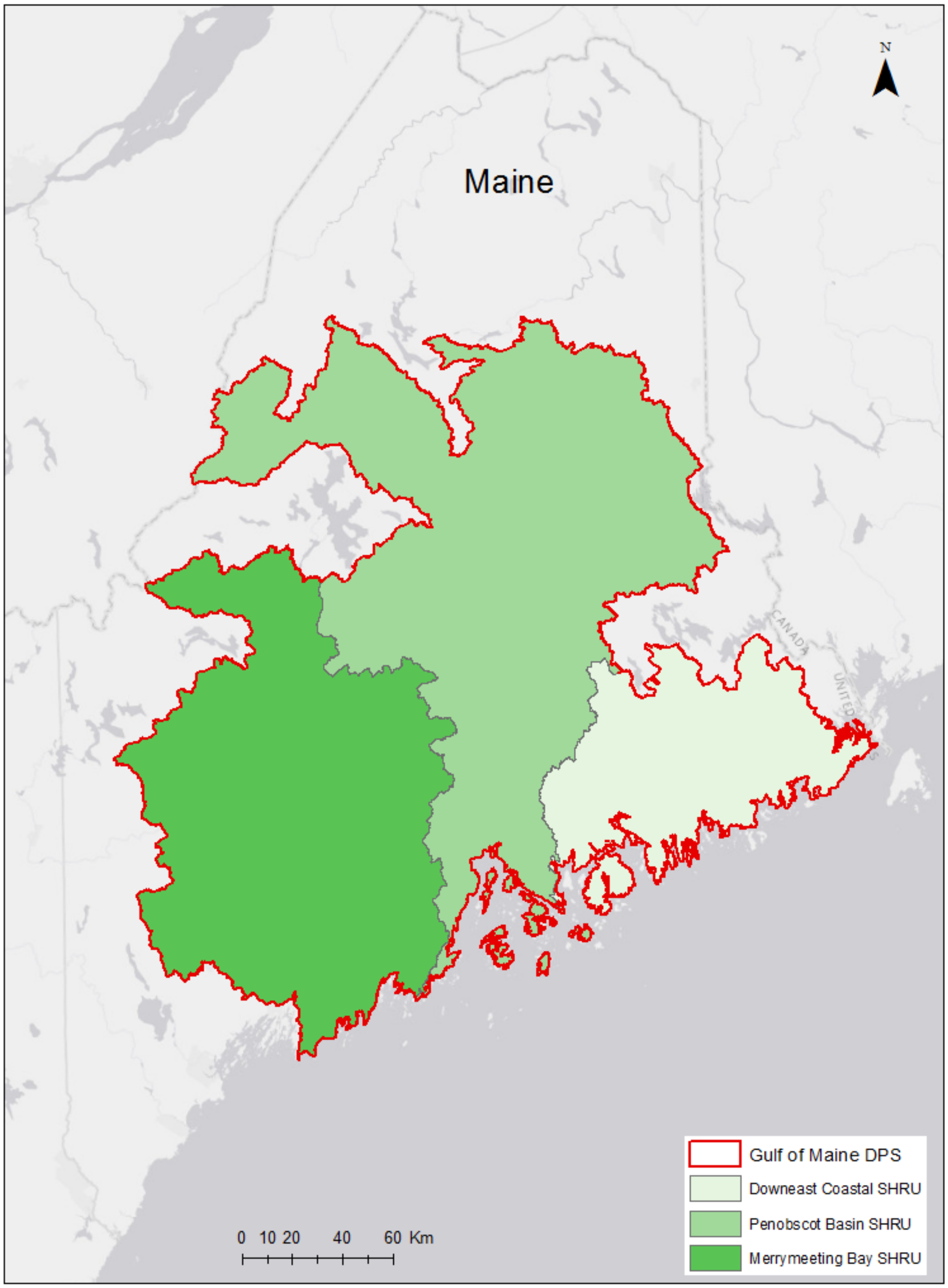


Figure 2. The Atlantic Salmon Gulf of Maine (GOM) Distinct Population Segment (DPS) (74 FR 29344, June 19, 2009) and three Atlantic Salmon Habitat Recovery Units (SHRUs): Downeast Coastal, Penobscot Basin and Merrymeeting Bay.

Methods

We followed the first four phases of the scenario planning process described in the National Park Service's (NPS) Climate Change Scenario Planning Handbook (Figure 3; Appendix 3; NPS 2013).

Phase 1: Orientation → Phase 2: Exploration → Phase 3: Synthesize & Create Scenarios → Phase 4: Application → Phase 5: Monitoring

Figure 3. The five phases of the scenario planning process outlined by the National Park Service Handbook (NPS 2013). Additional details of each phase are located in Appendix 3.

We held two working webinars (July and August 2017) and small group discussions (via phone) (July – September 2017) to conduct Phases 1 through 3, and a 2-day, face-to-face workshop in Portland, Maine (September 2017) to review and finalize Phase 3 and conduct Phase 4 (Figures 3 and 4). Participants were encouraged to attend all webinars and the workshop. For those unable to do so, materials and webinar recordings were available for review to ensure participants remained informed and could provide comments throughout the process.

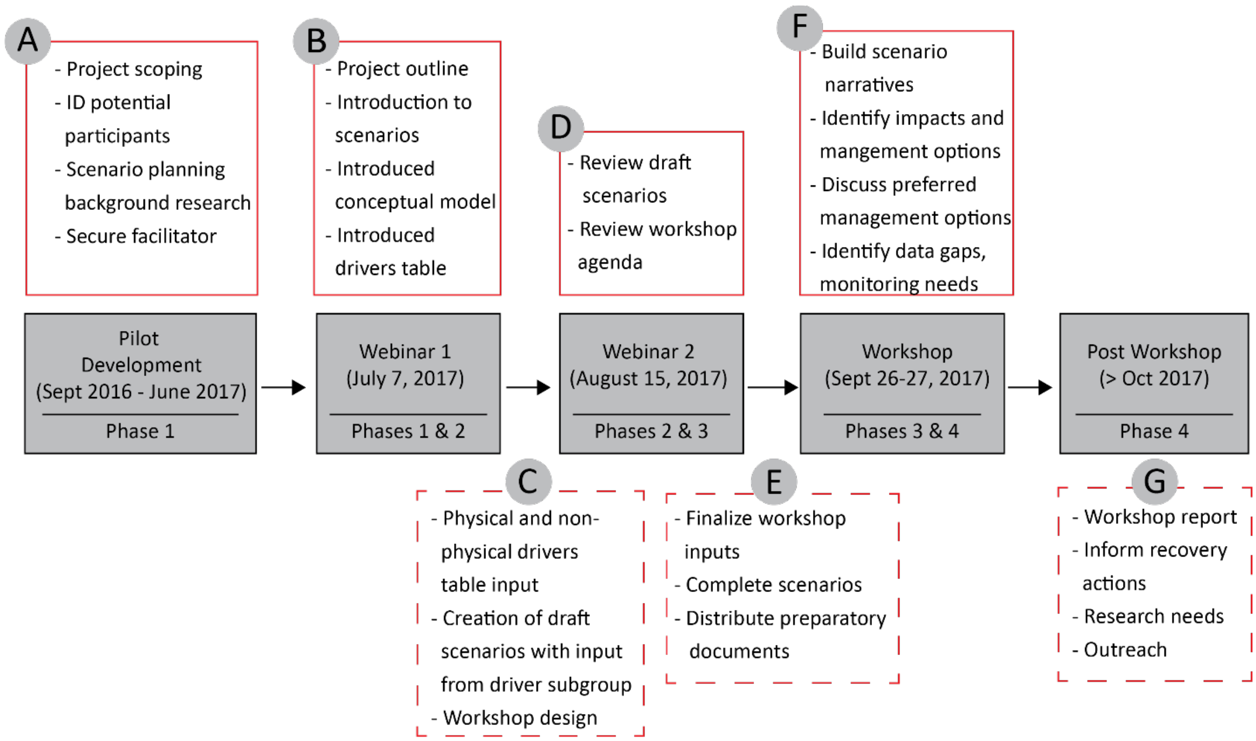


Figure 4. Outline of the process used for the Atlantic Salmon Climate Scenario Planning Pilot and how it aligns with NPS Scenario Planning Phases 1-4 (NPS 2013). Note: Box A includes items that supported pilot development, boxes B, D, and F include items discussed with the full group via phone or in person during one of the events noted in a shaded grey box, boxes C, E, and G include items that were completed outside of the events noted in a shaded grey box.

Phase 1: Orientation

<u>*Purpose and Focal Question*</u>

Our purpose was to explore what we can do to improve U.S. Atlantic salmon population resilience to changing climate conditions in riverine, estuarine (transition), and marine environments across its current range (e.g., the primary distribution areas and migration routes from Merrymeeting Bay, Maine to Greenland) (Figure 5). We did not include the Gulf of St. Lawrence region because it is not considered a primary migratory corridor for the GOM DPS.

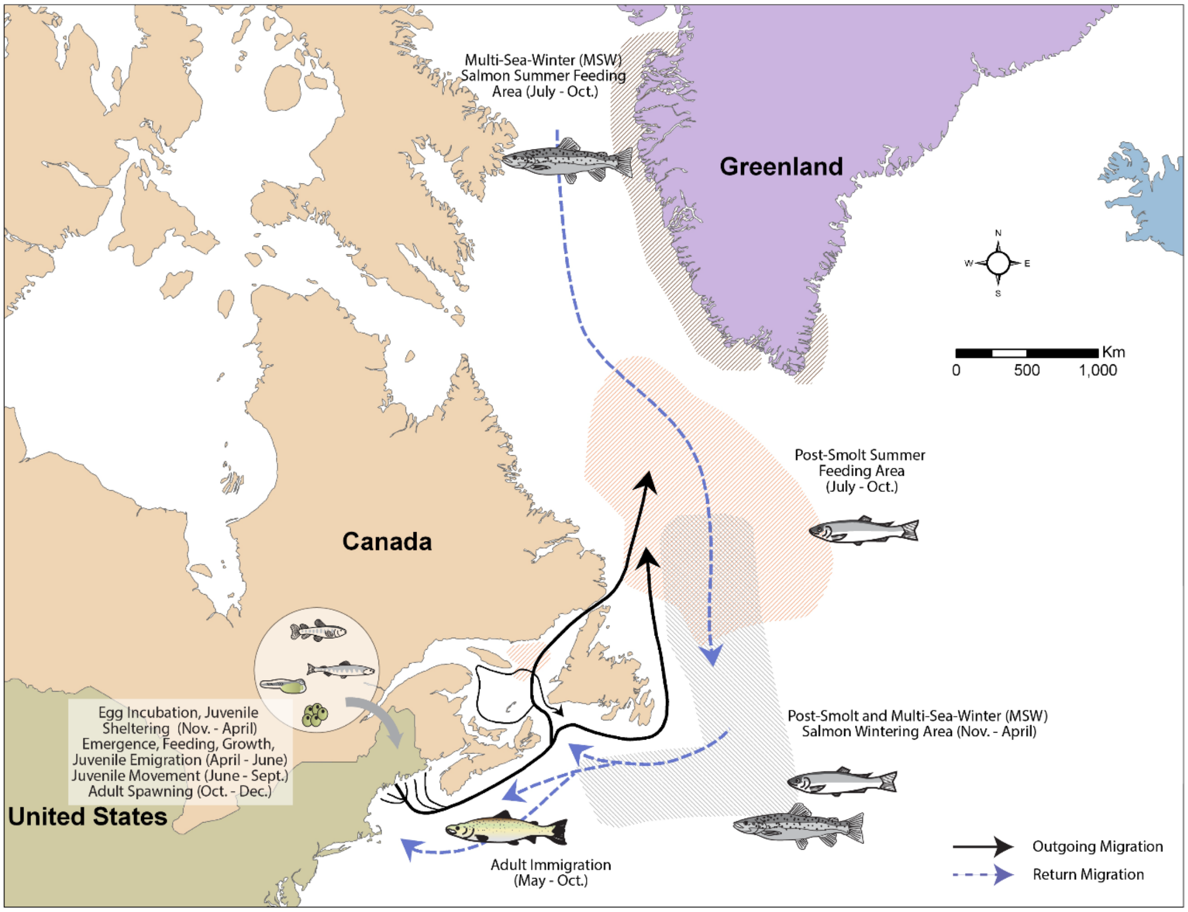


Figure 5. Range of Atlantic Salmon GOM DPS as considered in this pilot (Source: NOAA Fisheries with some modifications for this project).

Our focal question was: How can the effects of climate change impact the Atlantic Salmon GOM DPS (Figure 5) over the next 75 years? We selected 75 years because it aligned with the Draft Atlantic Salmon Recovery Plan[2] (2016 and subsequently with the 2019 Final Recovery Plan) and was consistent with commonly used climate projections from the Intergovernmental Panel on Climate Change (IPCC).

Participant Selection

A facilitation and scenario planning expert and an array of federal experts were assembled to implement the project. Participants were selected (Appendix 4) based on their expertise in Atlantic salmon science or management, climate (e.g., models, hydrology), watersheds (e.g., connectivity), and fish physiology.

[2] https://www.fisheries.noaa.gov/resource/document/recovery-plan-2019-gulf-maine-distinct-population-segment-atlantic-salmon-salmo.

Phase 2: Exploration

<u>*Critical Driver Identification*</u>

To help identify those variables thought to be critical to Atlantic salmon survival (i.e., "critical drivers"), we used the best available information and participant expertise to develop a variety of reference materials. These included a list of relevant literature (Appendix 5) and figures depicting the marine distribution (Figure 5) and general life history (Figure 6) of the species. Further, we synthesized the links between climate, local environment, and the species' response by developing a conceptual model (Figure 7) to identify the important climate drivers (and their degree of uncertainty, Appendix 6) affecting Atlantic salmon at each life stage.

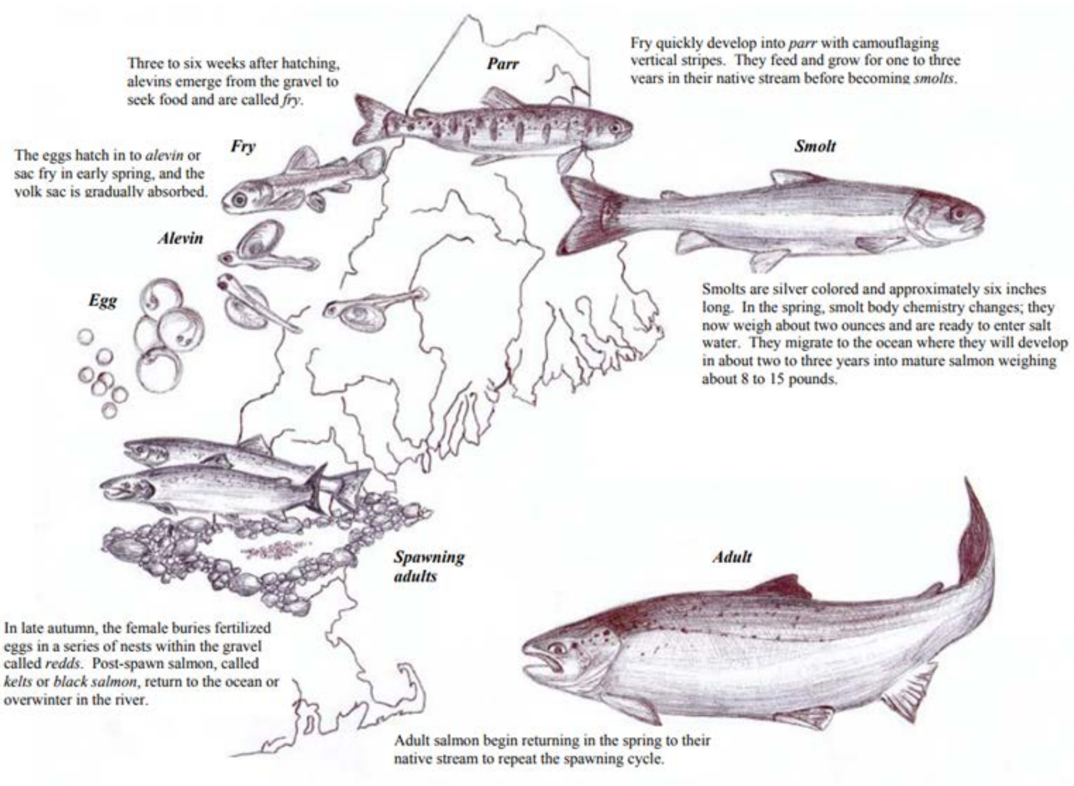


Figure 6. Atlantic salmon life history stages (Source: Original Artwork by Katrina Liebich, U. S. Fish and Wildlife Service).

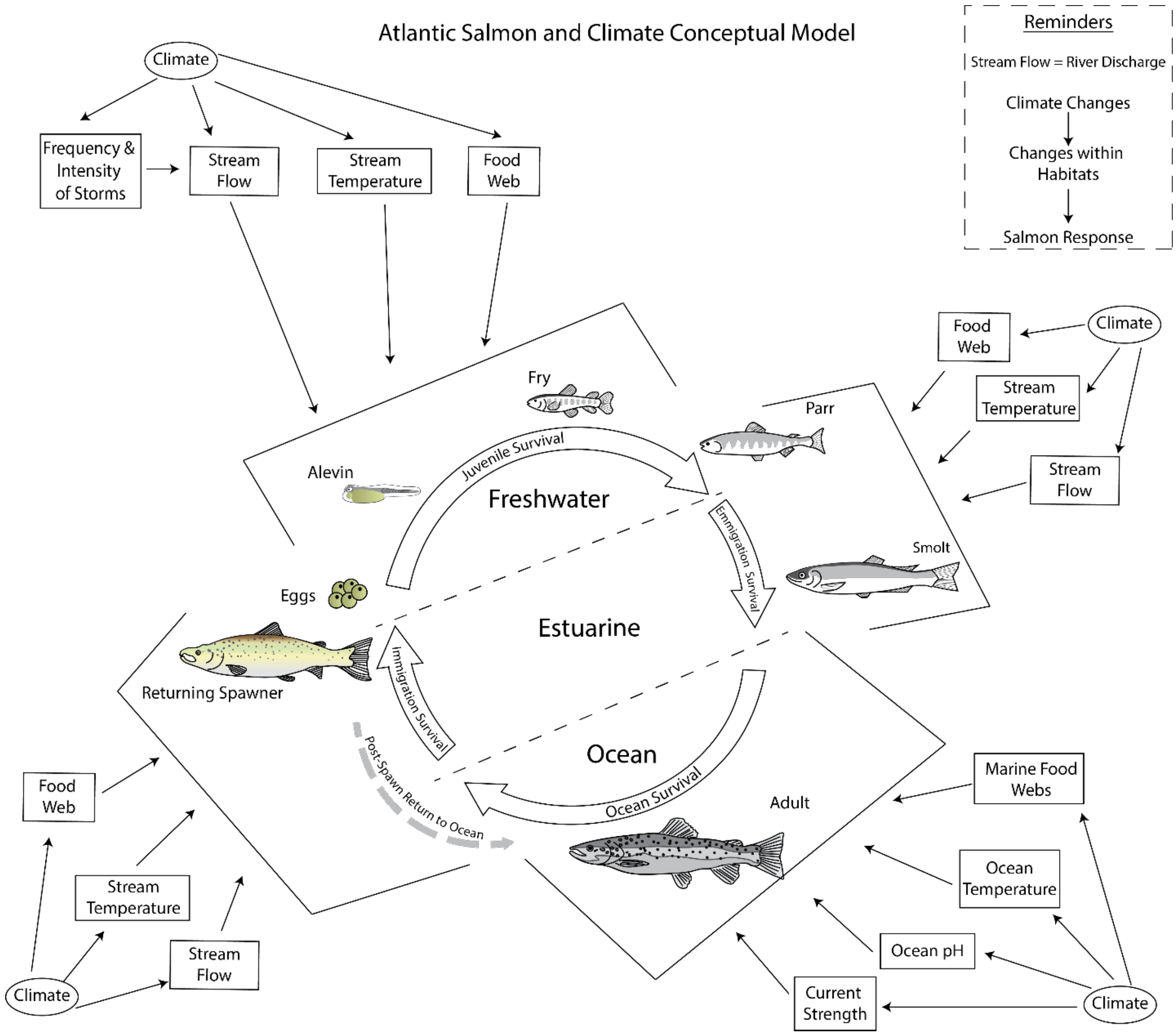


Figure 7. A conceptual model, developed for this process, of Atlantic salmon, depicting important climate/physical drivers in freshwater, estuarine, and ocean environments.

Using this information, we asked participants to identify variables thought to be critical to Atlantic salmon survival and place this information into one of three critical driver tables: (1) climate (physical) drivers (Appendix 6); (2) non-climate (biological, social, political, economic, technological) drivers (Appendix 7); and (3) any other relevant data that did not fall into either of the previous two tables (Appendix 8). We also requested they include any supporting information to these tables (e.g., references to data sources, comments regarding degree of confidence/uncertainty).

A small "driver subgroup" was formed to assess the various drivers from the three critical driver tables and select those they considered the most important and with the greatest uncertainty. The selected drivers were used to draft early versions of future scenarios that were shared with participants on a full-group webinar and modified based on feedback prior to the workshop. This preparatory work maximized the time available at the face-to-face workshop for applying the scenarios to Atlantic salmon management and research options.

Establishing a Common Understanding of Issues

Presentations and background information were provided at the workshop to ensure all attendees had a common understanding of the various issues affecting the species and the region of interest. These included presentations on the scenario planning process (Appendix 1), the species, climate/physical forces and non-climate factors affecting survival of Atlantic salmon (Appendix 9). In addition, participants received a reference packet containing the conceptual model, life history figures, and relevant climate information. The climate information consisted of future projections for important drivers created using the NOAA Climate Change Web Portal and USGS National Climate Change Viewer (Appendix 10), as well as complementary high-resolution graphics (Saba *et al.* 2016, Appendix 11) to help participants consider projected non-uniform enhanced warming and enhanced rainfall in the Gulf of Maine.

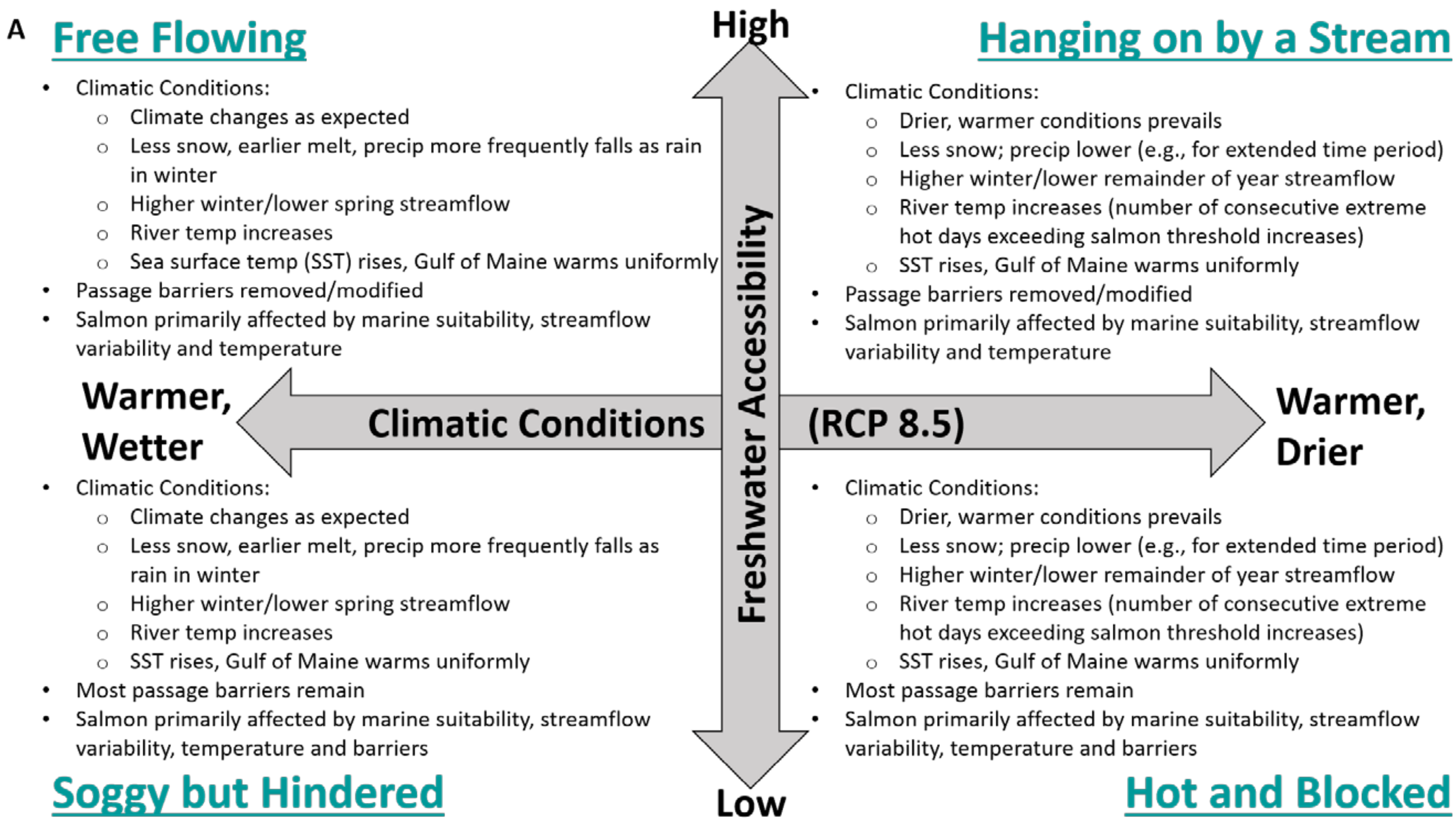
Phase 3: Synthesize and Scenario Creation

Future Scenario Matrix

There are multiple approaches for exploring critical drivers and associated uncertainty from which to develop a small number of future scenarios. One common method is a 2x2 matrix where two primary uncertainties form axes to create four different future scenarios (NPS 2013, Rowland *et al.* 2014). To help differentiate among the scenarios, the axes should result in scenarios considered plausible, challenging, relevant, and divergent. Using this method, we chose climatic conditions and habitat accessibility for the two axes of our 2x2 matrix (Figure 8A; Appendix 12 for pictorial representation). To meet the NOAA Fisheries' policy guidance on the treatment of climate change in ESA decisions, we based our future climate conditions on the IPCC's RCP 8.5 pathway in which greenhouse gas emissions continue to increase into the future (NMFS 2016). This axis considered a warmer future that was either wetter or drier based on the uncertainty surrounding future changes in precipitation and associated seasonality impacts on streamflow (i.e., higher winter/lower spring streamflow versus higher winter/lower remainder of year streamflow). To further differentiate among scenarios, the number of consecutive extreme hot days exceeding Atlantic salmon thermal threshold in the rivers was considered to increase in some, but not all, scenarios (see freshwater, marine, and estuarine presentations in Appendix 9 for more information). The other axis considered freshwater accessibility across a high to low spectrum depending on whether or not passage barriers (i.e., dams and culverts) are removed/modified (high accessibility) or remain in large numbers (low accessibility). Habitat accessibility is critical for Atlantic salmon to complete their life history. Conversely, impaired accessibility of freshwater habitats is a primary threat to Atlantic salmon recovery, and thus, a key theme for the recovery program. Other potentially important drivers were considered prior to and during the workshop (e.g., urban development, hatchery production).

An additional plausible future was developed and added at the workshop based on discussions regarding the importance of the marine environment off Greenland to Atlantic salmon. Instead of maintaining warming under the RCP 8.5 pathway, this marine-only future considered consistent, enhanced, non-uniform sea surface warming in the Gulf of Maine and cooling and/or less sea surface warming off Greenland[3] (Figure 8B; Saba *et al.* 2016; Appendix 11). We decided to include this future within the discussions of the other four scenarios rather than as a standalone fifth scenario.

[3] The sea surface temperature (SST) off Greenland in response to climate change is variable depending on the model used. Some models show cooling (Figure 8B), while others show warming but less than what is projected to occur off the Gulf of Maine. This area is strongly affected by the Atlantic Meridional Overturning Circulation (AMOC), which, when it slows, brings less warm water to the south of Greenland.


A
Free Flowing
High
Hanging on by a Stream
Climatic Conditions:
Climate changes as expected
Less snow, earlier melt, precip more frequently falls as rain in winter
Higher winter/lower spring streamflow
River temp increases
Sea surface temp (SST) rises, Gulf of Maine warms uniformly
Passage barriers removed/modified
Salmon primarily affected by marine suitability, streamflow variability and temperature
Climatic Conditions:
Drier, warmer conditions prevails
Less snow; precip lower (e.g., for extended time period)
Higher winter/lower remainder of year streamflow
River temp increases (number of consecutive extreme hot days exceeding salmon threshold increases)
SST rises, Gulf of Maine warms uniformly
Passage barriers removed/modified
Salmon primarily affected by marine suitability, streamflow variability and temperature
Freshwater Accessibility
Warmer, Wetter
Climatic Conditions
(RCP 8.5)
Warmer, Drier
Climatic Conditions:
Climate changes as expected
Less snow, earlier melt, precip more frequently falls as rain in winter
Higher winter/lower spring streamflow
River temp increases
SST rises, Gulf of Maine warms uniformly
Most passage barriers remain
Salmon primarily affected by marine suitability, streamflow variability, temperature and barriers
Climatic Conditions:
Drier, warmer conditions prevails
Less snow; precip lower (e.g., for extended time period)
Higher winter/lower remainder of year streamflow
River temp increases (number of consecutive extreme hot days exceeding salmon threshold increases)
SST rises, Gulf of Maine warms uniformly
Most passage barriers remain
Salmon primarily affected by marine suitability, streamflow variability, temperature and barriers
Soggy but Hindered
Low
Hot and Blocked

B

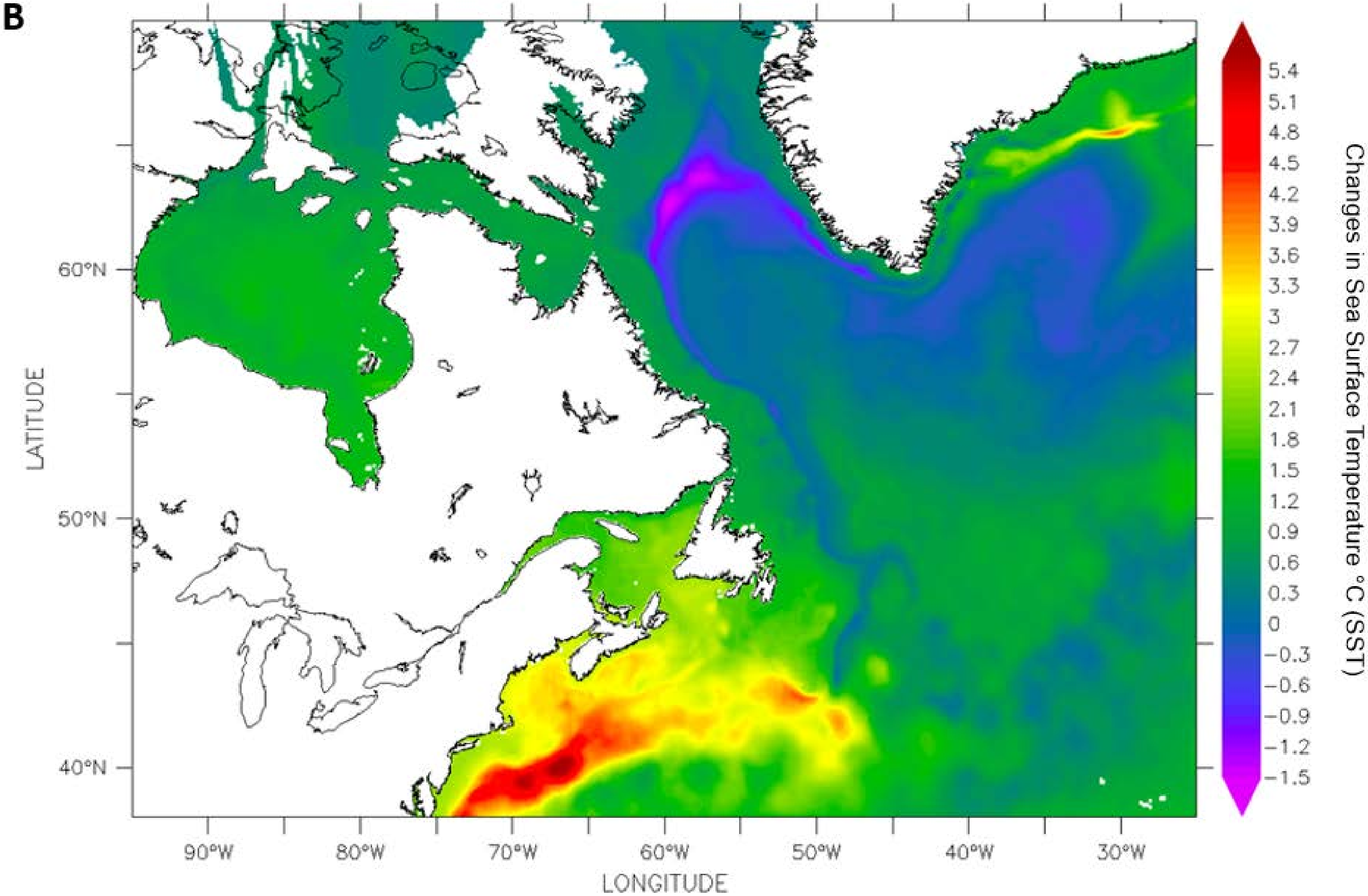


Figure 8. (A) Final scenario matrix describing the four primary future scenarios. (B) An additional plausible future was considered in which there was consistent, enhanced, non-uniform sea surface warming in the Gulf of Maine and cooling and/or less sea surface warming off Greenland (graphic courtesy of Saba *et al.* 2016; see Appendix 11 for additional details).

Scenario Narratives

Below, we provide descriptive narratives for the information provided in Figure 8. Please note that under each scenario, a future that included consistent, enhanced, non-uniform sea surface warming in the Gulf of Maine and cooling and/or less sea surface warming off Greenland (Saba *et al.* 2016) was also considered.

1. *Free Flowing:* In this future, the environment is warmer and wetter. River temperatures have increased. Winters experience less snow, and when it does snow, it melts earlier. Winter precipitation occurs more frequently as rain. Combined, these conditions lead to higher winter and lower spring streamflow. Sea surface temperature (SST) increases and the Gulf of Maine warms uniformly. Freshwater accessibility in the watersheds is high due to removal or modification of passage barriers. Atlantic salmon are primarily affected by the suitability of the marine habitat, the variability in streamflow, and increasing river temperature.
   -
2. *Hanging on by a Stream*: In this future, environmental conditions are warmer and drier. This leads to less snow in the winter and overall lower year-round precipitation for extended periods. River temperatures and the number of consecutive extreme hot days that exceed thermal thresholds for Atlantic salmon increase (Appendix 9). SST increases and the Gulf of Maine warms uniformly. Although freshwater accessibility in the watersheds is high due to removal or modification of passage barriers, the generally drier conditions lead to reduced streamflow year-round. Atlantic salmon are primarily affected by the suitability of the marine habitat, lower streamflow for extended periods, and higher river temperatures.
   -
3. *Soggy but Hindered*: In this future, the environment is warmer and wetter. River temperatures have increased. Winters experience less snow and, when it does snow, it melts earlier. Winter precipitation occurs more frequently as rain. Combined, these conditions lead to higher winter and lower spring streamflow. SST increases and the Gulf of Maine warms uniformly. Freshwater accessibility in watersheds is low because most passage barriers remain in place. Atlantic salmon are primarily affected by marine habitat suitability, streamflow variability, increasing river temperature, and the continued presence of barriers.
   -
4. *Hot and Blocked*: In this future, environmental conditions are warmer and drier. This leads to less snow in the winter and overall lower year-round precipitation for extended periods. River temperatures and the number of consecutive extreme hot days that exceed thermal Atlantic salmon thresholds increase (Appendix 9). SST increases and the Gulf of Maine warms uniformly. Freshwater accessibility in watersheds is low because most passage barriers remain in place. Atlantic salmon are primarily affected by marine habitat suitability, streamflow variability, increasing river temperature, and the continued presence of barriers.

Phase 4: Application

To help with discussions during our face-to-face meeting, we developed two worksheets. These sheets were designed to facilitate conversations about the conditions Atlantic salmon will face as climate changes (Scenario Development, Figure 9) and identifying possible management and research options (Generating Options, Figure 10).

At the workshop, participants were divided into four breakout groups, with each group assigned one of the four future scenarios for worksheet discussions. When possible, each group contained managers and scientists representing expertise across the varied disciplines (salmonid ecology, climate modeling, riverine dynamics, etc.).

<u>*Scenario Development*</u>

Scenario development conversations discussed what might happen between now and 75 years in the future for each of the four scenarios. For each scenario, specific discussion points included: 1) what the future climate would be like; 2) what non-climate features might be important; 3) a timeline of future events that might occur (including what had to happen for a future scenario to occur); and 4) identification of the possible main changes in conditions on Atlantic salmon (and associated life stages) in the watershed, estuarine (transition), and marine environments (Figure 9). Prior to moving to the Generating Options worksheet, groups reconvened to share their futures and discuss the similarities among all or some scenarios.

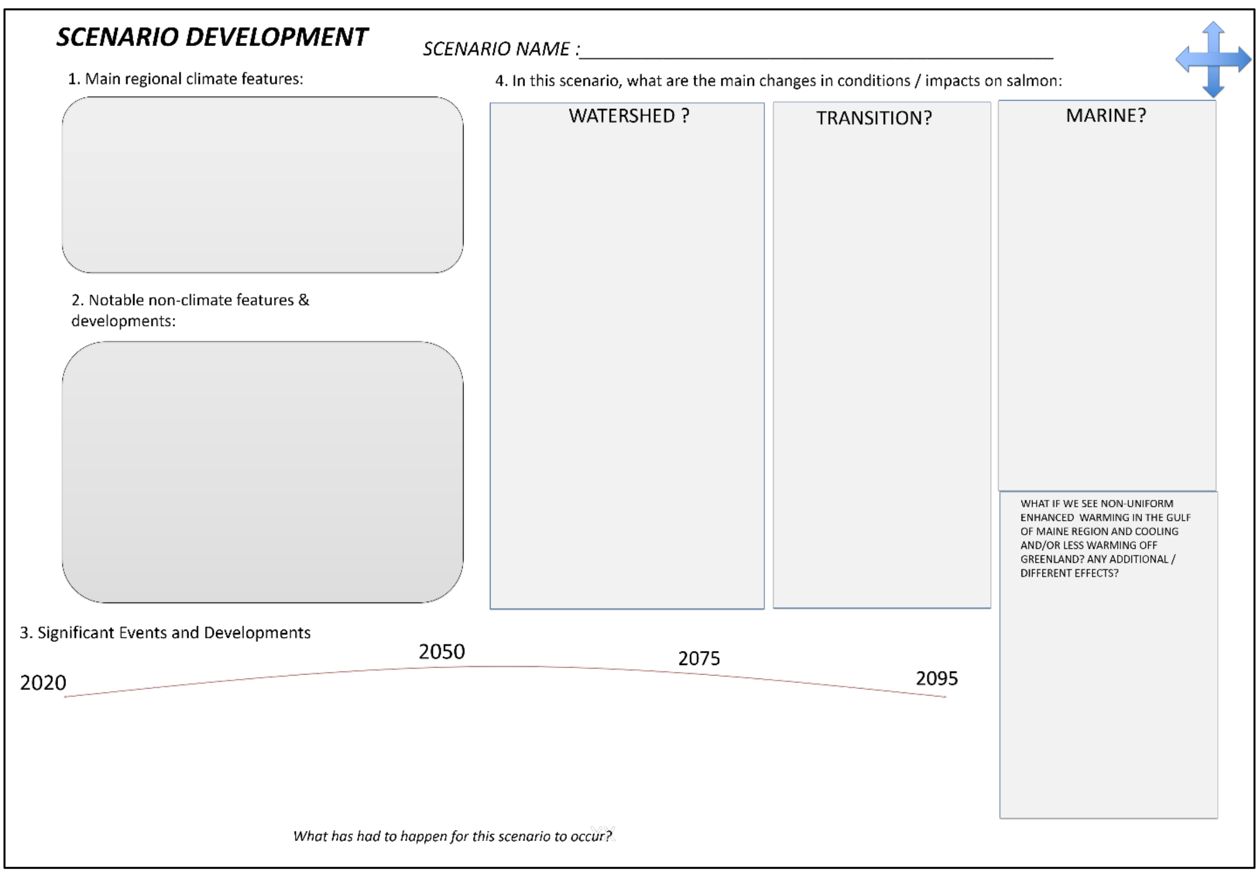


Figure 9. Scenario Development worksheet used in the Atlantic Salmon Scenario Planning Pilot exercise. Note: Transition refers to estuarine habitat.

Generating Options for Management and Research Priorities

This step began with a discussion centered on what changes are being observed now to Atlantic salmon and the climate as well as any other considerations participants thought important to share with the group. With the recognition of what is happening in the system now and how that could change over the next 75 years under each future scenario, participants next focused on a shorter 1-5 year period to generate possible actions NOAA Fisheries and others could/should do to prepare for each of these four futures. Actions/options were considered across a range of categories including: research, dams/other barriers, management (non-dam), relationships/collaboration, and other (Figure 10).

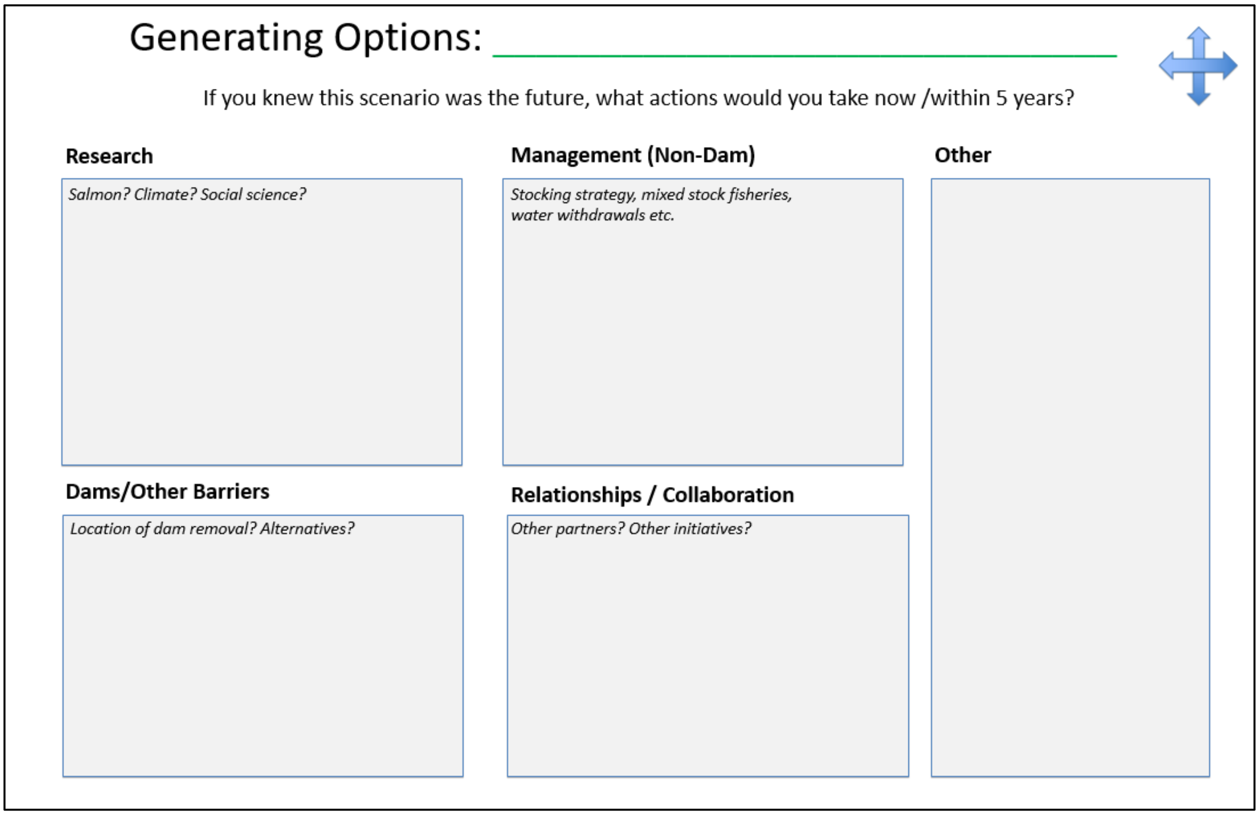


Figure 10. Generating Options worksheet used in the Atlantic Salmon Scenario Planning Pilot exercise.

Watershed and Estuarine (Transition)/Marine Breakout Groups

Following identification of scenario-specific options, participants divided into two new groups to identify high priority, short-term actions in the watershed and marine/estuarine (transition) environments. To focus discussion on what actions are most important to consider in the next 1, 3, and 5 years, the groups considered all scenarios equally plus other factors that affect planning (e.g., purpose, resources, and future conditions). These high priority actions were further synthesized and refined following the workshop into range-wide (U.S. headwaters to Greenland), marine, estuarine (transition), and watershed categories.

Results

Breakout Group Work

i. Scenario Development

The Scenario Development worksheet provided the opportunity for groups to develop their particular future. A common theme among all scenarios was the importance of including people as part of the solution through increased public awareness and appreciation of the species. This was particularly important for addressing issues related to habitat accessibility (e.g., passage barrier modification and/or removal). Although *Free Flowing* was identified as the best scenario for Atlantic salmon, the species would still face significant challenges. For example, without dams (also in the *Hanging on by a Stream* scenario) an entire freshwater species community shift is expected to occur, but how this shift would affect community structure and ecological interactions (e.g., predators, possible increase in invasive species) is difficult to predict. Given that ecological uncertainties would remain even under high habitat accessibility, there is a need to remove dams now to give species as much time as possible to adapt to new and existing pressures. Increasing the adaptive capacity of Atlantic salmon will facilitate resilience to a changing climate and providing access to all environments that were historically inhabited will be a critical component. Conversely, *Hot and Blocked* was considered the worst-case scenario for Atlantic salmon due to decreased habitat accessibility through a combination of a warmer and drier environment and the continued presence of barriers. Additional information from the Scenario Development worksheets can be found in Appendix 13.

ii. Generating Options

The Generating Options worksheet allowed groups the opportunity to identify possible relevant management and research actions that could be implemented under each scenario to improve Atlantic salmon resilience in a changing climate. Options identified by each group included activities unique to one scenario, as well as those that were common in two or more scenarios. Actions common across all four scenarios, or those that would be useful to undertake under any future, included:

- Research: Further barrier assessments, freshwater and marine suitability mapping, improved understanding of threats in the marine environment, and further tagging efforts.
- Management (Non-Dams): Hatchery and stock management strategy needed.
- Dams/Other Barriers: Providing access to all environments that Atlantic salmon historically inhabited is a critical component to increasing the adaptive capacity of Atlantic salmon and facilitating resilience to a changing climate.
- Relationships/Collaborations: Increase collaboration with other government and non-governmental organizations.
- Other: Outreach, engagement and education to the public.

Additional information from the Generating Options worksheets can be found in Appendix 14.

iii. Watershed and Estuarine/Marine

Based on workshop discussions, a number of high priority actions were identified as important to consider in the short-term and synthesized into broad spatial units (range-wide, watershed, estuarine (transition), and marine). Actions identified under *range-wide* will advance activities across the watershed, estuarine, and marine habitats. Additional information from these workgroups can be found in Appendix 15.

Range-wide (U.S. headwaters to Greenland)

- Synthesize and refine life stage specific quantitative environmental thresholds (e.g., temperature, flow etc.).
- Conduct range-wide habitat analysis/mapping of key attributes of the physical environment important to Atlantic salmon (e.g., streamflow, stream temperature, channel slope, cold water refugia, marine temperature) both for current and projected future conditions.
- Evaluate migration behavior and survival assessment
  - Develop migration model - what happens to survival during migration under changing environmental conditions? Will migration patterns change?
  - Assess historical Atlantic salmon behavior under past conditions and model future states - Is there alignment with marine regime changes?
  - Conduct modeling study to investigate Atlantic salmon habitat quality and availability in variable ocean environments.
- Assess genetic diversity
  - Determine at what minimum/maximum effective population sizes and census population abundances within hatchery genetic lines there would be a loss/gain of critical/functional diversity.
  - What strategies could be considered to supplement diversity of genetic lines when diversity is critically low?

Watershed

- Conduct site specific assessment of changing fish density related to impacts of temperature, elevation, and other climate proxies on freshwater productivity (document historical changes).
- Assess habitat productivity - determine what is needed to grow more smolts (i.e., may not be just habitat improvements).
  - Identify areas that produce smolts and those that do not (field data).
  - Identify what conditions make some habitats productive and others unproductive and the dynamic relationship of habitats across seasons/years.
  - Identify actions to increase habitat productivity (including using currently vacant habitat).
- Assess connectivity - are fish getting where they need to go?
  - Use the habitat productivity assessment to map the highest quality Atlantic salmon habitat.
  - Conduct barrier removal prioritization informed by habitat productivity assessment and mapping to identify specific removals that would have the biggest benefit to Atlantic salmon.

Marine

- Conduct tagging/tracking studies of Atlantic salmon in marine environment to understand:
  - Where they are in the ocean,
  - Where/why they are dying (bottlenecks),
  - How a changing climate might affect survival, and
  - Identify ways to increase marine survival both in general and in light of climate change.
- Invest in new technologies that may enable ocean tracking across greater temporal and spatial ranges (e.g., RAFOS Oceanic Acoustic Monitoring (ROAM), which is a new approach to marine tracking that is currently being tested for use in the Labrador Sea to monitor Atlantic salmon migration from natal rivers to the Labrador Sea/Greenland) and continue to utilize and combine as appropriate with existing technologies.
- Further assess forage fish and survival connection and forage fish energetics (e.g., historical and current prey energy density, size structure, abundance).
- Conduct a multi-disciplinary scenario planning workshop between U.S. and Canadian North Atlantic right whale scientists, Atlantic salmon researchers, climate scientists, managers - dedicate the workshop to understanding what is happening to key prey (e.g., *Calanus* copepods, capelin, and overall food web structure and function).
- Conduct an historical reanalysis of changes in oceanic conditions observed between 1958 and present using Regional Oceans Model Systems (ROMS).
- Evaluate population dynamics and estimate predatory demand (e.g., seals, striped bass) to Atlantic salmon in a changing climate (historical, current, and future).
  - Coordinate with Fisheries and Oceans Canada (DFO) (e.g., inquire to see if a study is underway or planned).
  - Adapt the ECOPATH model developed for sympatric river herring (Dias *et al.*, 2019) for Atlantic salmon under varying seal population abundances.
- Increase adult spawner abundance to offer buffer to low marine returns under high climate variability.

Estuarine (Transition)

- Understand how mortality may be affected (either positively or negatively) by changing environmental conditions in estuaries and develop strategies to reduce this mortality.
  - Conduct a scientifically-based review to assess the pros/cons and costs/benefits of possible management ideas to address changing predator/prey interactions as a result of changes in environmental conditions (e.g., new predators appear due to shifts in species' distributions, numbers of existing predators increase as a result of climate change, Atlantic salmon timing through the estuarine transition zone changes due to changing environmental conditions exposing them to new threats (Staudinger *et al.* 2019)).
  - Review assessments, conduct cost-benefit work, and develop recommended actions.
  - Develop implementation and monitoring plans for recommended actions.

- Reduce dam-associated indirect estuarine mortality rate.
    - Explore the mechanisms for how passage type (spill, bypass, or turbine) at upstream dams affects estuarine mortality.

Other actions not included in the above but mentioned during the meeting include:

- Assess ocean acidification impacts on prey.
- Consider lessons learned from other efforts (e.g., Connecticut and Merrimack River Atlantic salmon restoration efforts, Northeast river herring; Pacific salmon recovery efforts).
- Prioritize restoration efforts that focus on increasing natural spawning in rivers.
- Focus on research within restoration (i.e. consider treating some rivers as experiments to explore and test novel approaches; make decision points and take genomic approach).
- Develop a comprehensive plan and associated deadlines for moving actions identified in this effort forward.
- Align actions for Atlantic salmon with other diadromous species of high conservation concern (e.g., river herring, shad) to identify shared multi-species beneficial actions.

Summary and Next Steps

This pilot represents the first effort to explore scenario planning within NOAA Fisheries and demonstrates its applicability to help prioritize management and research needs. The scenario planning process structured and helped focus conversations that enabled out-of-the-box thinking, the emergence of new ideas, and increased federal partner coordination/collaboration. This process benefited by bringing together experts from different disciplines, including Atlantic salmon science and management, climate, watersheds, and fish physiology. Furthermore, the active consideration of climate change throughout the process resulted in identification of outcomes and products aimed to improve resilience of U.S. populations of Atlantic salmon in a changing environment. In addition to identifying critical and uncertain drivers important to the species survival, we were able to develop a number of plausible futures, highlight resource needs for recovery, and generate priority options that would be useful to carry out under some or all future scenarios. These options included identifying climate-related Atlantic salmon recovery needs and scientific data gaps that were added to the 2019 Recovery Plan (USFWS and NMFS 2019).

Although this process was considered successful, we encountered a number of challenges. Participants struggled with the complexity that resulted from considering the full spatial extent of the Atlantic Salmon GOM DPS. Because the species is diadromous, ranging from headwater tributaries in Maine to open ocean environments spanning the U.S. east coast to Greenland, we needed to consider a greater number of habitats, conditions, climate projections etc. than if we were considering watersheds or marine environments separately. This made differentiating the impacts to Atlantic salmon across the different future scenarios difficult. The large uncertainty in some climate/physical driver projections, especially at finer spatial scales (i.e., watershed, Gulf of Maine) was also challenging. For example, although precipitation is projected to generally increase across Maine in the future, the seasonality of that precipitation is highly uncertain and could significantly impact several life history stages. To help understand the nuances of such uncertainties, the group relied heavily on participant expert knowledge. Finally, although the choice to use a non-climate driver for one axis proved valuable for scenario development, it was challenging to decide which one to select from the many options (e.g., urban development, hatchery production). In the end, we selected habitat accessibility because of its importance to species recovery.

Nevertheless, discussion and collaboration among participants continued following the workshop and several action items are now completed or underway. These include:

1. The incorporation of high priority climate-related items into the revised Atlantic Salmon Recovery Plan (USFWS and NMFS 2019). Appendix 16 contains a list of Recovery Plan climate actions that were informed by the scenario planning effort.
2. A NOAA funded (NEFSC Atlantic Salmon Ecosystems Research Team, NOAA Fisheries Offices of Science and Technology and Protected Resources) project to conduct a range-wide habitat analysis/mapping of key attributes of the physical environment important to Atlantic salmon and synthesis of life stage specific quantitative thresholds.
3. A NOAA funded (Greater Atlantic Regional Fisheries Office Protected Resources Division and NMFS Office of Habitat Conservation) project to map GOM DPS Atlantic salmon cold water refugia under a changing climate.

4. The continued collaboration with external partners to develop and test new marine tracking technology (ROAM) to monitor Atlantic salmon migration from natal rivers to the Labrador Sea.
5. The continued building capacity for scenario planning within NOAA Fisheries through presentations, other protected species (e.g., North Atlantic right whales) exercises, and trainings.

This pilot demonstrated that the forward-looking scenario planning process aligns well with long-term recovery planning by providing scientists and managers a way to prepare for multiple futures by acting now with near-term actions. In addition, by providing an important launching point for continued discussions on Atlantic salmon recovery, current partnerships were strengthened and new ones built. To further Atlantic salmon recovery and move the full list of identified priority actions forward, additional collaborations will be needed. As new information becomes available (e.g., new climate projections, species and habitat information), the scenario planning framework used in this pilot can be revisited and updated as needed. The pilot may also serve as a useful reference for other scenario planning case studies, especially those considering the marine environment and protected resource management.

Acknowledgements

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List of Acronyms

DFO - Fisheries and Oceans Canada

DPS - Distinct Population Segment

GOM - Gulf of Maine

ESA - Endangered Species Act

ESRL - NOAA Earth System Research Laboratory

FERC - Federal Energy Regulatory Commission

GARFO - NOAA Fisheries, Greater Atlantic Regional Office

IPCC - Intergovernmental Panel on Climate Change

NMFS - National Marine Fisheries Service (NOAA Fisheries)

NEFSC - NOAA Fisheries Northeast Science Center

NOAA - National Oceanic and Atmospheric Administration

NPS - National Park Service

RCP - Representative Concentration Pathway

SHRUs - Atlantic Salmon Habitat Recovery Units

SWFSC - NOAA Fisheries Southwest Science Center

USGS - U.S. Geological Survey

USFWS - U.S. Fish and Wildlife Service

USFS - U.S. Forest Service

Webinar and Workshop Agendas

Atlantic Salmon Scenario Planning Pilot
Conference Call and Webinar 1
Friday, July 7, 2017 1-3 pm EDT

Agenda

Meeting Purposes:

- Background on initiative
- Introduction to scenario planning
- Atlantic salmon drivers and climate data
- Discuss next steps

Time	Topic	Speakers
1:00 - 1:10 pm	Introductions, round robin	Everyone
1:10 - 1:25 pm	Project background, context and questions	Dori and Diane
1:25 - 1:40 pm	Scenario Planning 101: principles, benefits, example applications in conservation and climate change, and questions	Jonathan Star
1:40 - 2:00 pm	Specific tasks / requirements for our scenario process in Webinar 1, Webinar 2, Scenario Session - and the intervening periods. (i.e. what will we do, and when?)	Jonathan Star
2:00 - 2:20 pm	Conceptual model discussion	Everyone
2:20 - 2:45 pm	Drivers discussion - how to use the table, correct drivers identified, are there more to include, where to find information?	Everyone
2:45 - 2:50 pm	Other sources of information valuable to highlight (e.g. other drivers, on impacts and potential management options)	Everyone
2:50 - 3:00 pm	Questions and next steps	Everyone

Atlantic Salmon Scenario Planning Pilot
Conference Call and Webinar 2
Tuesday, August 15, 2017 1-3 pm EDT

Agenda

Meeting Purposes:

- Brief project recap
- Driver update and draft matrix
- Workshop design
- Discuss next steps

Time	Topic	Speakers
1:00 - 1:05 pm	Welcome, introductions	Everyone
1:05 - 1:15 pm	Project recap, goals, conceptual model	Dori
1:15 - 1:25 pm	Update on Drivers Subgroup, matrix development	Diane
1:25 - 1:35 pm	Current draft matrix	Jonathan Star
1:35 - 2:00 pm	Questions and discussion	Everyone
2:00 - 2:30 pm	September workshop design	Jonathan Star
2:30 - 2:55 pm	Open questions and discussion (workshop, drivers, draft matrix, other)	Everyone
2:55 - 3:00 pm	Next steps (e.g., workshop logistics)	Everyone

NOAA Atlantic Salmon Climate Scenario Planning Workshop
September 26th & 27th 2017

U.S. Custom House, 312 Fore Street, Portland, Maine
(Please use the Commercial Street entrance)

Day 1 – Tuesday Sept 26th - Background and Scenario Development

Time	Topic
8.30am	**Arrival**
9.00am	**Welcome, introductions, objectives, agenda etc.** • Dori Dick and Diane Borggaard welcome participants, provide very brief background and context, including 'focal question' and outputs. Then hand over to Jonathan Star for introductions, objectives, agenda, etc.
9.30am	**Salmon background briefing (30 minutes)** • Dan Kircheis provides quick overview of Recovery Plan (10 min.) • Tim Sheehan (marine and estuary; 10 min.) and Dan Kircheis (freshwater; 10 min) provides basic background on the biology (including temperature tolerances) and distribution of Atlantic salmon.
10.00am	**Opening conversation: What have we already seen?** • Participants share personal perspectives on how they have seen climate change affecting salmon in Maine to date. Core team member records on flip chart.
10.30 am	**BREAK**
10.45 am	**Drivers of Change** • Presenters outline research on the drivers and sources of future uncertainty affecting salmon. o This will include climatic/physical drivers (temp, precip, streamflow, etc.) (e.g., Mike Alexander (30 min.), Robert Dudley (15 min.)) o Plus non-climate/physical drivers (e.g., Dan Kircheis; 10 min.)
11.30am	**Presenting Scenarios** • Jonathan Star describes the background, principles, applications and steps involved in scenario planning • He presents the scenario framework we will use for the conversations. • At tables, groups are given one scenario and asked to familiarize themselves with / validate that scenario. Does their scenario allow them to tell a plausible, challenging, relevant story about the issues facing salmon over the next 20-30 years? Does it work for marine, watershed, and estuarine (transition) areas? (short discussion; 10-15 minutes). • Groups briefly report -out, leading to a plenary conversation about the overall set of scenarios. Do they work as a set? Are they different from each other? Is there an important development or story that is missing from the set?
12.45pm	LUNCH
1.30pm	**Understanding the Impact on Salmon** • Opportunity to remind participants of the Conceptual Model • Introduce spatial data/map information packet of the region • Overview of research on the potential impacts of climate change on salmon in the region (Tim Sheehan; 10 min.)
2.00pm	**Scenario Deepening and Development** • Exercise set up. Groups are given a briefing document on the scenarios, and asked to focus on describing one scenario. • Small groups (~5 participants per group) tell salmon-specific stories and outline the implications and impacts of their scenario on marine / watershed / estuarine (transition) areas • Groups include story elements based on non-climate/physical drivers (e.g., stocking strategy, mixed stock fisheries, water withdrawal) • Ask tables to describe conditions by referring to maps etc. as appropriate • Include a timeline of plausible, indicative events that add color to the stories

Time	Topic
	• Impacts and implications categorized into different aspects considering all life stages (using the conceptual model) • Conversations recorded on pre-printed large worksheets
3.30pm	**BREAK**
3.45pm	**Sharing across scenarios** • Display each of the scenario worksheets so that participants can review other groups' work. Then report-out for groups to share their stories with others
4.30pm	**Wrap-up, reflections, and early thoughts on options** • Plenary conversation that discusses the overall scenarios and how they fit together. Have we told provocative stories? Are they plausible? Will they help us generate ideas and investigate the decision issues tomorrow? • Any early thoughts on options (to be further discussed in Day 2)?
5.30pm	**ADJOURN**

Day 2 – Wednesday Sept 27th - Generating and Assessing Options

Time	Topic
7.30am	**Arrival**
8.00am	**Overnight Thoughts** • Plenary discussion to reflect on Day 1, and suggest any 'must-dos' for Day 2
8.30am	**Generating Options** • Groups identify options (e.g., actions and research) that would make sense to pursue in each of the scenarios. • Divide into marine activities, watershed activities, estuarine (transition) activities etc. • Ask groups to describe conditions by referring to maps etc. as appropriate
10.30am	**BREAK**
10.45am	**Report Out and No-Regret Options** • Each group reports out their findings per scenario. Then we look across all scenarios to assess any no-regrets / robust options. • We also discuss if there are ways to push towards a preferred scenario (and away from a worst case) • This conversation will provide us with a sense of priority actions.
12.00pm	**LUNCH**

1.00 pm	**Specific Conversations - Subgroups**
	• Opportunity for each of the 3 SHRUs, plus the marine and estuarine areas, to be the focus of specific conversations about issues of most importance (determined by participants).
	• Could also create a separate 'climate scientists' group if appropriate.
	• These conversations are now based not only on the scenarios, but on the other factors that affect strategy (goals, capabilities, resources etc.). Includes discussion of what most important to do.
	• Report out (5 minutes per group)
	    o Read-out exercise and plenary discussion
	    o Does the exercise reveal a clear way forward for a specific management option and/or research need?

2.00 pm	**Specific Conversations - Large Group** • Larger group discussion. Prioritize actions (by watersheds, Marine, Estuarine, Overall).
3.00 pm	**BREAK**
3.15pm	**Wrap-up, Review Conversations & Next Steps** • Wrap-up and review • Discuss next steps on priority actions (management and research needs) and monitoring, product development, additional meeting. • Discuss possible future directions to extend outcomes, new projects and meetings, new avenues for collaborations or additional scenario exercises within NMFS.
4.30pm	**ADJOURN**

Appendices

Appendix 1. Jonathan Star's Scenario Planning Introduction presentation provided during the first webinar.

1 What are scenarios?

"Scenarios are stories about the ways that the world might turn out tomorrow…

…that can help us recognize and adapt to changing aspects of our current environment"

Peter Schwartz

2 Scenarios are "alternative conditions you might face"

Low Trust Globalization	Open Doors	Flags
A legalistic world of competing standards and divergent initiatives aimed at solving global problems	*A pragmatic world of incentives and soft power aimed at promoting inclusive globalization*	*A dogmatic world of populist policies and bilateral agreements aimed at pushing national agendas*

Source: 2005 Shell Global Scenarios to 2025

3 Benefits from scenario planning

1. *Flexibility to react quickly to a changing world*
2. *More robust decisions and plans*
3. *Innovative ideas*
4. *Early and broad risk identification*
5. *Alignment towards a common vision*

4 For Resource Managers

"The greatest utility [of scenarios] is in creating a wedge into a discussion to overcome initial hurdles to get people talking about climate change".

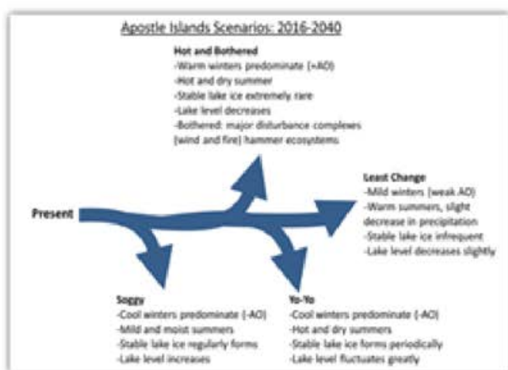
"There is a tendency for resource managers or others I work with to be paralyzed by the uncertainty. But framing things in scenarios helps them get over that mental hurdle"

5 Example: Apostle Islands National Lakeshore

Purpose: *apply scenario planning to a range of park decisions, including dock design and visitor management*

Process: *created 4 climate scenarios describing different conditions*

6 APIS Scenario Set



7 Example: Apostle Islands National Lakeshore

Outcomes / Lessons:

- *Tested existing dock designs and discussed how to build in more flexibility*
- *Highlighted the importance of community engagement for supporting visitor numbers*
- *Identified flexible staffing arrangements as critical for dealing with visitor number spikes*
- *Explored various adaptation options for important species*

8 A typical scenario creation process

Appendix 2. Recent examples of organizations that have used scenario planning to help inform climate change related management challenges.

Key Organization*	**Location**	**Weblink**
National Park Service	General Information	https://www.nps.gov/subjects/climatechange/scenarioplanning.htm https://irma.nps.gov/DataStore/Reference/Profile/2201674
	Acadia National Park	https://www.nps.gov/subjects/climatechange/upload/Scenario-Workshop-ACAD-508compliant.pdf
NOAA Greater Farallones National Marine Sanctuary	North-Central California Coast	http://farallones.noaa.gov/manage/climate/adaptation.html
Tijuana River National Estuarine Research Reserve	Tijuana River Estuary	http://trnerr.org/wp-content/uploads/2014/03/future_scenarios_summary.pdf
GeoAdaptive, Florida Fish and Wildlife Conservation Commission	KeysMAP: Florida Keys Marine Adaptation Planning Project	http://geoadaptive.com/projects/keysmap1/
University of Alaska Anchorage	Salmon 2050, Kenai Peninsula, Alaska	https://www.alaska.edu/epscor/archive/phase-4/southcentral-test-case/salmon-2050/
Point Blue Conservation Science	San Francisco Bay Estuary	http://climate.calcommons.org/project/using-scenario-planning-support-climate-smart-adaptation-south-bay-salt-ponds-restoration

** Scenario planning is often a process that benefits from broad stakeholder engagement; however, there is often one or two key groups who lead the process. For brevity we list the primary stakeholder of each example and provide links where additional details pf each project can be found.*

Appendix 3. Five phases of the scenario planning process as outlined by the National Park Service Handbook (NPS, 2013).

Phase	Goal	Steps	Outcomes/Products
Phase 1: Orientation	Set up project for success	• Establish purpose of project • Determine desired outcomes • Specify Issue or "Strategic Challenge" to explore using scenarios • Recruit core team	• An understanding of the purpose, desired outcomes, and scope of project • Core team to help with exercise • Statement describing issue or "strategic challenge" • Clearly articulated focal question • Draft/final project schedule • Draft/final participant list
Phase 2: Exploration	Identify and analyze critical forces, variables, trends, and uncertainties that may affect strategic challenge and focal question	• Identify critical forces (drivers) that affect strategic challenge • Identify potential impacts • Engage participants before workshop (webinars, conf. calls) to help familiarize with scenario planning process	• Tables and charts that capture drivers, variables, uncertainties, and impacts that may affect focal question • Graphics, maps to help with discussion • Any materials and background information that participants should review before workshop
Phase 3: Synthesize & Create Scenarios	Produce small number of scenarios using critical forces and impacts identified in Phase 2	• Divide critical forces into important elements* and critical uncertainties** • Build scenario frameworks and choose scenarios • Identify scenario impacts • Describe scenarios in detail and develop scenario narratives • Review scenarios for plausibility and consistency	• 3-5 plausible, relevant, challenging and divergent scenarios using critical uncertainties to inform, inspire and test actions/strategies
Phase 4: Application	To answer "So what?" questions: What do these scenarios mean to NMFS? What do they mean to focal question and strategic challenge? What do we do about it?	• Identify scenario implications • Develop, test and prioritize actions • Use scenarios to inform strategies	• List of actions, strategies, or areas for additional research based on discussions initiated by scenarios
Phase 5: Monitoring	To identify important indicators (trigger points) that can signal changes in the environment as future unfolds	• Select indicators to monitor • Scan and monitor environment changes • Communicate scenarios and workshop outcomes • Workshop deliverables	• List of indicators and early warning signals for continued research and monitoring • A monitoring strategy • Workshop deliverables e.g., scenarios, implications, actions, indicators to monitor, monitoring strategies

* Important elements are forces important to the focal question for which available information includes a high degree of confidence and direction and magnitude of future changes.
** Critical uncertainties are variables very important to the focal question for which available information is limited or unknown and characterized by significant uncertainties.

Appendix 4. Participants in the scenario planning pilot exercise[4].

Name	Affiliation
Mike Alexander	NOAA, Office of Oceanic and Atmospheric Research, Earth Systems Research Laboratory
Matt Bernier	NOAA Fisheries, Office of Habitat Conservation
Diane Borggaard	NOAA Fisheries, Greater Atlantic Region, Protected Resources Division
Matt Collins	NOAA Fisheries, Office of Habitat Conservation
Julie Crocker	NOAA Fisheries, Greater Atlantic Region, Protected Resources Division
Kim Damon-Randall	NOAA Fisheries, Greater Atlantic Region, Protected Resources Division
Dori Dick	Ocean Associates Inc. in support of NOAA Fisheries, Office of Protected Resources
Robert Dudley	USGS, New England Water Science Center
Roger Griffis	NOAA Fisheries, Office of Science and Technology
Sean Hayes	NOAA Fisheries, Northeast Science Center, Protected Species Branch
Mike Johnson	NOAA Fisheries, Greater Atlantic Region, Habitat Conservation Division
Dan Kircheis	NOAA Fisheries, Greater Atlantic Region, Protected Resources Division
John Kocik	NOAA Fisheries, Northeast Science Center, Protected Species Branch
Ben Letcher	USGS, Silvio O. Conte Anadromous Fish Research Center
Nate Mantua	NOAA Fisheries, Southwest Science Center
Keith Nislow	USFS, Northern Research Station
Rory Saunders	NOAA Fisheries, Greater Atlantic Region, Protected Resources Division
Tim Sheehan	NOAA Fisheries, Northeast Science Center, Protected Species Branch
Jonathan Star	Scenario Insight
Michelle Staudinger	USGS, Northeast Climate Adaptation Science Center
Vince Saba	NOAA Fisheries, Northeast Science Center
Wendy Morrison	NOAA Fisheries, Office of Sustainable Fisheries

[4] Experts were invited from NOAA Fisheries (Headquarters, Northeast Fisheries Science Center (NEFSC), Greater Atlantic Regional Fisheries Office (GARFO), and Southwest Fisheries Science Center (SWFSC)), NOAA Earth System Research Laboratory (ESRL), U. S. Geological Survey (USGS), U. S. Fish and Wildlife Service (USFWS), and U. S. Forest Service (USFS).

Appendix 5. Relevant literature compiled by participants as part of the Critical Driver identification process.

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Appendix 6. Climate (physical) drivers table. Note: This table lists those drivers initially considered for this scenario planning exercise. The high-resolution projections from Saba *et al.* 2016 for precipitation and air temperature were not originally included, but were considered during the in-person workshop (see Appendix 11).

Climate/Physical Variable	Expected General Change	Specified Change Expected and Reference Period	Patterns of change	Confidence	Primary Source and Context
Sea surface temperature	↑	2050-2099: ↑3.2 to 4°C 2060-80: ↑3 to 5°C			https://www.esrl.noaa.gov/psd/ipcc/ocn/ Saba *et al.* 2016. doi.1002/2015JC011346/full
Precipitation	↑	2050-2099: ↑120 to 160 mm	Larger ↑ in the north		https://www.esrl.noaa.gov/psd/ipcc/ocn/ https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp
Ocean bottom temperature	↑	2050-2099: ↑2.5°C 2060-80: ↑3 to 6°C			https://www.esrl.noaa.gov/psd/ipcc/ocn/ Saba *et al.* 2016. doi.1002/2015JC011346/full
Sea surface pH (ocean acidification)	↓	2050-2099: ↓0 to 0.28			https://www.esrl.noaa.gov/psd/ipcc/ocn/
Sea surface salinity	No Δ to ↓	2050-2099: ↓0 to 0.2 psu	↓ mid-Maine northward		https://www.esrl.noaa.gov/psd/ipcc/ocn/
Air temperature	↑	2050-2099: ↑4 to 5°C	Larger ↑ in the north		https://www.esrl.noaa.gov/psd/ipcc/ocn/ https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp
Ice affected stream flow	↓	1936-2000: ↓20 days			Hodgkins *et al.* 2005. doi:10.1007/s10584-005-5926-z
Snow pack (storage)/Annual mean snow	↓	2075-2099: ↓0 to 80 mm	Biggest ↓ along mountain ridges and peaks, ↓ also to the north, smaller ↓ along coast		https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp
Stream flow (discharge)/Annual mean runoff	↓ to No Δ	2075-2099: ↓0 to 15 mm/month (full range), but general change is ↓0 to 7 mm/month with much of the southern 2/3 of Maine mostly 0 mm/month.	Greater ↓ to the north, little change closer to the coast		https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp Demaria *et al.* 2016a doi.org/10.1175/JCLI-D-15-0632.1 Demaria *et al.* 2016b doi.org/10.1016/j.ejrh.2015.11.007
Seasonality of stream flow	Changes in seasonality and timing of peak	Increases in late fall-winter (but sign and magnitudes differ with model)	Changes in seasonality of peak and		Neff *et al.* 2000 http://www.int-res.com/articles/cr/14/c014p207.pdf Tu 2009. doi:10.1016/j.jhydrol.2009.10.009

Climate/Physical Variable	Expected General Change	Specified Change Expected and Reference Period	Patterns of change	Confidence	Primary Source and Context
	flows; early winter spring snowmelt-related streamflow runoff largely a function of air temperature in the northeast (Dudley *et al.*, 2017); anticipated increases in air temperature should drive earlier snowmelt-related runoff during winter/spring (i.e. generally higher winter flows and lower spring flows)		timing of peak flows		Dudley *et al.* 2017. doi.org/10.1016/j.jhydrol.2017.01.051
Stream temperature as a function of air temperature					NE-specific stream temperature projections? http://northatlanticlcc.org/teams/coastal-resiliency/projects/hurricane-sandy/impacts-of-climate-change-on-stream-temperature/impacts-of-climate-change-on-stream-temperature
changes in surface water runoff and ground water discharge and its affects on stream flow and temperature					
Extreme Events: i) Temperature	↑ warm events, ↓ cold events				
ii) Precipitation	↑				
iii) Storms	↑				
Sediment transport	↑				Yellen *et al.* 2016 doi: 10.1002/esp.3896 Cook *et al.* 2015 doi:10.1002/2015GL064436.
Water quality			eutrophication (algae blooms)		

Climate/Physical Variable	Expected General Change	Specified Change Expected and Reference Period	Patterns of change	Confidence	Primary Source and Context
			in fresh and salt water, low dissolved oxygen		

Appendix 7. Non-climate (biological, social, political, economic and technological) drivers table. Note: This table lists those drivers initially considered for this scenario planning exercise.

Biological, social, political, economic, technological	**Projected change (if applicable)**	**Source and context**	**Comments**
Freshwater habitat availability	Very uncertain	http://ice.ecosheds.org/; http://db.ecosheds.org/viewerhttp://db.ecosheds.org/viewer; Dan Kircheis' powerpoint; Atlantic salmon designated critical habitat. http://www.nmfs.noaa.gov/pr/pdfs/criticalhabitat/atlanticsalmon.pdf	This variable incorporates many rows (predator/ prey; competition; dams/ dam removal; incidental take; and even hatcheries). Dan Kircheis has current habitat availability and historic freshwater availability for Maine.
Marine habitat availability	Very uncertain	Todd et al 2012; Friedland *et al.* 2003	Negative correlations for growth and post-smolts survival and warmer waters in NW Atlantic
Societal awareness and concern for issue			
Species climate vulnerability	↓	Hare *et al.* 2016 http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0146756	Very high for biological sensitivity and exposure
Rate and magnitude of greenhouse emissions			
Leadership (local, state, national, international)			
Budgets (for science, management)			"Management" should include conservation hatcheries
Urban development			
Fisheries			Relevant to marine stages
Predator/prey dynamics (biological)			Relevant to all life stages
Competition (biological)			
Dams / dam removal			Including FERC relicensing of hydropower projects (This may be duplicative with 1)
Permitted incidental take			e.g., Section 7 consultations for projects and research with permitted take; bycatch (this may be duplicative with 1)
Illegal take			e.g, poaching (may be duplicative with #1)
Chemical use	↑		e.g., increase in use of pesticides and herbicides for pest control: urban, agricultural and forestry environments
Water withdrawals	↑		e.g., withdrawals during low flow periods and droughts for irrigation, drinking and process water
Hatchery Production	↓		This should not be a major part of this exercise but the fact that 80% plus of returns come from conservation hatcheries needs to be reinforced.

Appendix 8. Other relevant data sources compiled by participants.

Data Type/Description	Source
Northeast Ocean Data	http://www.northeastoceandata.org/
State of Rivers and Dams in Maine	https://wiki.colby.edu/display/stateofmaine2009/State+of+Rivers+and+Dams+in+Maine
Maine GIS Data	http://www.maine.gov/megis/catalog/
NE Coastal Acidification	http://necan.org/
National Climate Change Viewer (USGS)	https://www2.usgs.gov/climate_landuse/clu_rd/nccv.asp

Appendix 9. Workshop presentation summaries and slides.

Summaries and slides of the presentations given during the workshop are below. To request a copy of a specific presentation, please contact Diane Borggaard (diane.borgaarrd@noaa.gov or 978-282-8453) or Dori Dick (dori.dick@noaa.gov or 301-427-8430).

Overview of Scenario Planning:

Jonathan Star (Scenario Insights) provided a reminder of scenario planning (Appendix 1) which included information from the manuscript introduction (e.g., the five steps as outline in the NPS Handbook; Appendix 3). This pilot considered two main uncertainties but there are many changes (e.g., populations of Maine, technology, hatcheries) happening in the world around these that can be considered. Although this pilot is looking out 75 years, it can also help look at a shorter time frame (e.g., 1-5 years) which will also be considered in this pilot.

Overview of Recovery Plan:

Dan Kircheis (NMFS) noted that Atlantic salmon are listed as endangered in the United States under the ESA and in Canada under the Species At Risk Act. The Gulf of Maine includes the last U.S. population; other areas such as central New England and Long Island Sound have been extirpated. The Gulf of Maine Distinct Population Segment includes three salmon habitat recovery units or SHRUs (Penobscot Bay, Merrymeeting Bay and Downeast Coastal). Major threats impeding their recovery include connectivity (dams and road crossings), marine survival (climate change, fishing) and culmination of other threats (e.g., freshwater habitat degradation, aquaculture, hatchery practices). There are many factors that led to the Atlantic salmon’s decline. Dams and marine survival are the biggest threats. The draft recovery plan identifies and addresses threats and workshop plans contain more specific actions by SHRU. There is some acknowledgement of climate change in the draft recovery plan (e.g., about 10%of the action implicitly address climate change). The draft recovery plan is currently available and additional actions could be incorporated based on the outcomes of this meeting. Critical Habitat was designated in 2009 whereby climate change was not taken into account.

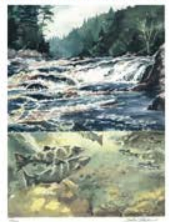
1

Atlantic Salmon Recovery Plan

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

U.S. Department of Interior Fish and Wildlife Service
Ecological Services and Fisheries (Lead)

Recovery Plan for the
Gulf of Maine Distinct Population
Segment of
Atlantic Salmon (*Salmo salar*)



2

ASF.CA

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3

US Atlantic Salmon Stock Structure

Outer Bay of Fundy DU
- Designatable Unit - Core in Canada
- Endangered under SARA

Gulf of Maine
- Last Remnant US Populations
- Endangered
- Nearly extirpated early 1900's

Central New England
- Merrimack Restoration ended 2010
- Extirpated mid-1800's

Long Island Sound
- Connecticut River (Legacy Program)
- Extirpated early 1800's

4

Current U.S. Range:

3 Salmon Habitat Recovery Units (SHRU's)

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5

Critical Habitat

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6

Factors that lead to their initial decline

- Dams
- Overfishing
- Pollution

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7

Major Threats Impeding their Recovery:

Connectivity

- Dams
- Road crossings

Marine Survival

- Fish are dying at sea of which climate change is at least part of this equation
- Fishing at sea

Culmination of other threats

- E.g. freshwater habitat degradation, aquaculture, hatchery practices, etc…

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8

Recovery Goal: (Delisting)

Abundance:

- Minimum of 2,000 wild adults in each SHRU

Productivity:

- growth rate of greater than 1.0 in the 10-year (two-generation) period preceding delisting
- Less than a 50-percent probability of falling below 500 adult wild spawners in the next 15 years.

Habitat:

- A minimum of 30,000 accessible and suitable HUs in each SHRU

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9

Phased Approach to recovery:

each Action in the plan is linked to a recovery phase

4 phases of recovery:

1. ID threats and characterize habitat requirements (1990 – 2006) (what's wrong?)
2. Ensure the species survival and abate imminent threats to their continued existence (2006 – present) (stop the bleeding)

Linked to down listing criteria

3. Increase abundance, distribution, and productivity. Transition from hatchery dependence, to self sustaining. (enable healing)

Linked to de-listing criteria

4. Self sustaining population – Mechanisms are in place the prevent or abate all foreseeable threats to the long-term survival of the species (prevent it from happening again)

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10

Threats abatement Criteria for Reclassification: (Climate Change)

- A water quality monitoring program is established to track climate change trends and effects on: (a) freshwater, estuarine, and marine habitats, and (b) salmon health. This program includes adaptive management strategies to mitigate or protect salmon from any harmful effects associated with climate change.
- Freshwater areas that have greater resilience to climate change are identified, quantified, and incorporated into recovery goals and actions.

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11

Threats Abatement Criteria for Delisting

- Sufficient data, data collection tools, and predictive models are in place to allow for accurate forecasting of climate conditions as they relate to Atlantic salmon survival in freshwater and marine environments
- Robust predictive models and appropriate actions are incorporated into Atlantic salmon management and regulatory mechanisms.
- Climate resilient habitats are identified and incorporated into management measures

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12

Recovery Actions

- Site Specific Actions in the recovery plan are scaled to the SHRU. The SHRUs constitute the geographic scale in which recovery progress will be measured and adaptive management will be applied.
- SHRU-level workplans identify activities that should be implemented in the short term that address the plan's recovery actions. Although these workplans link back to the recovery plan, they are not considered part of the plan itself.

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13

Recovery Actions

- 72 Recovery actions
- About 10% of the actions implicitly address climate change. These actions include removing barriers to fish passage; increased monitoring of stream temperatures; additional science and monitoring to identify threats in the estuary and marine environment

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14

Workplans

OVERARCHING THREATS WITHIN THE PENOBSCOT SHRU	THREAT NUMBER	RECOVERY ACTIVITY
Climate change has, and will likely continue to change the spatial landscape of habitats most suitable for Atlantic salmon. Throughout the basin there are areas that may be more vulnerable to climate change and may become less suitable for Atlantic salmon, while other areas may be more resilient and warrant greater protection.	PBS1.0	Remove all fish passage impediments (dams, culverts, remnant dams) to allow salmon to find and use areas of cold water refuge on timescales that they deem necessary.
		Identify and protect habitat areas throughout the basin that may have higher resilience to climate change, particularly warming
		Develop outreach material to articulate the impacts of climate change on aquatic ecosystems and the mechanisms to combat it
		Evaluate and implement Best Management Practices for agriculture and forest lands that may help offset the effects of warming

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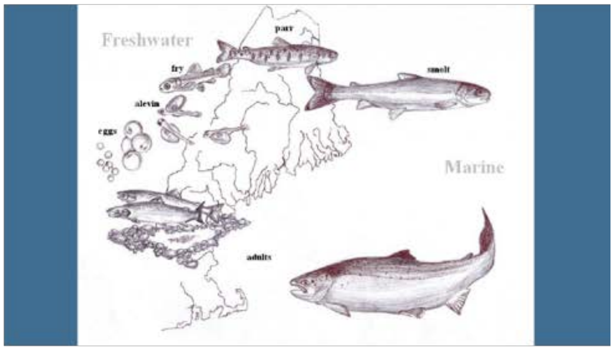
Basic background on the biology (including temperature tolerances) and distribution of Atlantic salmon:

Freshwater:

Dan Kircheis (NMFS) discussed what Atlantic salmon need in freshwater. He noted that important freshwater habitat features include suitable temperature (e.g., ~0-27.5 °C based on literature), flow (e.g., meets oxygen demands and stimulus for migration) as well as others (e.g., space for feeding and sheltering). Dan noted the seasonality of Atlantic salmon in freshwater, estuary and marine emphasizing that they are found everywhere all the time. Water temperature preferences were provided for various behaviors (e.g., migration) and stages (e.g., smolts) based on literature; temperature is the number one limiting factor that determines the latitudinal range. The smolt migration window typically falls between April 15-June 10. A number of climate related factors including water temperature, stream flow, and water chemistry can directly or indirectly effect smolt survival during this migration period. Dan also noted that flow influences salmon (e.g., low summer flows results in less space and more competition) however, there are uncertainties such as how much flow influences emigration. Flow and temperature interactions are important.

1

2



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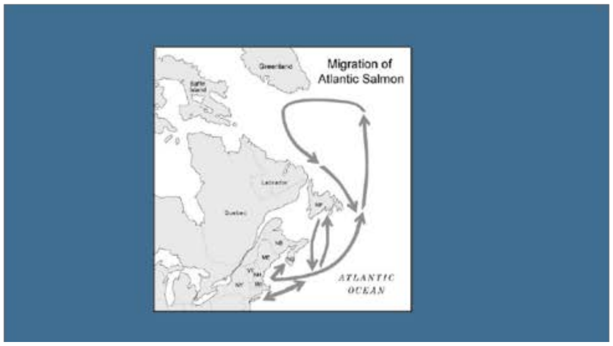

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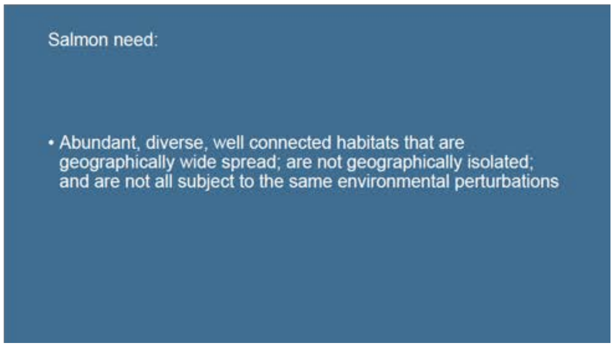


5

Important freshwater habitat features

Temperature:

- Atlantic salmon are poikilothermic with an upper and lower minima/maxima for survival ranging from ~0 °C to 27.5 °C (Garside 1973; Elliot 1991). The upper temperature threshold is a function of oxygen availability.

Flow:

- Atlantic salmon's oxygen demands for all life stages is high. Flowing water helps meet these demands.
- Moving water is a stimulus for both upstream and downstream migration
- The speed of downstream migrating smolts is influenced by flow
- Flow variability helps maintain habitat diversity

6

Others:

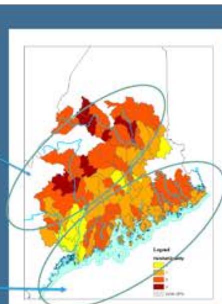
- Space for feeding and sheltering
- Habitat diversity (many different options)
- Clean, well oxygenated water
- Diverse communities of native fish that salmon co-evolved with and are likely dependent on

7

Where are these habitats?

Higher elevation, higher gradient, more diverse freshwater habitats containing long stretches of riffles and fewer deadwaters

lower elevation, lower gradient, more homogenous habitats containing low gradient riffles divided by long stretches of deadwater.



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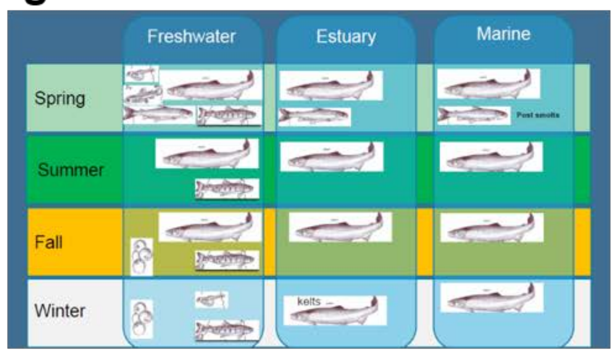

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Water Temperature:

- #1 limiting factor that occurs in nature that determines the latitudinal range of the species.
- minima/maxima for survival ranges from ~0 °C to 27.5 °C (Garside 1973; Elliot 1991).
- Salmon can and do move and will seek out cooler waters if water temperatures exceed their range of tolerance for feeding and survival (Cunjak *et al*., 2005).

10

Water Temperature – Feeding and growth

- The lower and upper temperature limits for growth are ~ 6.0 and 22.5 °C (Elliott and Hurley, 1997)
- Optimal growth between 15 – 19 °C. (Decola 1970).
- Most growth occurs in the spring and fall.

11

Temperature – Smolts (April 15 – June 10)

- Temperature has a role in the timing of smolting by affecting the rate of development and interacting with the photoperiod (McCormick et al. 2002).
- Downstream movement of smolts typically peaks when water temperatures range from 8 to 10 °C (Whalen *et al.* 1999; and *summarized in* McCormick et al. 1998).
- Smolts loose their ability to transition into salt water the longer they spend in freshwater. The window of opportunity shortens with higher water temperatures. There is an 80% loss of enzyme activity (which is equivalent to parr levels) 400 degree-days after the peak of enzyme activity in smolts (McCormick et al. 1999).

12

Adult Migration: Temperature

- Reduced activity: ~ 20 – 23 °C (Danie et al. 1984; Shepard, 1995; Hawkins, D., 1989)
- Indirect lethal: 20 – 27 °C
- Lethal: >27 °C
- Need access to areas with cool water.

13

Temperature – spawning adults

- spawning period of Atlantic salmon was found to be complete in 7–10 days at a water temperature that ranged from 8.3 to 10.5 °C at the onset of the spawning activity (Beland et al., 1982)

14

Temperature: Embryo and larval fry (November – April)

- The incubation period ranges from 100 days at 5 °C to 50 days at 10 °C
- Upper Limit: 10 °C (Decola 1970)
- Excessive mortality of eggs and sac fry when temps are at or near 10 °C. (Decola 1970)

15

What do we know about flow?

- Flow does influence the speed in which smolts emigrate.
- Low summer flows = less space = more competition
- High fall flows followed by low winter flows can cause some redds to dry up or freeze
- Rain on snow events can push the icepack onto the stream bed that can effect juvenile survival.
  - More diverse substrates are less vulnerable.
- Mid-winter ice outs can scour out redds
- Rick Cunjak is a leading expert on flow and overwinter survival related to Atlantic salmon

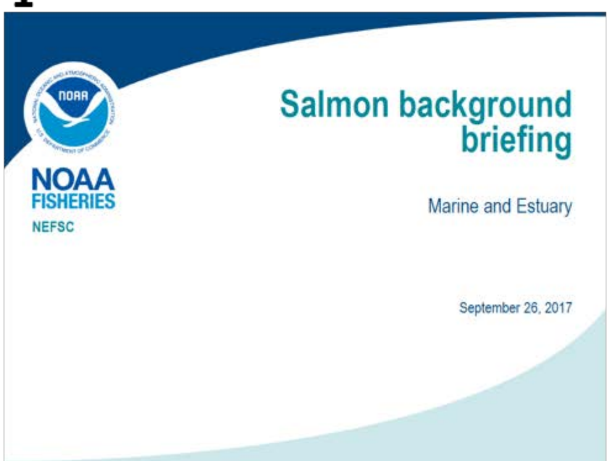
16

- Cunjak, R.A., Roussel, J.-M., Gray, M.A., Dietrich, J.P., Cartwright, D.F., Munkittrick, K.R. & Jardine, T.D. (2005) Using stable isotope analysis with telemetry or mark-recapture data to identify fish movement and foraging. Oecologia, 144, 636–646.
- Danie, D., J. Trial, J. Stanley, L. Shanks, and N. Benson. 1984. Species profiles: life histories and environmental requirements of coastal fish and invertebrates (North Atlantic): Atlantic salmon. USFWS, report FWS/OBS-82/11.22
- Decola, J. N. 1970. Water quality requirements for Atlantic salmon, US Department of the Iinterior. Federal Water Quality Administration, N.E., Region, Boston, Mass. 42 pp.
- Elliott, J. M. 1991. Tolerance and resistance to thermal stress in juvenile Atlantic salmon, *Salmo salar*. Freshwater Biology. 25: 61-70
- Elliott, J. M., and M. A. Hurley. "A functional model for maximum growth of Atlantic salmon parr, Salmo salar, from two populations in northwest England." *Functional Ecology* 11.5 (1997): 592-603.
- Garside, E. T. "Ultimate upper lethal temperature of Atlantic salmon Salmo salar L." Canadian Journal of Zoology 51.8 (1973): 898-900.
- Hawkins, A. D. (1989). Factors affecting the timing of entry and upstream movement of Atlantic salmon in the Aberdeenshire Dee. In Salmon and Trout Migratory Behaviour and Dispersal Symposium (Brannon, E. & Jonsson, B., eds), pp. 100–105. Seattle, WA: School of Fisheries, University of Washington.
- McCormick, S.D., J.M. Shrimpton, S. Moriyama, and B.T. Bjornsson. 2002. Effects of an advanced temperature cycle on smolt development and endocrinology indicate that temperature is not a zeitgeber for smolting in Atlantic salmon. Journal of Experimental Biology. 205: 3553-3560
- McCormick, Stephen D., et al. "Movement, migration, and smolting of Atlantic salmon (Salmo salar)." Canadian Journal of Fisheries and Aquatic Sciences 55.S1 (1998): 77-92.
- McCormick, Stephen D., et al. "Temperature-related loss of smolt characteristics in Atlantic salmon (Salmo salar) in the wild." Canadian Journal of Fisheries and Aquatic Sciences 56.9 (1999): 1649-1667.
- Shepard, S.L. 1995. Atlantic Salmon Spawning Migrations in the Penobscot River, Maine: Fishways, Flows and High Temperatures. M.S. Thesis. University of Maine. Orono, ME. 112pp.
- Whalen, Kevin G., Donna L. Parrish, and Stephen D. McCormick. "Migration timing of Atlantic salmon smolts relative to environmental and physiological factors." Transactions of the American Fisheries Society 128.2 (1999): 289-301.

Marine and estuarine:

Tim Sheehan (NMFS) gave an overview of the estuarine and marine stages of Atlantic salmon. He described the historic marine range of Atlantic salmon (Long Island Sound north to Greenland and from Northern Portugal to the Barents Sea). He described the various sources of information pertaining to the marine life stage of Atlantic salmon. Marine survey data are mostly from DFO (1965-2009), marine tag recoveries of U.S. origin fish have occurred along the coast of North America and western Greenland (1963-1992), and more recently (1996-present) tracking studies have occurred in U.S. coastal waters (acoustic tracking) and along the coast of West Greenland/ Labrador Sea (pop-off satellite tags). Tim also provided an overview of the different life stages of marine Atlantic salmon, their assumed location in time and space, and their preferred habitat characteristics. One identified need is to pull together a more formal compilation of all available information to help identify gaps.

1



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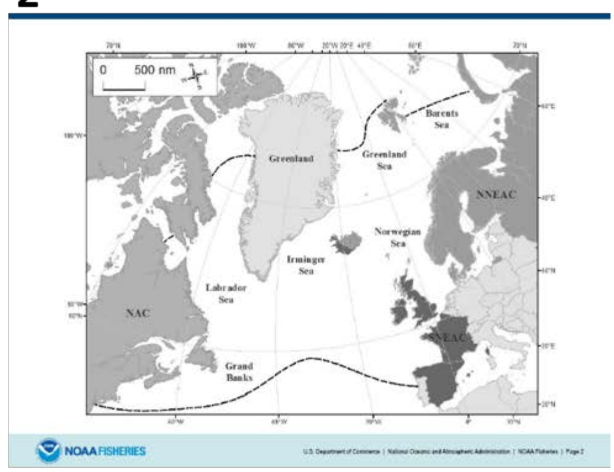

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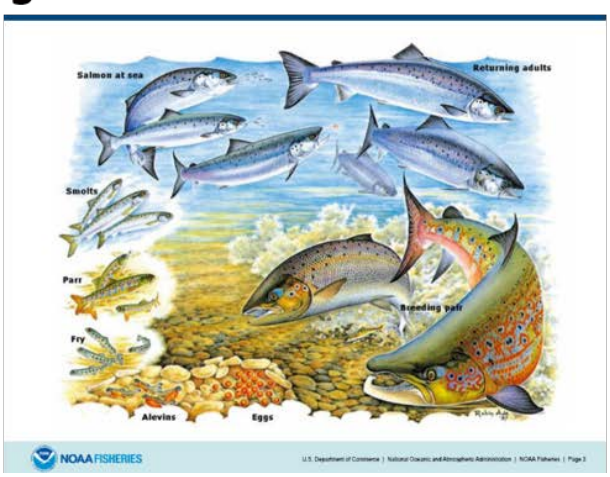

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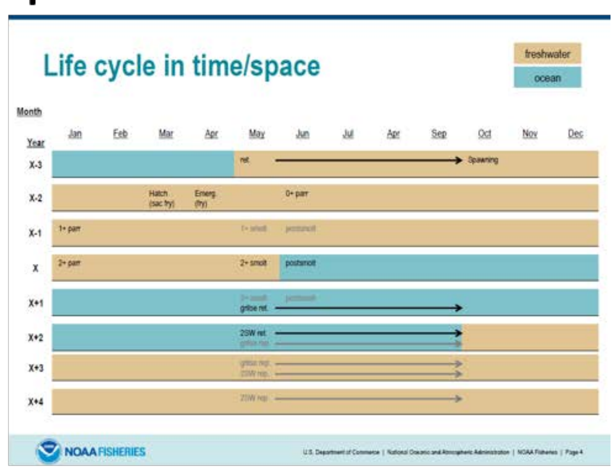

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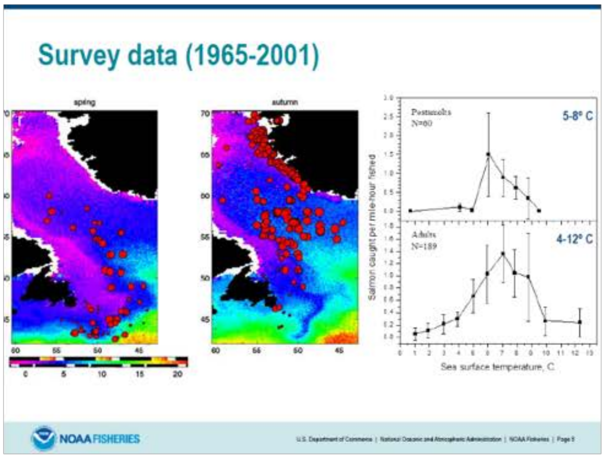
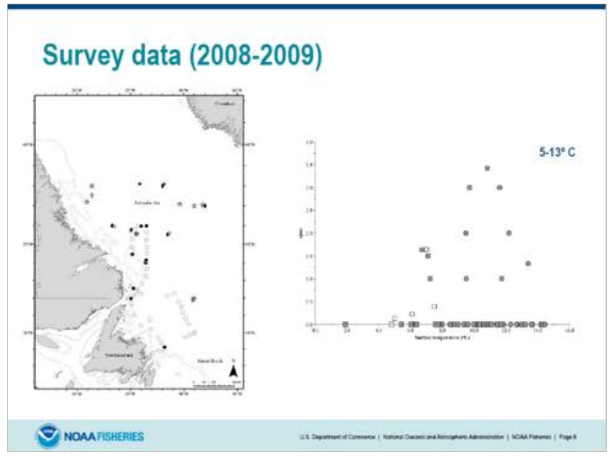
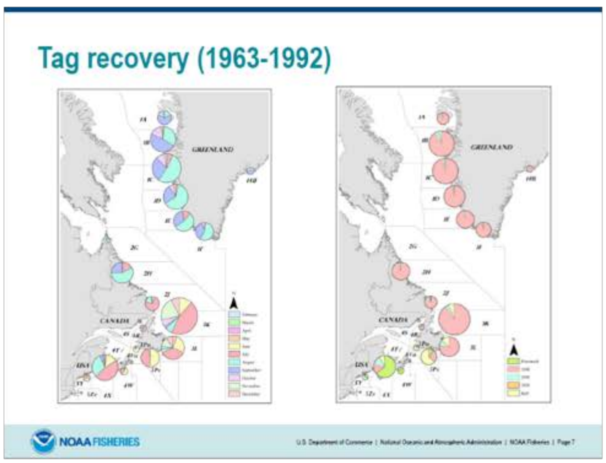

Survey data (1965-2001)
spring
autumn
Postsmolts
N=60
5-8° C
Adults
N=189
4-12° C
Salmon caught per mile-hour fished
Sea surface temperature, C
NOAA FISHERIES

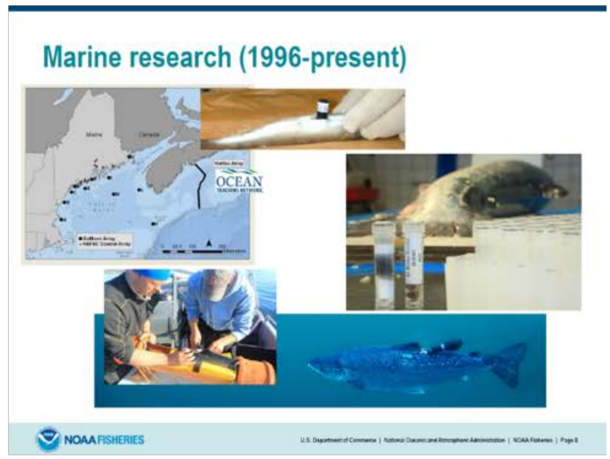
6


Survey data (2008-2009)
5-13° C
NOAA FISHERIES

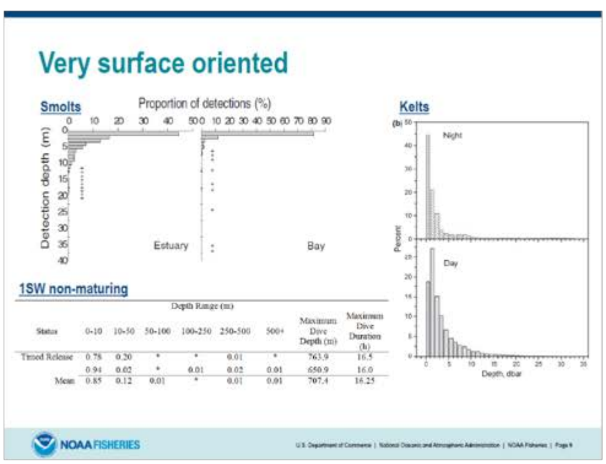
7


Tag recovery (1963-1992)
GREENLAND
CANADA
NOAA FISHERIES

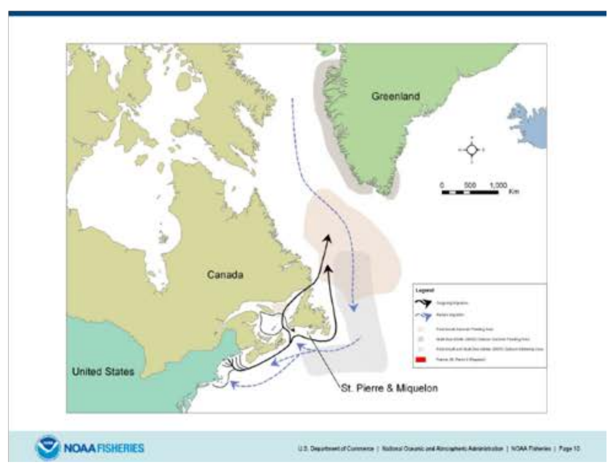
8


Marine research (1996-present)
OCEAN
NOAA FISHERIES

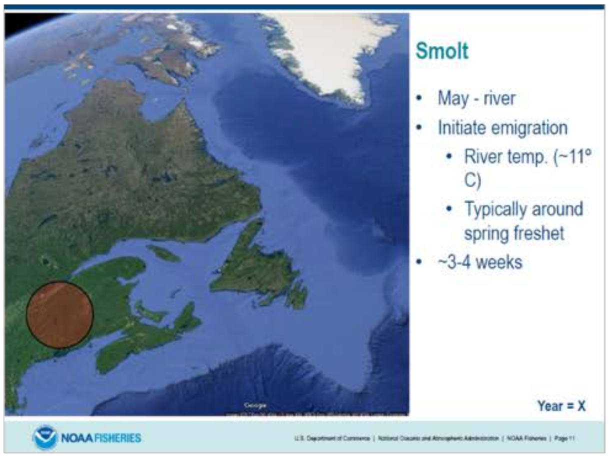
9


Very surface oriented
Smolts
Proportion of detections (%)
Detection depth (m)
Estuary
Bay
Kelts
Night
Day
Percent
Depth, dbar
1SW non-maturing
Depth Range (m)
Status
0-10
10-50
50-100
100-250
250-500
500+
Maximum Dive Depth (m)
Maximum Dive Duration (h)
Timed Release
Mean
NOAA FISHERIES

10


Greenland
Canada
United States
St. Pierre & Miquelon
Legend
NOAA FISHERIES

11



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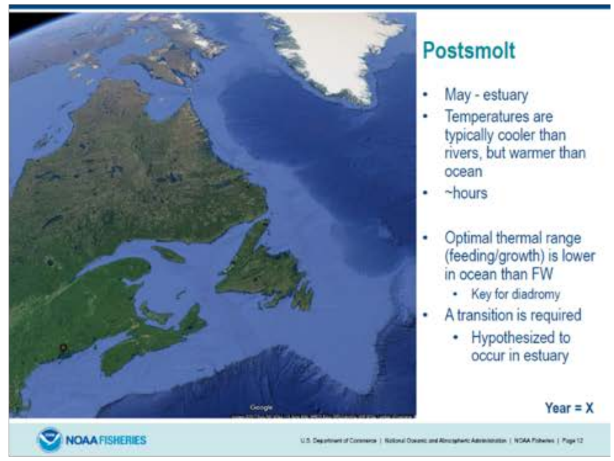

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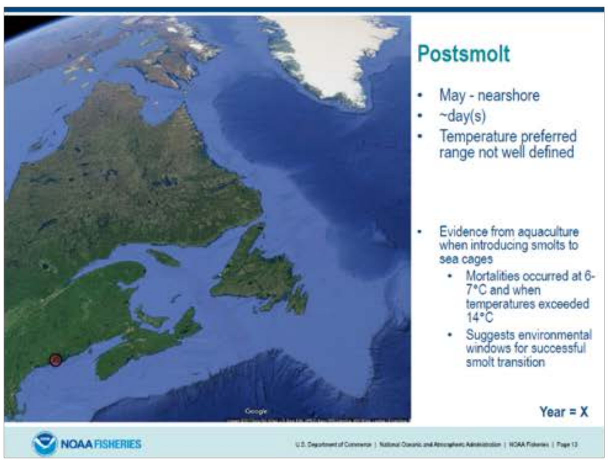

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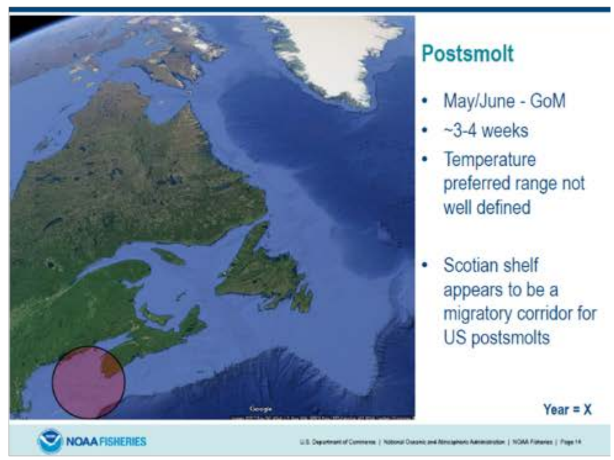

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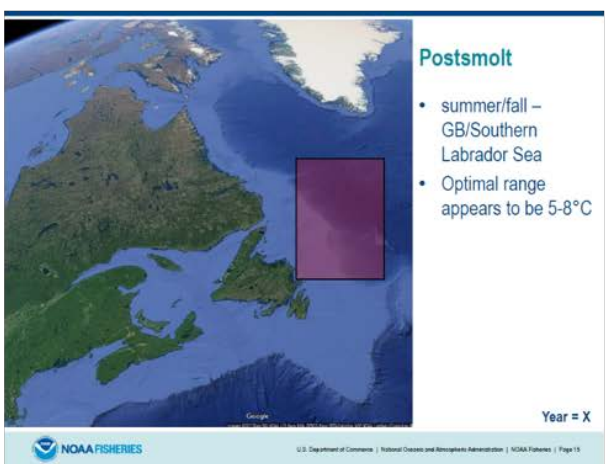

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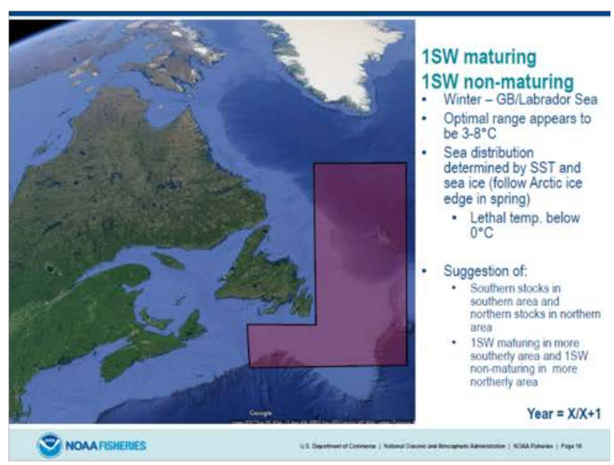

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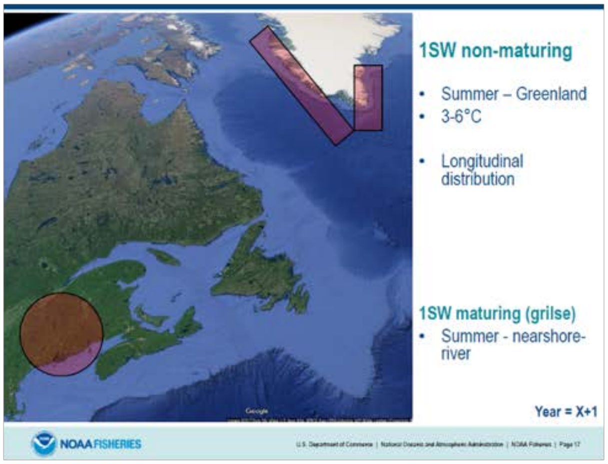
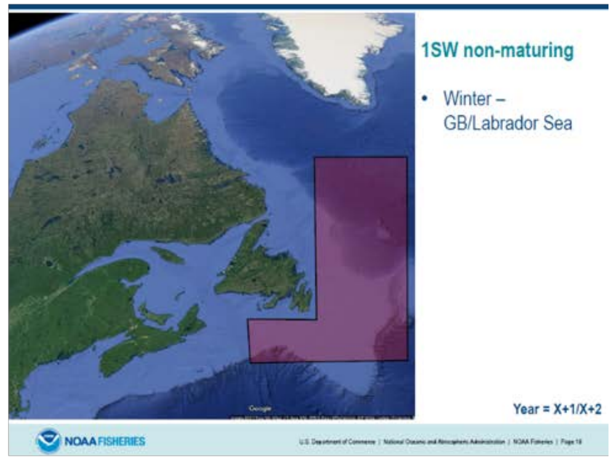
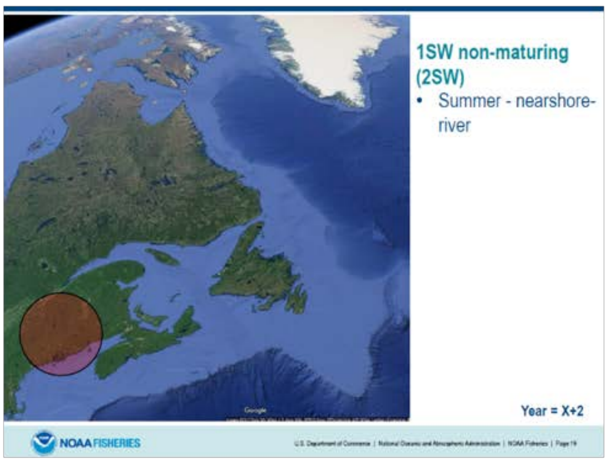

1SW non-maturing
Summer – Greenland
3-6°C
Longitudinal distribution
1SW maturing (grilse)
Summer - nearshore-river
Year = X+1
NOAA FISHERIES

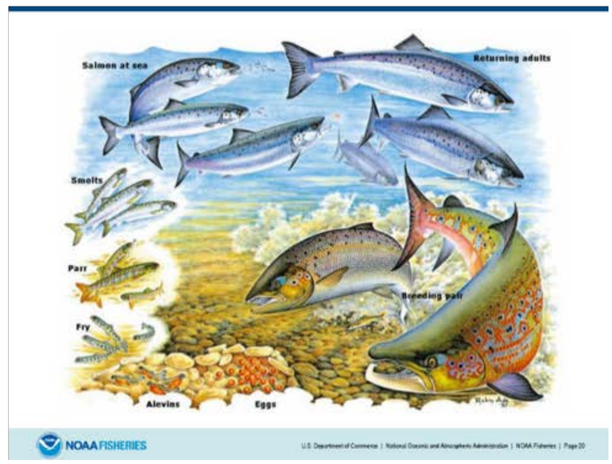
18


1SW non-maturing
Winter – GB/Labrador Sea
Year = X+1/X+2
NOAA FISHERIES

19


1SW non-maturing (2SW)
Summer - nearshore-river
Year = X+2
NOAA FISHERIES

20


Salmon at sea
Returning adults
Smolts
Parr
Fry
Breeding pair
Alevins
Eggs
NOAA FISHERIES

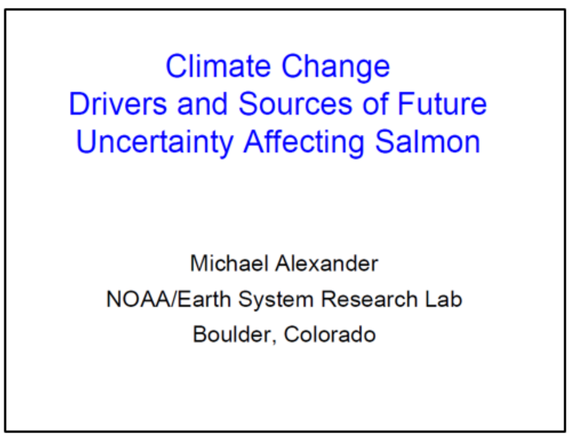
Drivers of Change:

This included presentations to outline research on the climate drivers and sources of future uncertainty affecting salmon.

<u>Climatic/physical drivers (temperature, precipitation, streamflow, etc.):</u>

Mike Alexander (ESRL) noted that in the North Atlantic, sea surface temperature (SST) is warming but not uniformly and this warming may be especially large in the Gulf of Maine. The surface-intensified ocean warming and freshening (north of ~45°N) increases stratification. Over land in New England, there is strong warming and enhanced precipitation mainly in fall and winter but precipitation is variable so there could be dry periods. The area is predicted to be warm so there is enhanced evapotranspiration. Thus, there is less water in rivers than we might anticipate. Early snow melt and runoff (river flow) is also predicted. There is less warming or even cooling in some model simulations off Greenland, due to a slowing of the Atlantic Meridional Overturning Circulation. Recent research by Saba *et al.* (2016) indicates an enhanced, non-uniform warming in the Gulf of Maine. When considering climate change there are many sources of uncertainty (e.g., forcing such as greenhouse gases, model response (e.g., model sensitivity) and internal (natural) variability. For example, all models show warming but there is strong variability and it is important to consider natural variability as well. The climate change signal is stronger later in the 21st century.

1



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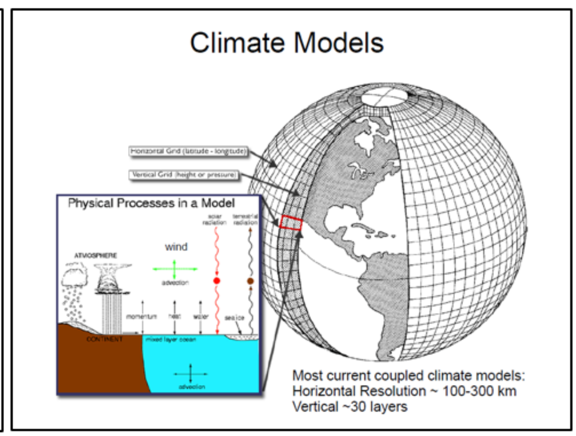

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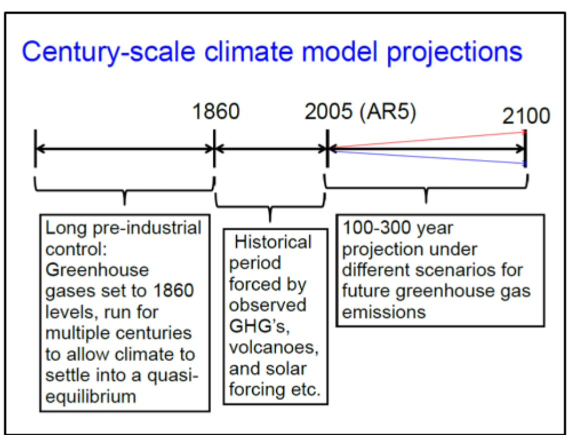

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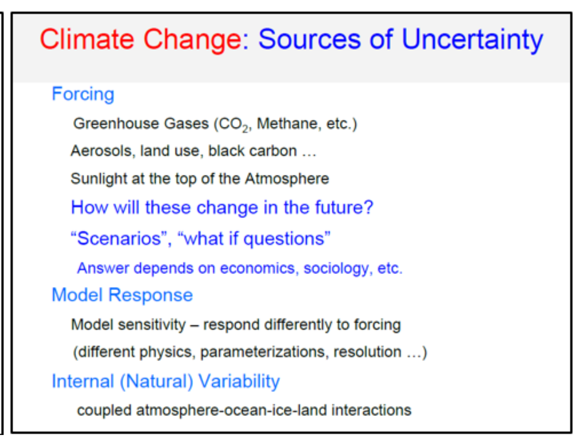

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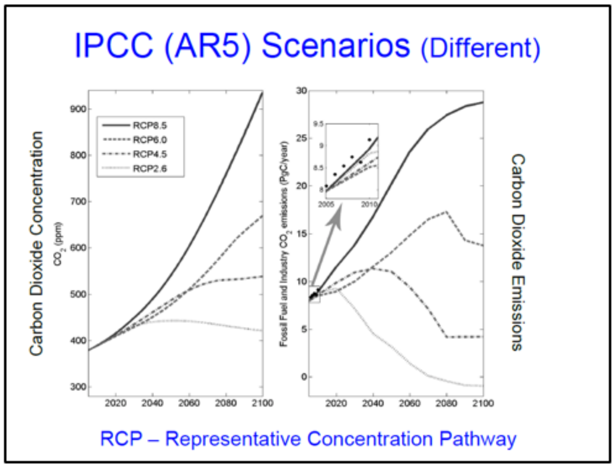
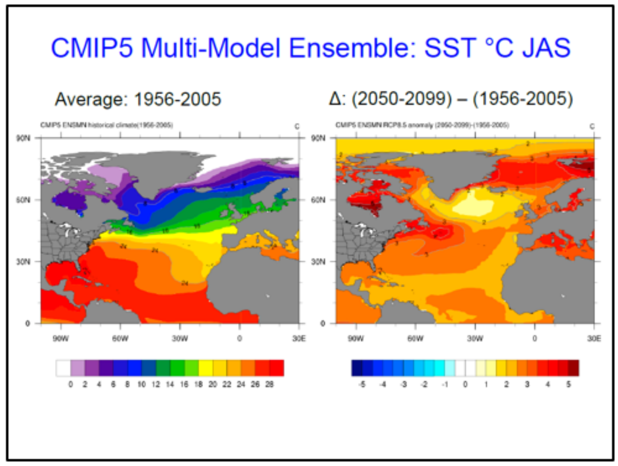
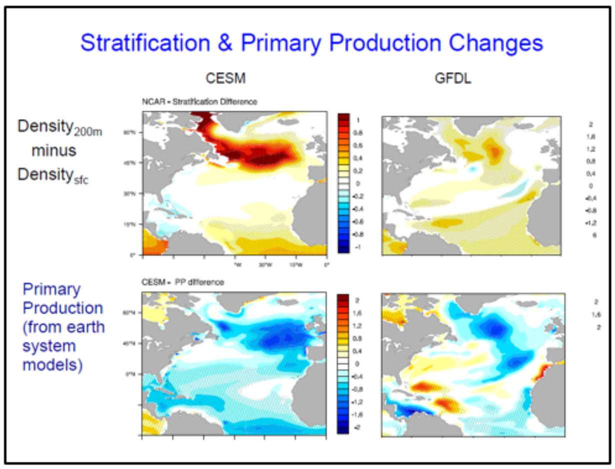

IPCC (AR5) Scenarios (Different)
Carbon Dioxide Concentration
Carbon Dioxide Emissions
RCP8.5
RCP6.0
RCP4.5
RCP2.6
RCP – Representative Concentration Pathway

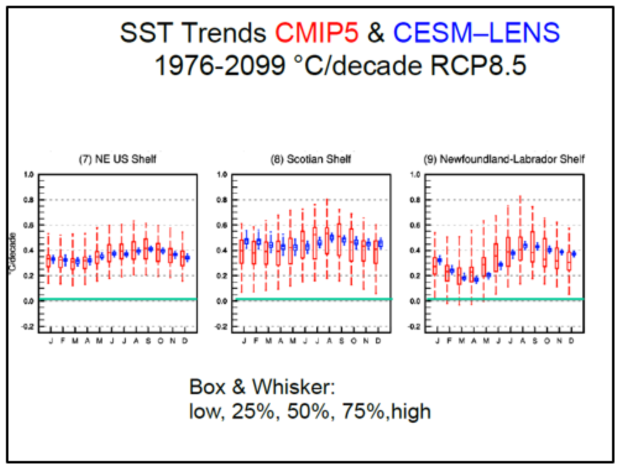
6


CMIP5 Multi-Model Ensemble: SST °C JAS
Average: 1956-2005
Δ: (2050-2099) – (1956-2005)

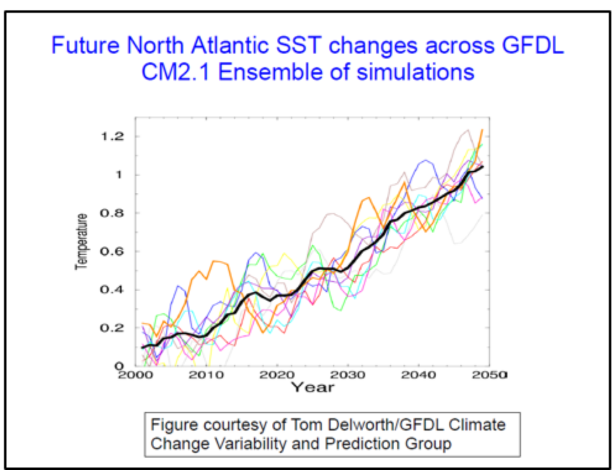
7


Stratification & Primary Production Changes
CESM
GFDL
Density200m minus Densitysfc
Primary Production (from earth system models)

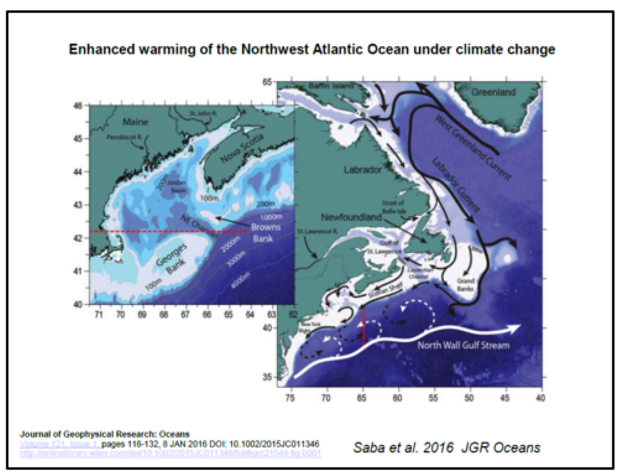
8


SST Trends CMIP5 & CESM–LENS
1976-2099 °C/decade RCP8.5
(7) NE US Shelf
(8) Scotian Shelf
(9) Newfoundland-Labrador Shelf
Box & Whisker:
low, 25%, 50%, 75%,high

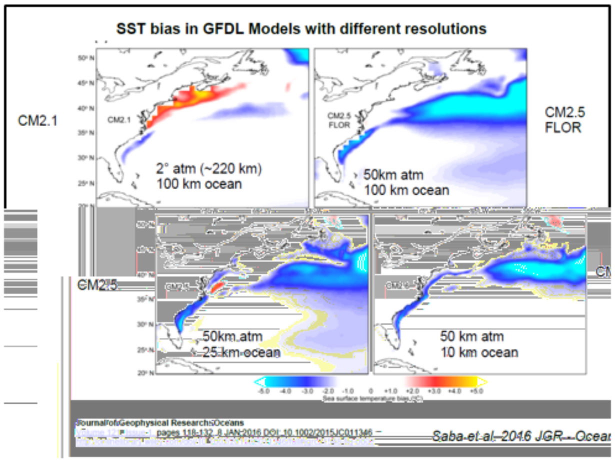
9


Future North Atlantic SST changes across GFDL CM2.1 Ensemble of simulations
Temperature
Year
Figure courtesy of Tom Delworth/GFDL Climate Change Variability and Prediction Group

10


Enhanced warming of the Northwest Atlantic Ocean under climate change
Greenland
Labrador
Newfoundland
Maine
Nova Scotia
Georges Bank
North Wall Gulf Stream
Journal of Geophysical Research: Oceans
Saba et al. 2016 JGR Oceans

11



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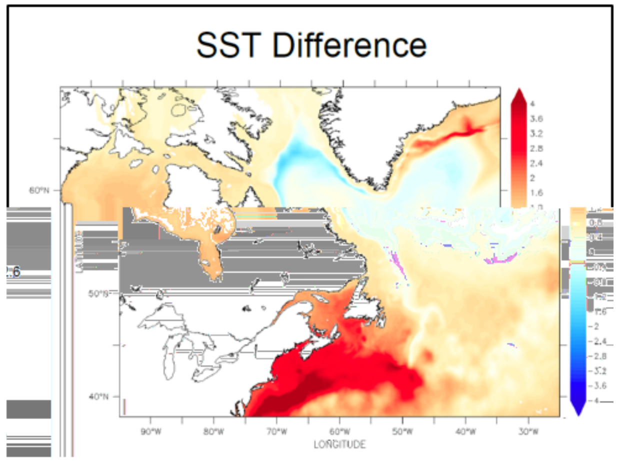
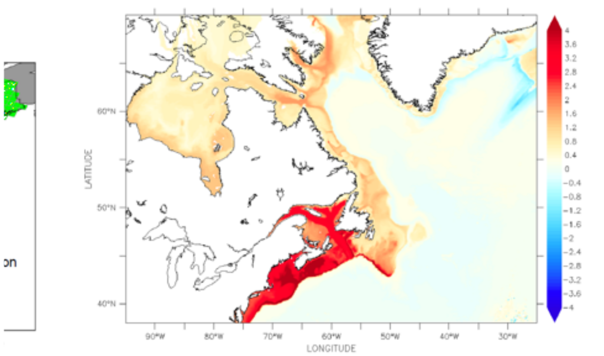
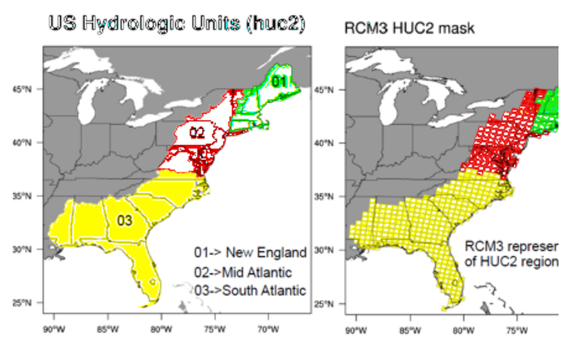


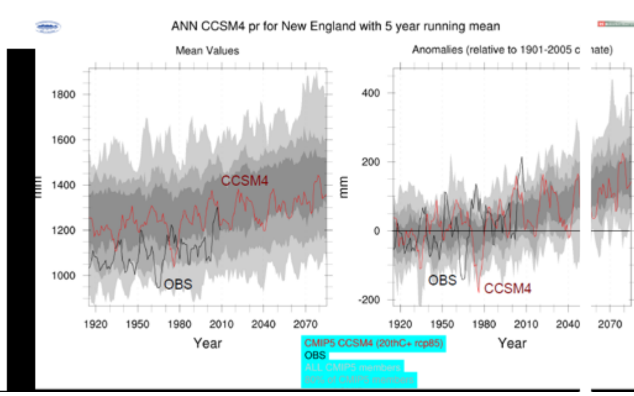
Bottom Temperature Difference CM2.6



Regional Watersheds



Precipitation New England RCP8.5



Regional Climate Change

Most Global Climate models (GCM) currently have a course resolution (on the order of 100-200 km)

One method to obtain higher resolution is through Dynamical Downscaling

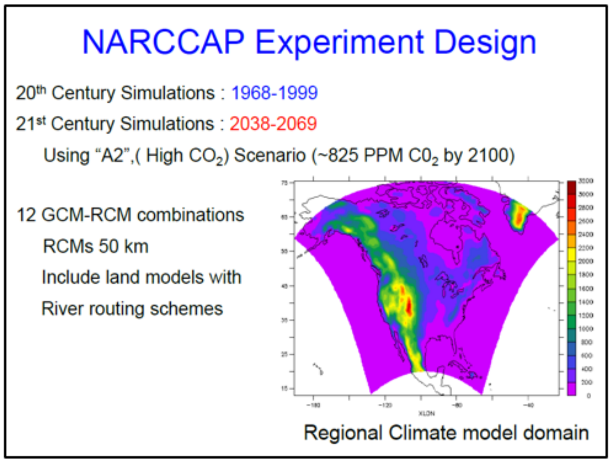
Use finer scale physical models in a region where boundary conditions are provided by GCMs

(or observations for the past)

North American Regional Climate Change Assessment Program (NARCCAP)

Uses multiple climate models with multiple regional atmospheric models to simulate climate change over North America at 50 km resolution

17



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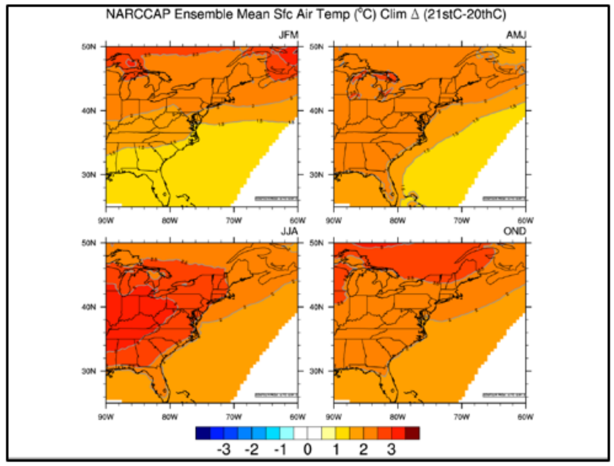

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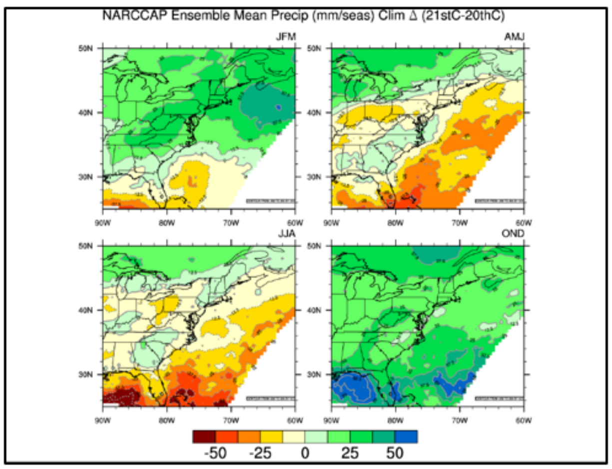

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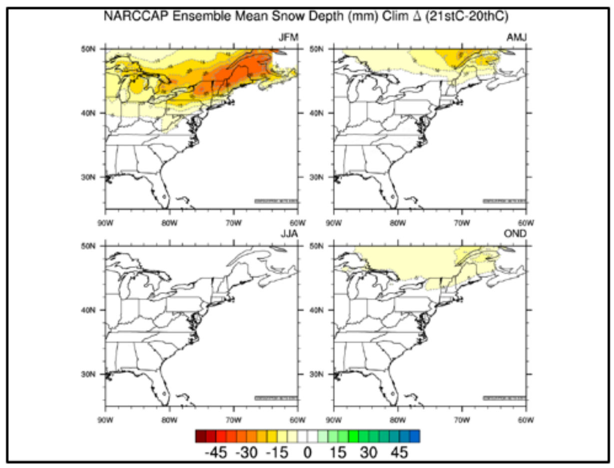

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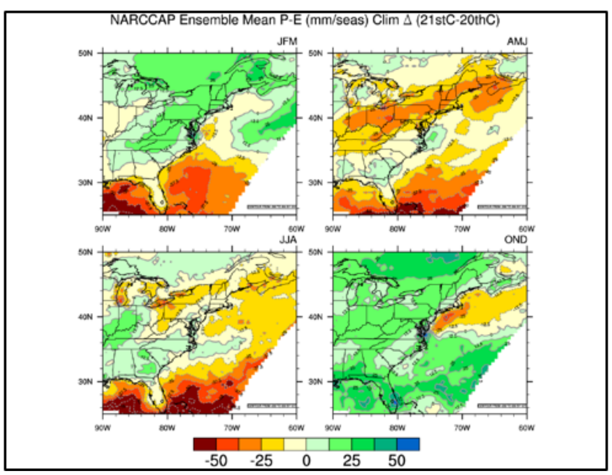

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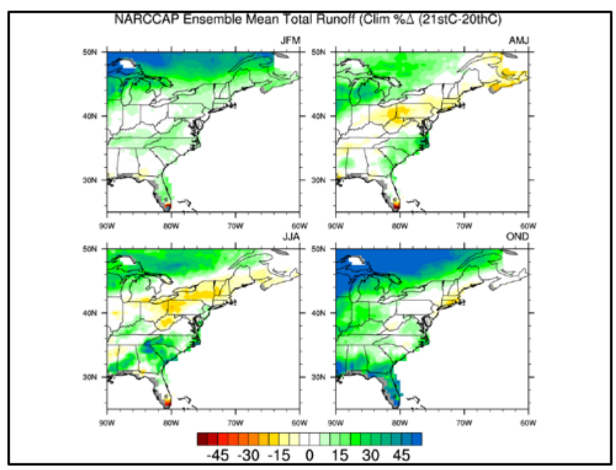

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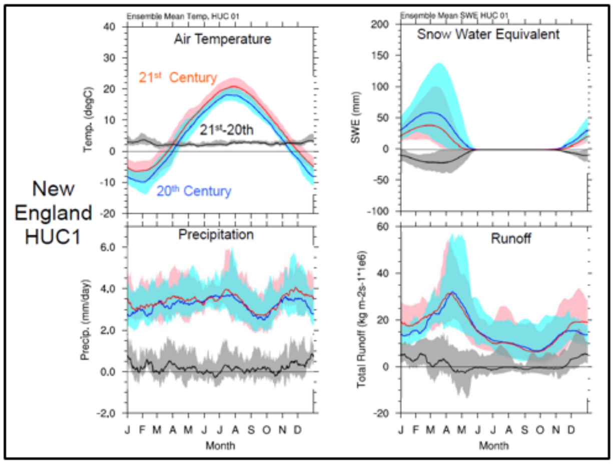
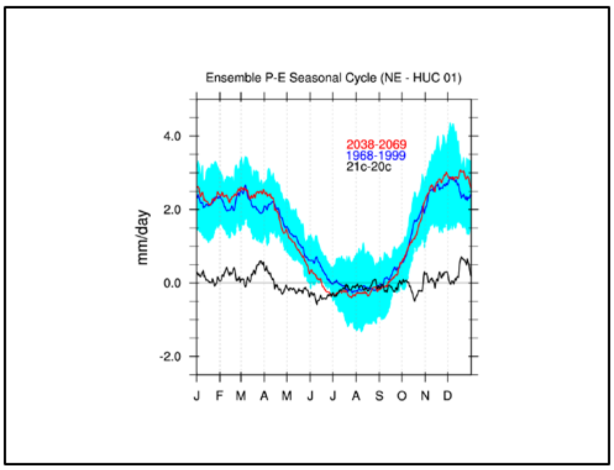


24

Summary of response to greenhouse

- North Atlantic
  - SST Warming but not uniform and may be especially large in the Gulf of Maine
  - Surface-intensified ocean warming and freshening (north of ~45° N) increased stratification
- Land (New England)
  - Strong warming
  - Enhanced precipitation mainly fall & winter
    - But precipitation variable so could be dry periods
    - Warm so enhanced evapotranspiration
    - Thus less water in rivers than might anticipate
  - Early snow melt and runoff (river flow)
    - In addition warm so enhanced evapotranspiration

25



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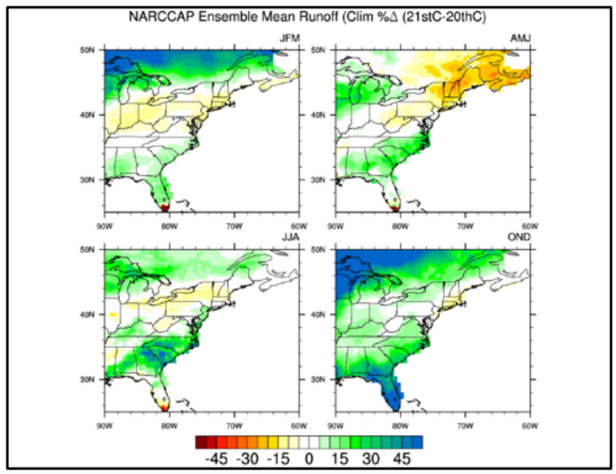

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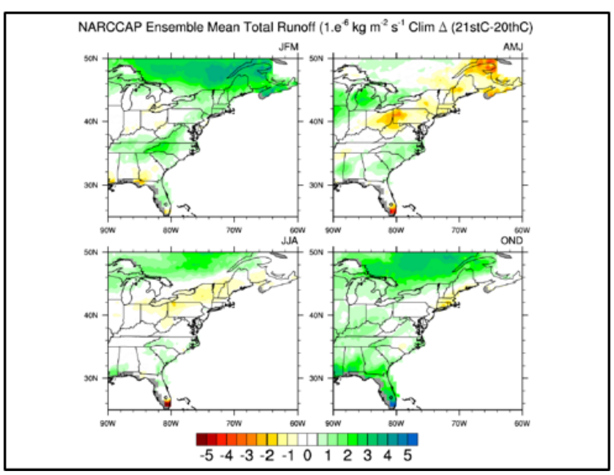

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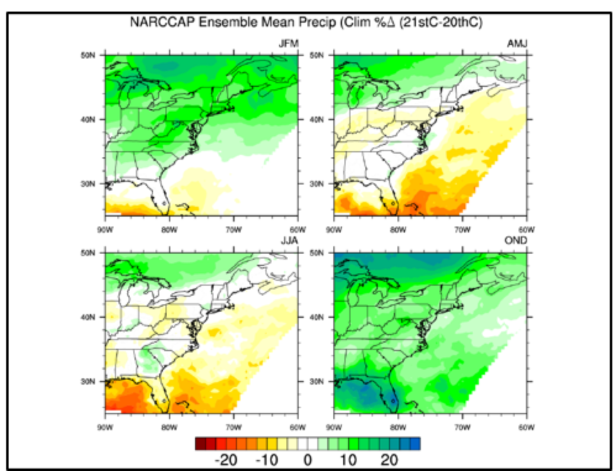

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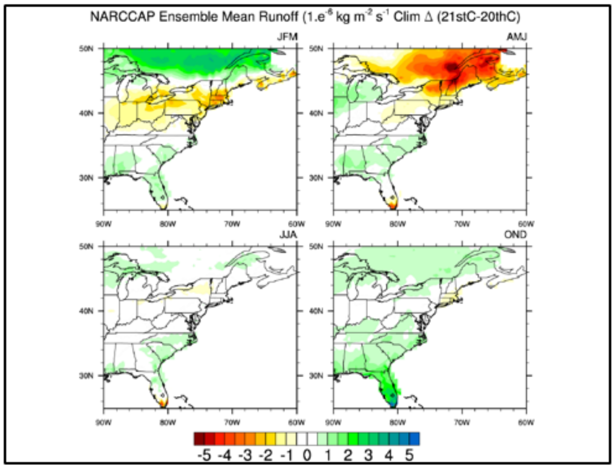

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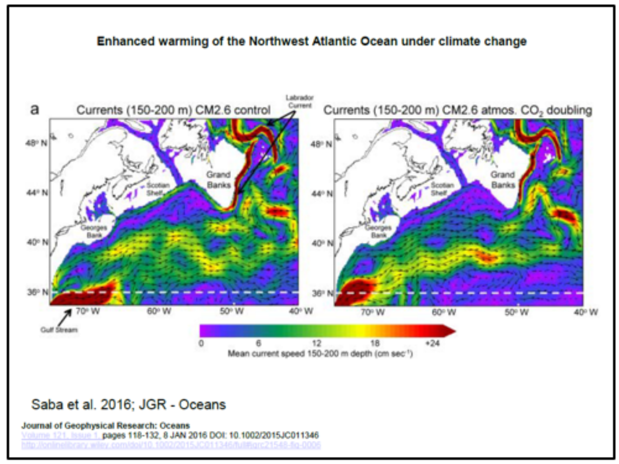

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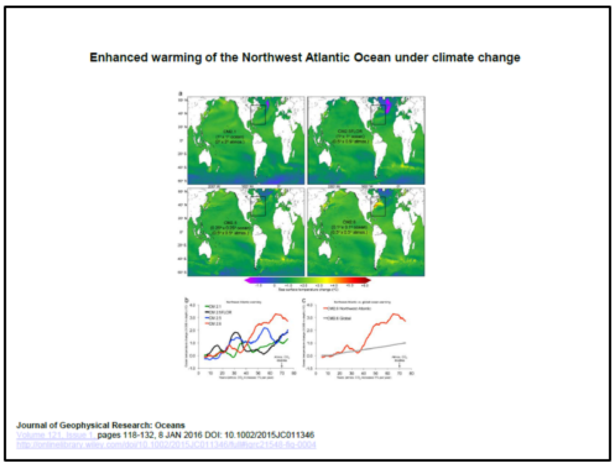

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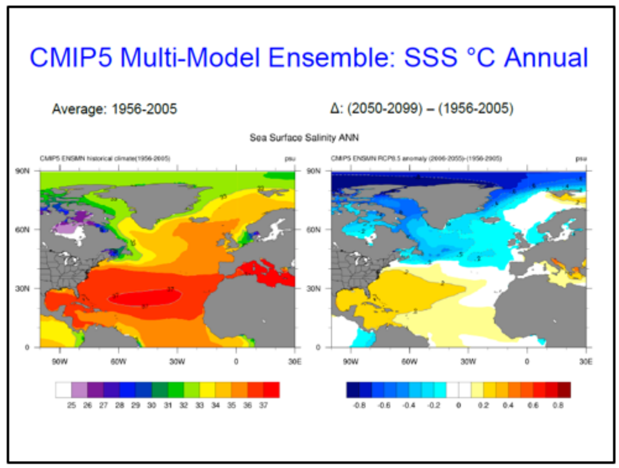

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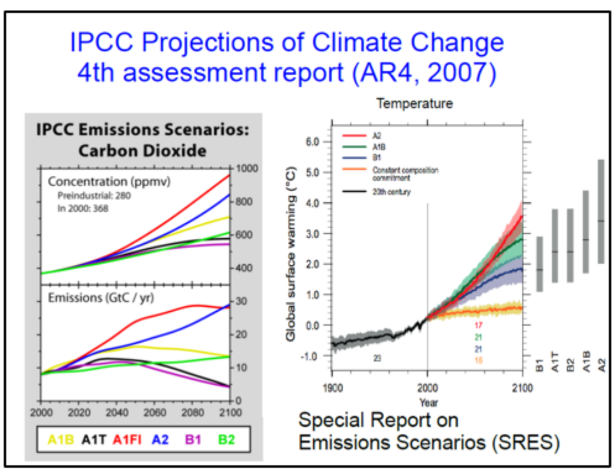


34

Should I weight models based on skill metrics?

Active area of research that could reduce uncertainty due to inter-model spread

No accepted method - many cases where a model's ability to match contemporary regional features was unrelated to a model's ability to match the warming trend (don't like draft a "good hitting" pitcher in the American league)

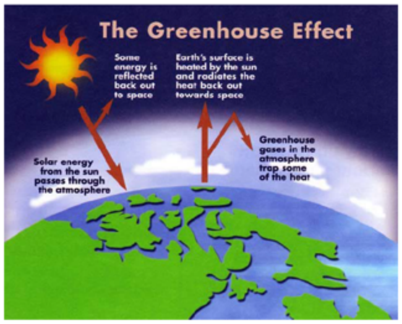
Present default is not to weight, though some "culling" of highly aberrant simulations may be necessary (e.g., Overland et al., J. Climate, 24 2011)

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

35

Greenhouse Effect: Natural + Human

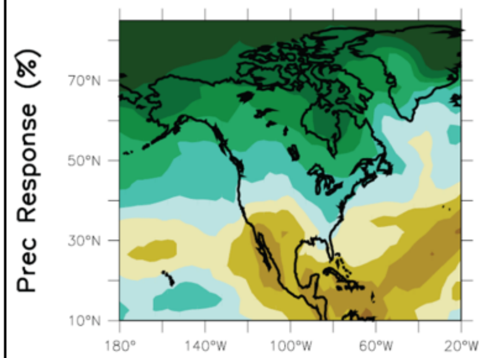
Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system.



Greenhouse gases include carbon dioxide (CO_2), water vapor, ozone, methane

36

Annual Precipitation: End of 21st Century



IPCC 4th Assessment: Working Group I, Chapter 11, Regional Projections

37

What are Climate models?

- Very sophisticated models of the atmosphere, ocean, land, sea ice
  - Millions of lines of code
- Systems of differential equations derived from the basic laws of physics and fluid dynamics
- Equations solved numerically on a 3-D grid
- At each grid point, the equations for heat, motion (winds, currents), and surface fluxes are calculated
  - Considering each grid volume updating millions of variables (lat, lon, height/depth), multiple variables, every time step (~15 minutes)
- The computations are stepped forward in time from seasons to centuries depending on the study.

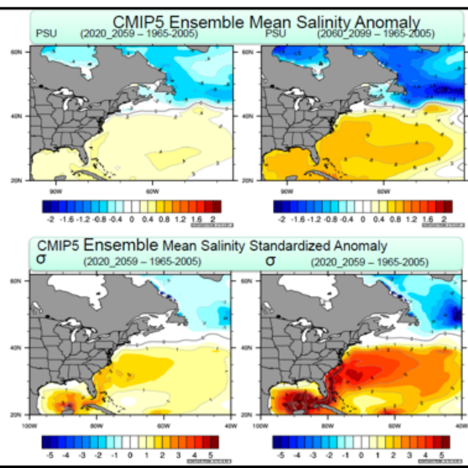
38

Projected Changes in Weather Extremes

Table 1: Estimates of confidence in observed and projected changes in extreme weather and climate events.

Confidence in observed changes (latter half of the 20th century)	Changes in Phenomenon	Confidence in projected changes (during the 21st century)
Likely[7]	**Higher maximum temperatures and more hot days over nearly all land areas**	Very likely[7]
Very likely[7]	**Higher minimum temperatures, fewer cold days and frost days over nearly all land areas**	Very likely[7]
Very likely[7]	**Reduced diurnal temperature range over most land areas**	Very likely[7]
Likely[7], over many areas	**Increase of heat index[12] over land areas**	Very likely[7], over most areas
Likely[7], over many Northern Hemisphere mid- to high latitude land areas	**More intense precipitation events[b]**	Very likely[7], over many areas
Likely[7], in a few areas	**Increased summer continental drying and associated risk of drought**	Likely[7], over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Not observed in the few analyses available	**Increase in tropical cyclone peak wind intensities[c]**	Likely[7], over some areas
Insufficient data for assessment	**Increase in tropical cyclone mean and peak precipitation intensities[c]**	Likely[7], over some areas

39



40

Refined resolution AOGCMs

Could fundamentally improve the resolution of shelf-scale processes and basin-shelf interactions in climate models

Computational costs increase with the cube of horizontal grid refinement

Processes that were once sub-grid scale are now resolved: parameterizations must be reformulated; some large-scale features may look worse.

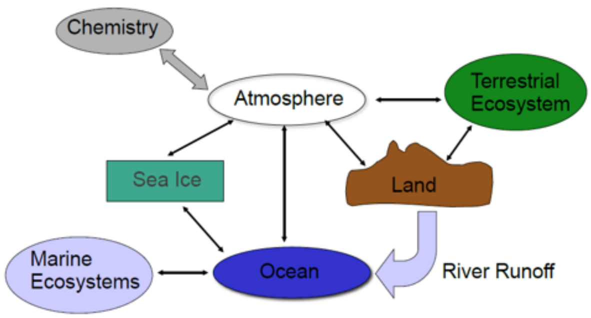
May address some biases, but not all biases rooted in resolution.

While more refined-resolution simulations (~1/8-1/4 degree) will be available in IPCC AR5, most will have resolutions similar to those in IPCC AR4.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

41

Components of Climate Models



Components can be run independently or as subsets

42

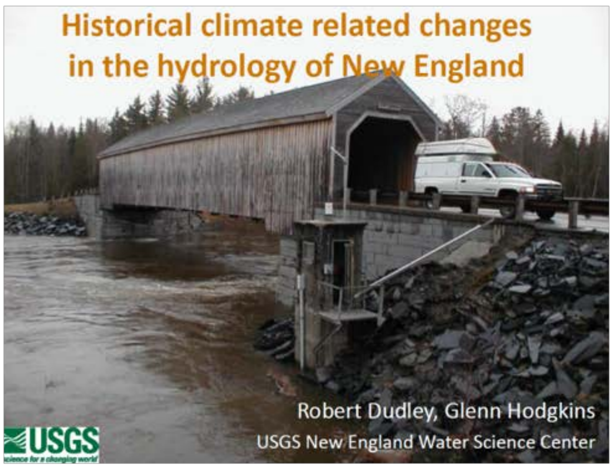
Natural Climate Variability

- Given the nonlinear nature of the climate system very small changes can result in a very different state of the atmosphere ("butterfly effect") after just a few weeks. Extends to the climate system as a whole by ~5-10 years.
- This has surprising consequences
- Won't have skillful (deterministic) forecasts of the atmosphere after ~2-3 weeks
  - Can't forecast the NAO beyond 2 weeks
- Still have lots of natural variability at decadal and longer time scales frequency; e.g
  - Can have 50 year trends in a given location In a "20^{th} century simulation" where climate model is initialized in the 19^{th} century) a given time in the model will NOT match nature
  - Can't directly compare time series from model to nature. Can compare average over a period

Historical climate related changes in the hydrology of New England:

Robert Dudley (USGS) noted that historical changes in New England include earlier snowmelt-related runoff whereby the timing of snowmelt-related runoff is sensitive to small changes in air temperature in areas that have a large annual snowpack. Generally, the region has seen trends toward more rain and increased low streamflows and groundwater levels over the past several decades. Increased heavy precipitation has driven increased minor flooding. Additionally, there is some evidence of long-term ocean/atmosphere oscillations being related to the occurrence of major floods. Modeled future changes in New England include increases in temperature that are expected to drive decreases in snowpack and affect the timing of snowmelt-related runoff. Future changes in minor floods will generally depend on precipitation changes, and changes in major floods will generally depend on relative precipitation and temperature changes.

1



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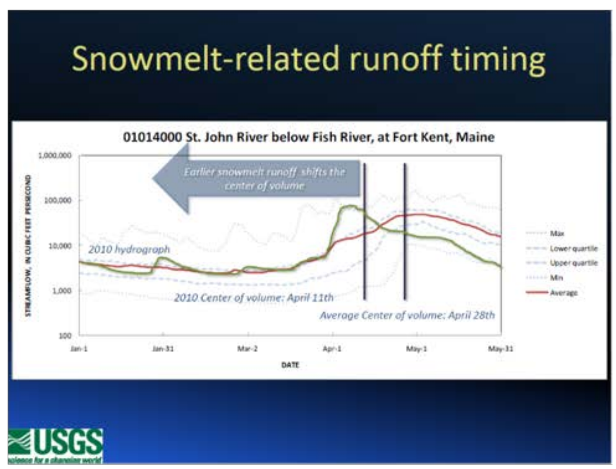

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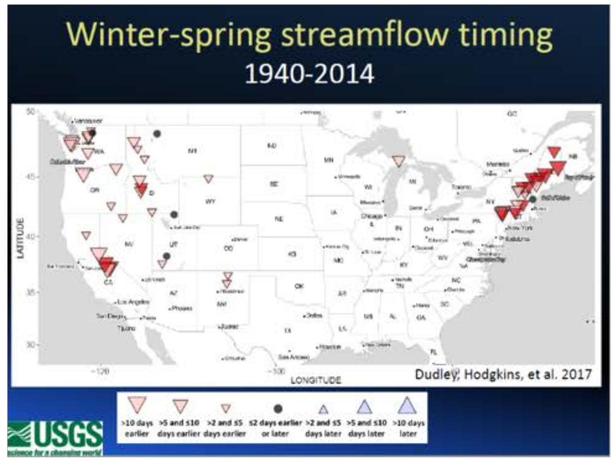
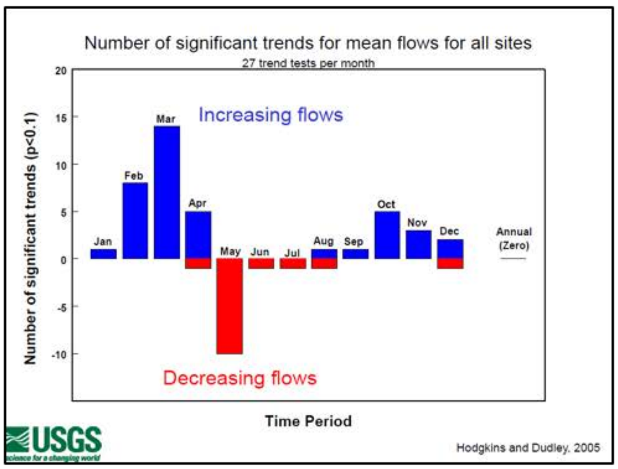
SOURCE: https://www.nytimes.com/interactive/2015/03/05/us/one-giant-picture-of-all-the-snow-across-the-us.html?_r=0

6


Winter-spring streamflow timing
1940-2014
LATITUDE
LONGITUDE
Dudley, Hodgkins, et al. 2017
>10 days earlier
>5 and ≤10 days earlier
>2 and ≤5 days earlier
≤2 days earlier or later
>2 and ≤5 days later
>5 and ≤10 days later
>10 days later

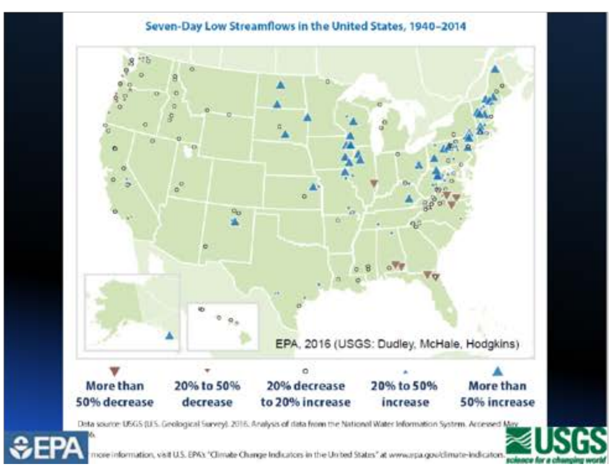
7


Number of significant trends for mean flows for all sites
27 trend tests per month
Number of significant trends (p<0.1)
20
15
10
5
0
-5
-10
Increasing flows
Decreasing flows
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual (Zero)
Time Period
Hodgkins and Dudley, 2005

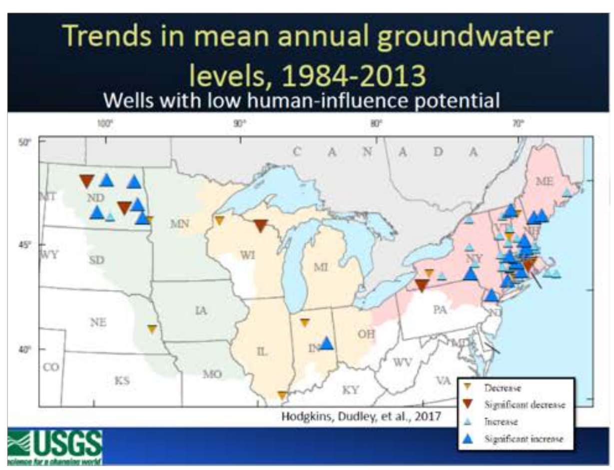
8


Historical low flow trends

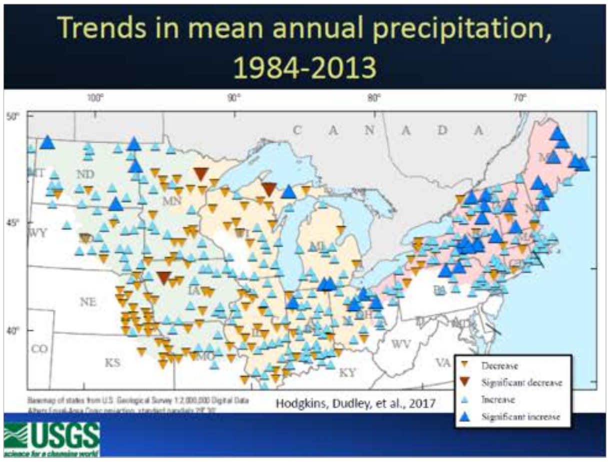
9


Seven-Day Low Streamflows in the United States, 1940–2014
EPA, 2016 (USGS: Dudley, McHale, Hodgkins)
More than 50% decrease
20% to 50% decrease
20% decrease to 20% increase
20% to 50% increase
More than 50% increase

10


Trends in mean annual groundwater levels, 1984-2013
Wells with low human-influence potential
C A N A D A
Hodgkins, Dudley, et al., 2017
Decrease
Significant decrease
Increase
Significant increase

11



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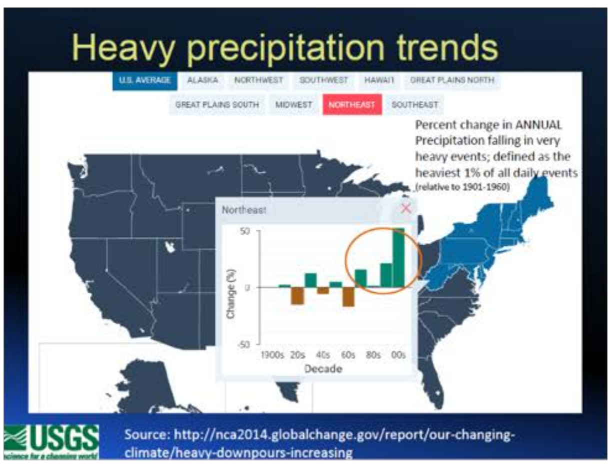

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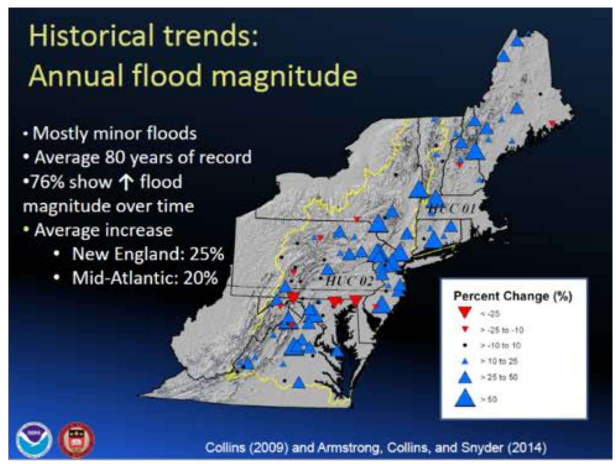

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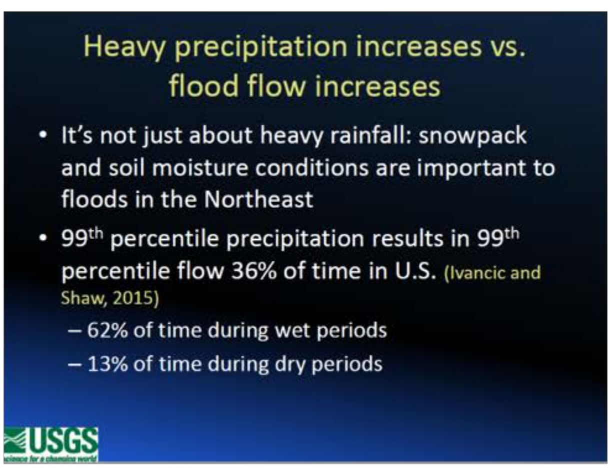

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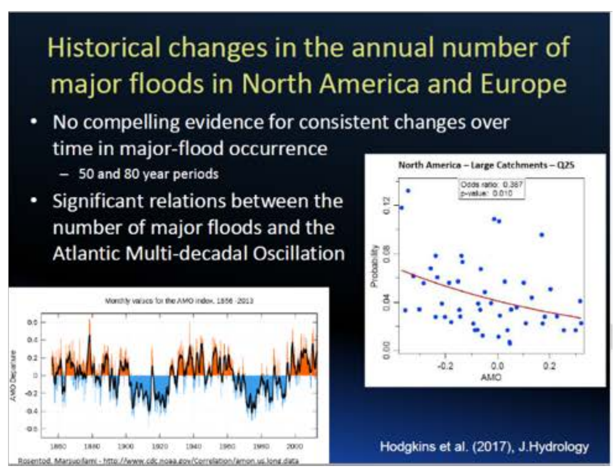

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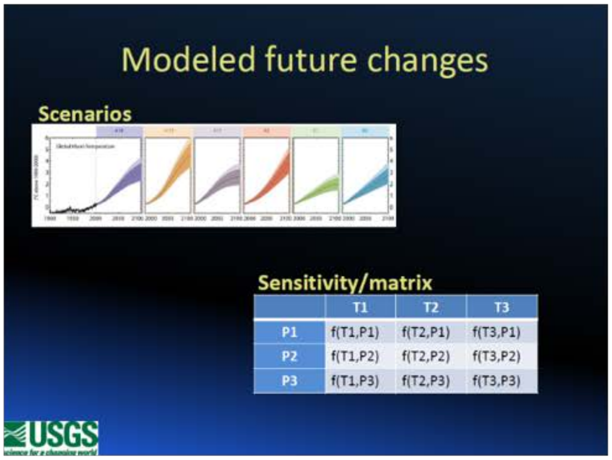
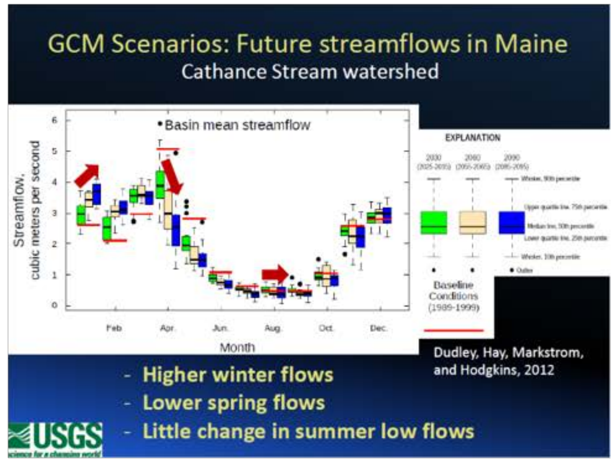
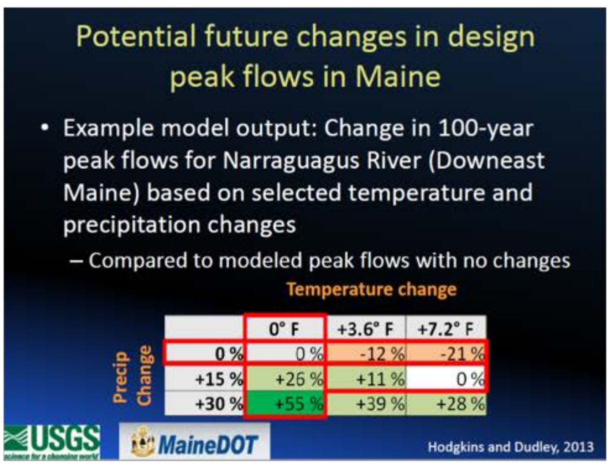


	T1	T2	T3
P1	f(T1,P1)	f(T2,P1)	f(T3,P1)
P2	f(T1,P2)	f(T2,P2)	f(T3,P2)
P3	f(T1,P3)	f(T2,P3)	f(T3,P3)

18

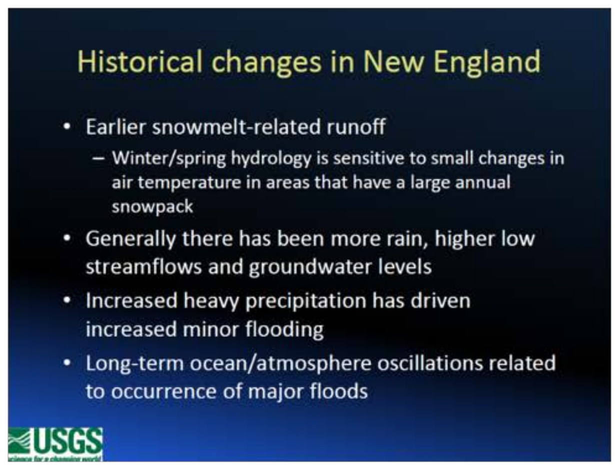


19



	0° F	+3.6° F	+7.2° F
0 %	0 %	-12 %	-21 %
+15 %	+26 %	+11 %	0 %
+30 %	+55 %	+39 %	+28 %

20



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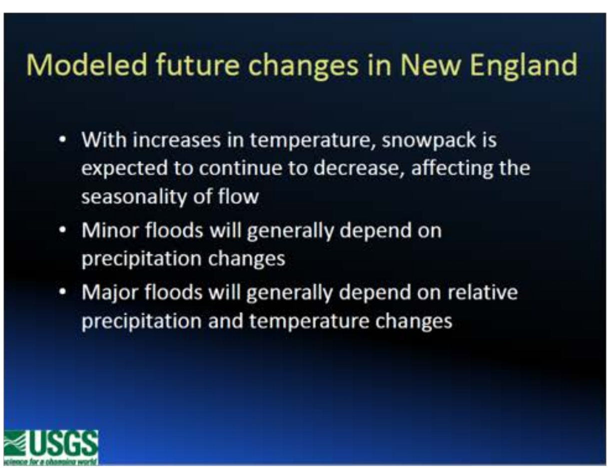

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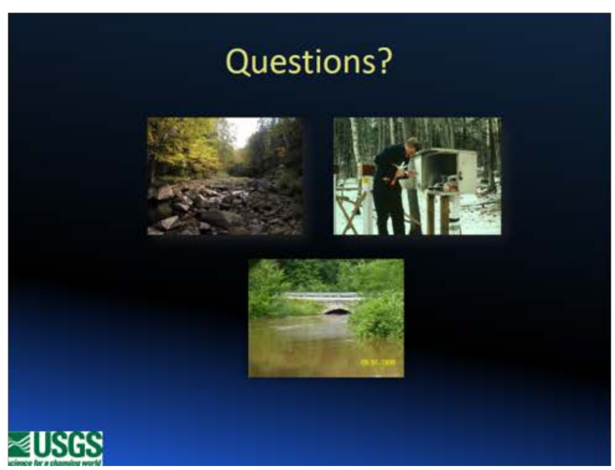
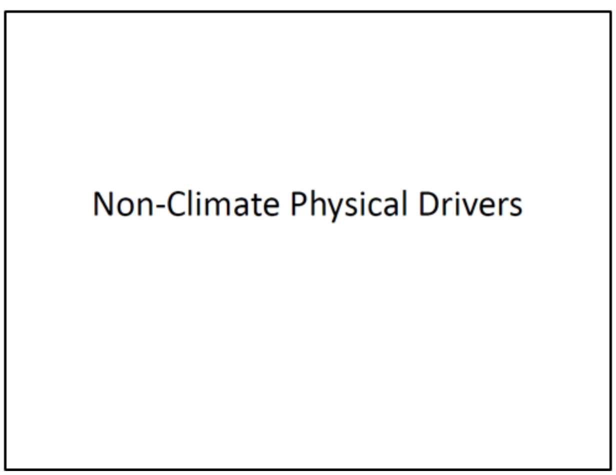


Non-climate/physical drivers:

Dan Kircheis (NMFS) described non-climate factors affecting survival of Atlantic salmon in freshwater. These included significant declines in the species range and abundance from dams; decreases in freshwater productivity from dams; pollution and habitat modifications; overfishing and pollution; significant loss of access to diverse habitat types from dams leading to a loss of species diversity; significant changes from dams in the biological communities with which Atlantic salmon coexist; stocking and habitat modifications; and significant changes in stream flow from dams including significant increases in the total surface area of lakes, ponds, deadwaters and reservoirs. Threats from pollution have largely been addressed while threats from habitat modification and stocking have been partially addressed. Although the threat associated with commercial and recreational fishing in U. S. waters has been addressed, the threat from the West Greenland fishery remains. Dams remain a major threat to Atlantic salmon. For example, over 600 dams block or impede passage of sea-run fish in Maine. Over 400 of these dams are in the range of the GOM DPS. Most of the fishways in the mainstem Penobscot Watershed and the Downeast Watershed were built following the Anadromous Fish Conservation Act of 1965. There remains considerable variability in the effectives of these fishways in passing fish. Habitat features that Atlantic salmon most often select for include water temperature, substrate diversity, cover and flow. However, dams have lessened the available suitable habitat for spawning and rearing. Less than 10% of the habitats best suited for spawning and rearing are in areas unimpeded by dams. Non-climate factors affecting Atlantic salmon in the marine environment includes fishing. Additional, natural mortality impacts (e.g., prey changes, predation changes such as from seals) may change due to climate change but we do not have a good understanding at this point.

1



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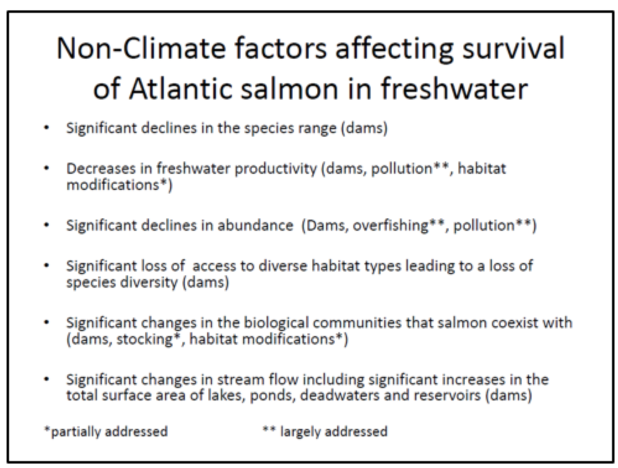

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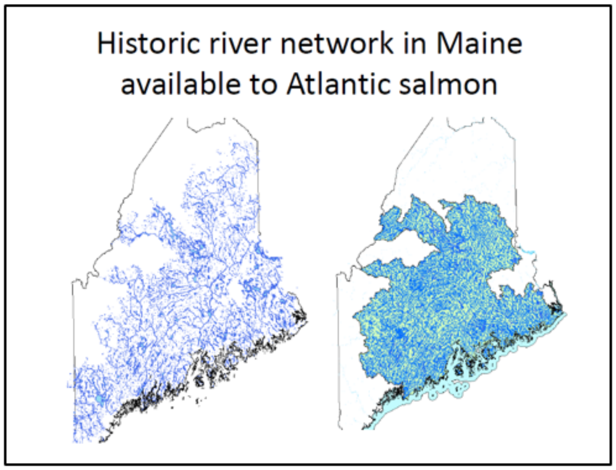
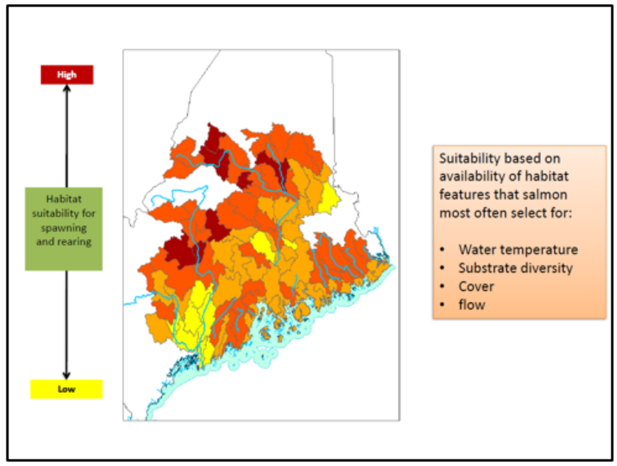
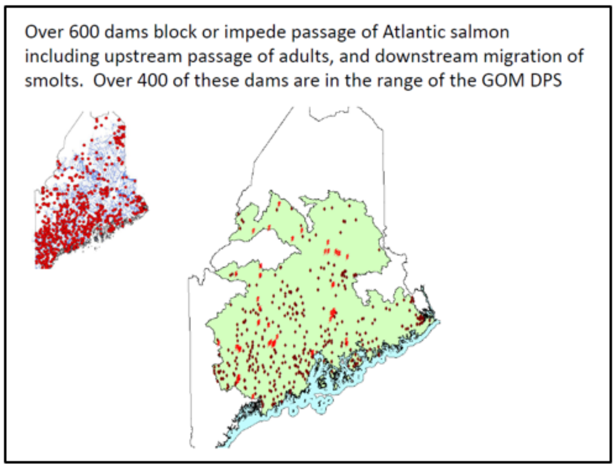

Historic river network in Maine available to Atlantic salmon

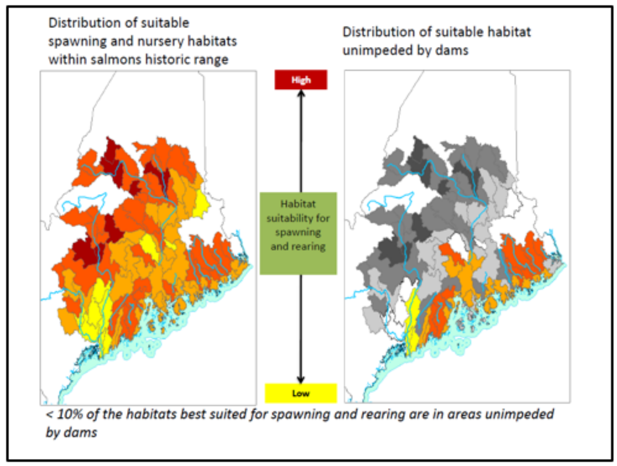
4


High
Habitat suitability for spawning and rearing
Low
Suitability based on availability of habitat features that salmon most often select for:
• Water temperature
• Substrate diversity
• Cover
• flow

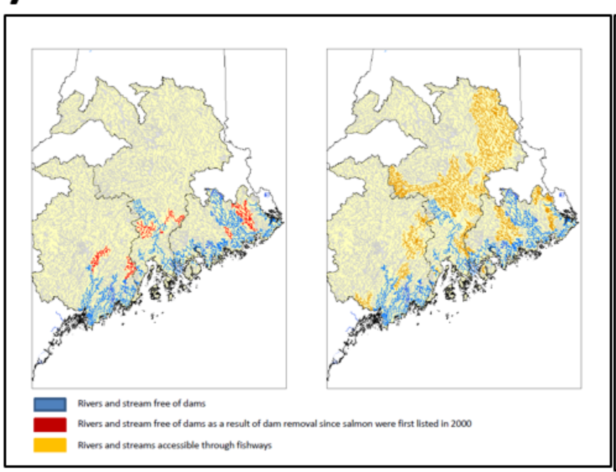
5


Over 600 dams block or impede passage of Atlantic salmon including upstream passage of adults, and downstream migration of smolts. Over 400 of these dams are in the range of the GOM DPS

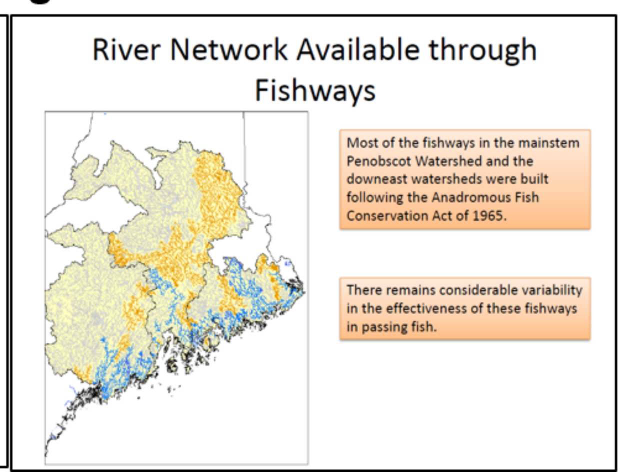
6


Distribution of suitable spawning and nursery habitats within salmons historic range
Distribution of suitable habitat unimpeded by dams
High
Habitat suitability for spawning and rearing
Low
< 10% of the habitats best suited for spawning and rearing are in areas unimpeded by dams

7


Rivers and stream free of dams
Rivers and stream free of dams as a result of dam removal since salmon were first listed in 2000
Rivers and streams accessible through fishways

8


River Network Available through Fishways
Most of the fishways in the mainstem Penobscot Watershed and the downeast watersheds were built following the Anadromous Fish Conservation Act of 1965.
There remains considerable variability in the effectiveness of these fishways in passing fish.

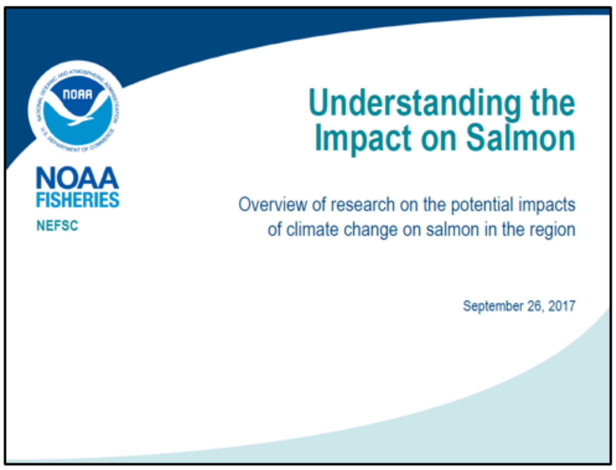
9

Non-Climate Factors Affecting Salmon
in the Marine Environment

Understanding the Impact on Salmon:

Tim Sheehan (NMFS) provided an overview of research on the potential impacts of climate change on Atlantic salmon, noting that most is marine focused. He noted that there is not a lot to draw from, but some relevant information. Most studies are retrospective lacking quantitative projections and associated causal mechanisms. Tim noted that one key missing product is a comprehensive summary of expected future conditions across the freshwater and marine range of U.S. Atlantic salmon coupled with their environmental preferences and tolerances.

1



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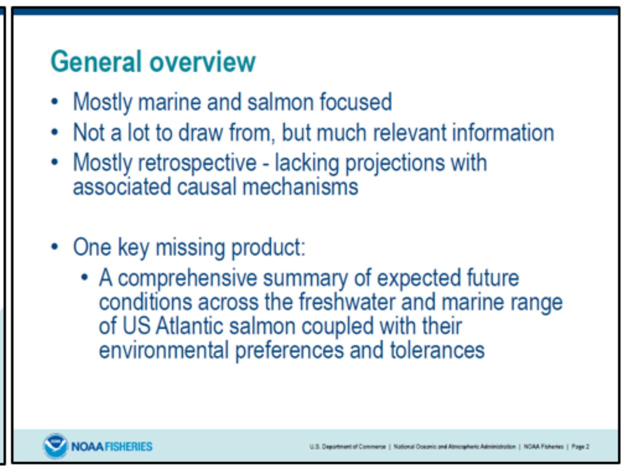

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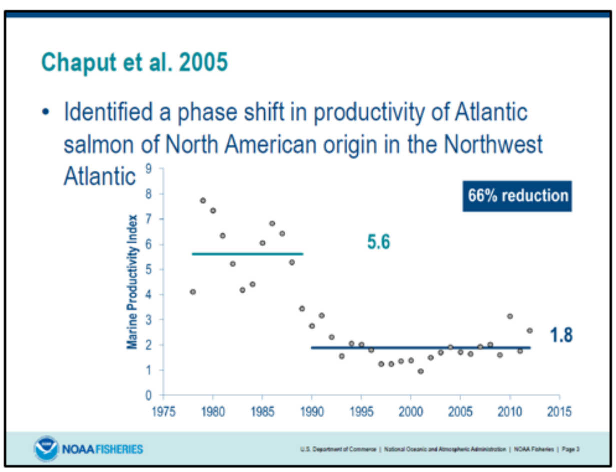

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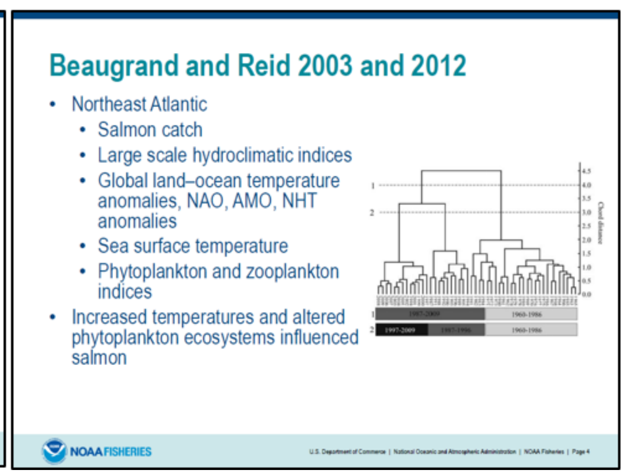

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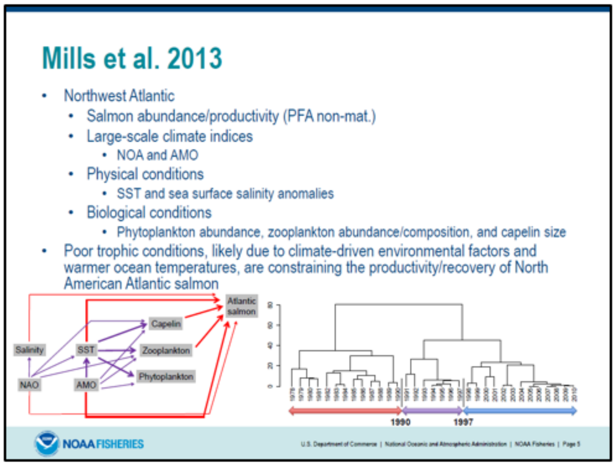
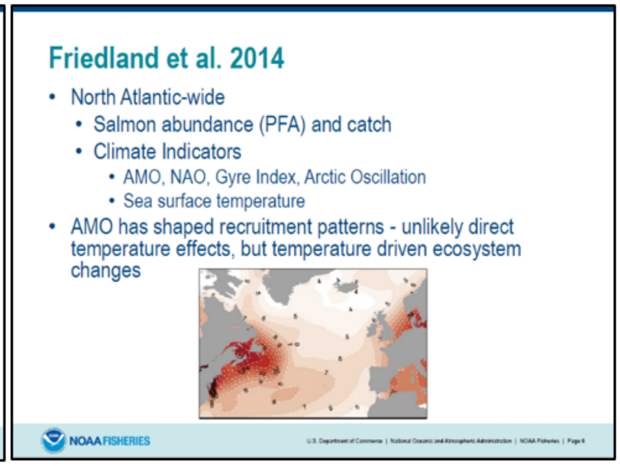
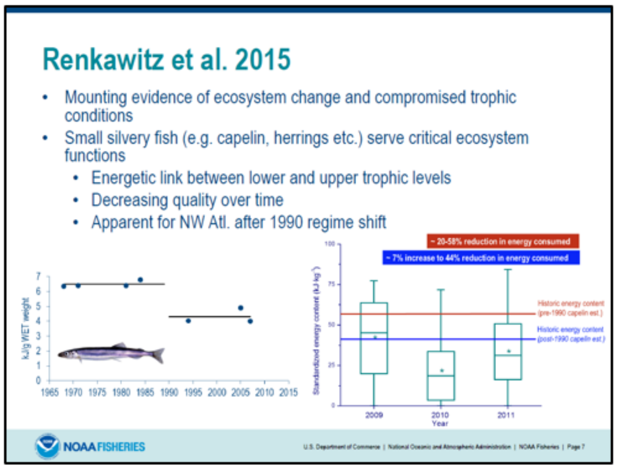

Mills et al. 2013
• Northwest Atlantic
• Salmon abundance/productivity (PFA non-mat.)
• Large-scale climate indices
• NOA and AMO
• Physical conditions
• SST and sea surface salinity anomalies
• Biological conditions
• Phytoplankton abundance, zooplankton abundance/composition, and capelin size
• Poor trophic conditions, likely due to climate-driven environmental factors and warmer ocean temperatures, are constraining the productivity/recovery of North American Atlantic salmon
Atlantic salmon
Capelin
Salinity
SST
Zooplankton
Phytoplankton
NAO
AMO
1990
1997
NOAA FISHERIES

6


Friedland et al. 2014
• North Atlantic-wide
• Salmon abundance (PFA) and catch
• Climate Indicators
• AMO, NAO, Gyre Index, Arctic Oscillation
• Sea surface temperature
• AMO has shaped recruitment patterns - unlikely direct temperature effects, but temperature driven ecosystem changes
NOAA FISHERIES

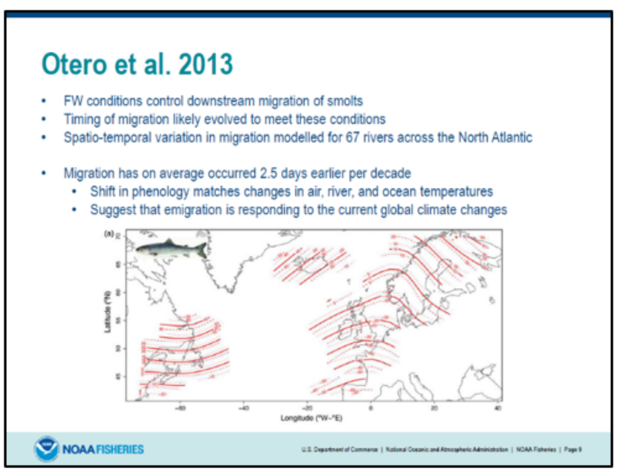
7


Renkawitz et al. 2015
• Mounting evidence of ecosystem change and compromised trophic conditions
• Small silvery fish (e.g. capelin, herrings etc.) serve critical ecosystem functions
• Energetic link between lower and upper trophic levels
• Decreasing quality over time
• Apparent for NW Atl. after 1990 regime shift
kJ/g WET weight
1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015
~ 20-58% reduction in energy consumed
~ 7% increase to 44% reduction in energy consumed
2009
2010
2011
Year
NOAA FISHERIES

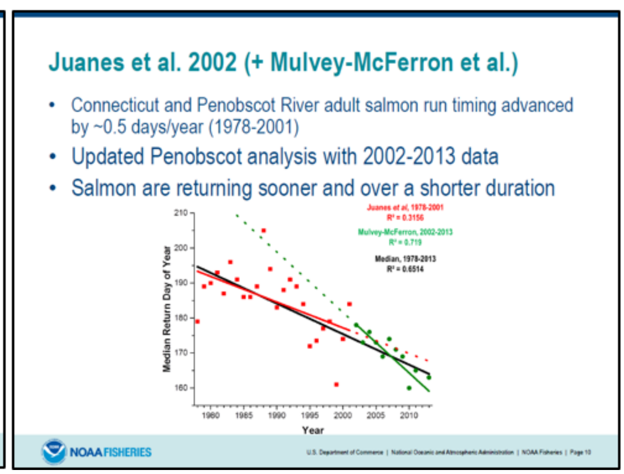
8


Next steps
1. NEFSC/GMRI collaboration - Impacts of a Changing Ecosystem on Atlantic Salmon Marine Productivity
• Evaluate ecosystem influences on marine growth over time
• Model energy flow on growth, survival, and productivity
2. NEFSC/U. of Waterloo collaboration - Lipid content of Atlantic salmon at West Greenland
3. NEFSC/Greenland Institute of Natural Resources - Proximate composition of primary mid-trophic prey species at West Greenland
NOAA FISHERIES

9


Otero et al. 2013
• FW conditions control downstream migration of smolts
• Timing of migration likely evolved to meet these conditions
• Spatio-temporal variation in migration modelled for 67 rivers across the North Atlantic
• Migration has on average occurred 2.5 days earlier per decade
• Shift in phenology matches changes in air, river, and ocean temperatures
• Suggest that emigration is responding to the current global climate changes
Latitude (°N)
Longitude (°W-°E)
NOAA FISHERIES

10


Juanes et al. 2002 (+ Mulvey-McFerron et al.)
• Connecticut and Penobscot River adult salmon run timing advanced by ~0.5 days/year (1978-2001)
• Updated Penobscot analysis with 2002-2013 data
• Salmon are returning sooner and over a shorter duration
Median Return Day of Year
Year
NOAA FISHERIES

11

Dempson et al. 2017

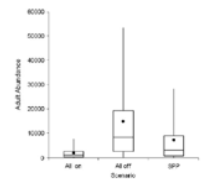
- Examined run timing for 13 Newfoundland and Labrador rivers
- Significant variation between rivers (median date up to 5 weeks apart)
- Median date of return has advanced ~12 days over a 35-years (1978 to 2012)
  - Some rivers up to 21 days

NOAA FISHERIES U.S. Department of Commerce | National Oceanic and Atmospheric Administration | NOAA Fisheries | Page 11

12

Nieland et al. 2015

- Population viability analysis to assess demographic effects of dams on Penobscot River Atlantic salmon
- Without hatchery supplementation, adult abundance equaled zero with base marine and freshwater survival rates
  - Increases in marine and freshwater survival rates needed

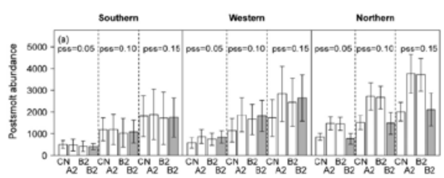


NOAA FISHERIES U.S. Department of Commerce | National Oceanic and Atmospheric Administration | NOAA Fisheries | Page 12

13

Hedger et al. 2013

- Stream temperature and discharge from downscaled Global Climate Models
- Individual-based freshwater model
- In Norway, some ‘winners’ and some ‘losers’ due to climate change



NOAA FISHERIES U.S. Department of Commerce | National Oceanic and Atmospheric Administration | NOAA Fisheries | Page 13

14

Jonsson and Jonsson 2009

- Reviewed effects of water temperature and flow on migrations, embryonic development, hatching, emergence, growth, life-history traits in light of climate change (Atlantic salmon and brown trout)
- Northward movement of the thermal niche of anadromous salmonids with decreased production and population extinction in the southern part of the distribution areas, earlier migrations, later spawning, younger smolting and sexual maturity, and increased disease susceptibility and mortality

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Poesch et al. 2016

- Evidence of the impacts of climate change on fw fish distributions, phenology, and population and assemblage dynamics is mounting
  - Earlier spawning runs and smolt outmigration (Russell et al. 2012)
  - Mismatch between the timing of smolting (Friedland et al. 2003)

- Optimum temperature (growth; °C), 6–19
- Lower/upper range for survival, 0/(23.3–26.7)
- Salinity tolerance, Euryhaline
- Colonization potential, Populations in Ungava Bay (QC) but never colonized habitat outside of their native range to date
- Current/projected status, Large range of temperature tolerance but least tolerant to low temperatures of Salmo species, northern tip of Québec may be a migration barrier

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ICES 2010

- Identify/compile time series of biological characteristics data, conduct preliminary analyses to test hypotheses relating observed changes to abundance trends and/or environmental changes

- Literature review
  - life history strategies of salmon and changes in biological characteristics of different life stages across the geographic range of the species in relation to key environmental variables
- Data sets
  - time series of various biological characteristics were made available to the Study Group
- Case studies
  - Information from new investigations presented and reviewed
- Exploratory analyses
  - stock-specific biological characteristics were examined for possible temporal trends over a broad spatial scales

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ICES 2017

Report of the Workshop on Potential Impacts of Climate Change on Atlantic Salmon Stock Dynamics (WKCCISAL)

- Section 1
  - Background of CC, the latest Intergovernmental Panel on Climate Change (IPCC) forecasts, scaling issues, and weather
- Section 2
  - Identify and discuss environmental and biological drivers in freshwater, estuaries, and marine waters that impact on Atlantic salmon
  - Discuss projections of CC effects on these drivers
- Section 3
  - Discuss consequences of CC on drivers
- Section 4
  - Overall conclusions
- Annex
  - Reference list on CC effects on Atlantic salmon provided

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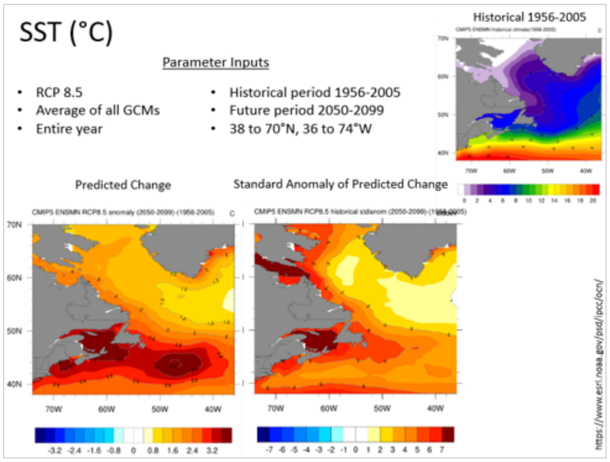
Appendix 10. NOAA Climate Change Web Portal and USGS National Climate Change Viewer graphics.

1



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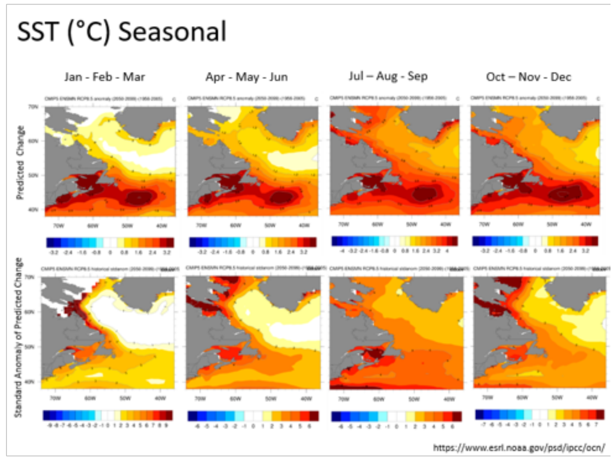

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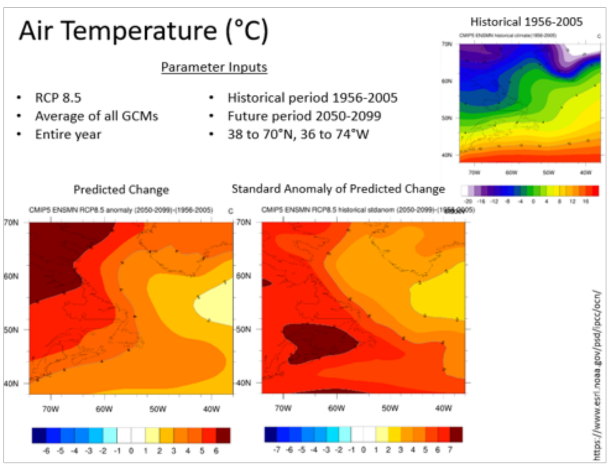

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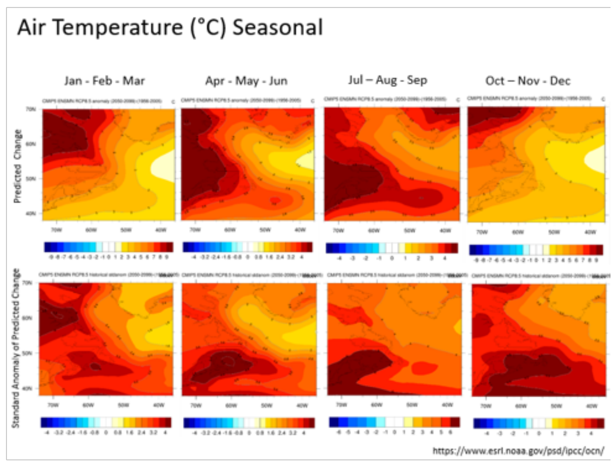

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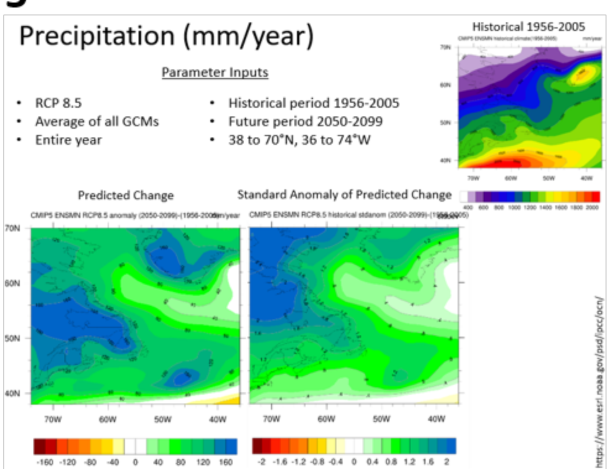

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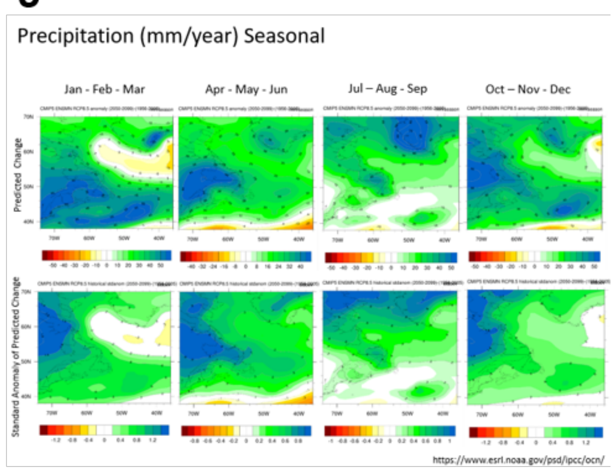

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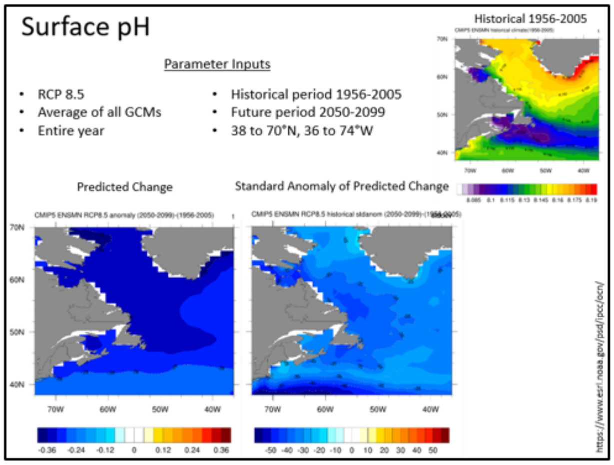
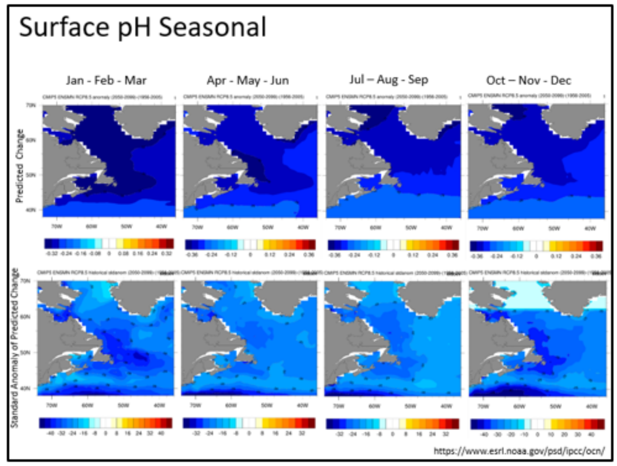
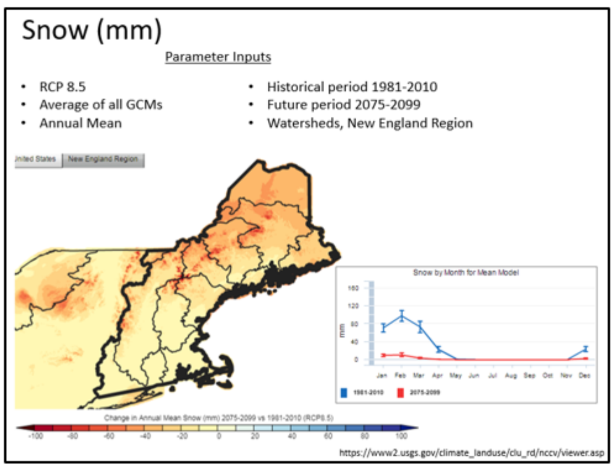

Surface pH
Parameter Inputs
• RCP 8.5
• Average of all GCMs
• Entire year
• Historical period 1956-2005
• Future period 2050-2099
• 38 to 70°N, 36 to 74°W
Historical 1956-2005
Predicted Change
Standard Anomaly of Predicted Change
https://www.esrl.noaa.gov/psd/ipcc/ocn/

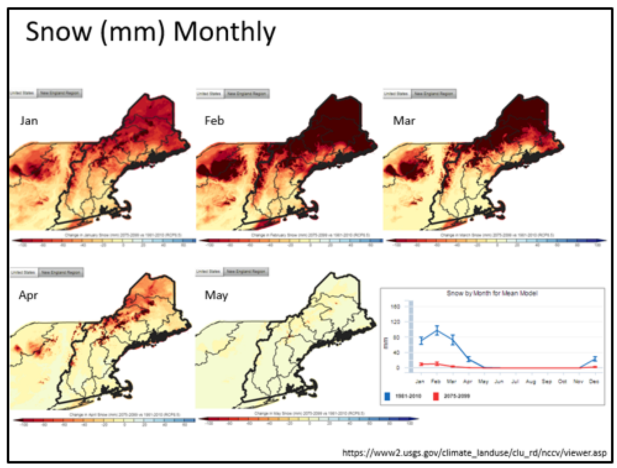
8


Surface pH Seasonal
Jan - Feb - Mar
Apr - May - Jun
Jul – Aug - Sep
Oct – Nov - Dec
Predicted Change
Standard Anomaly of Predicted Change
https://www.esrl.noaa.gov/psd/ipcc/ocn/

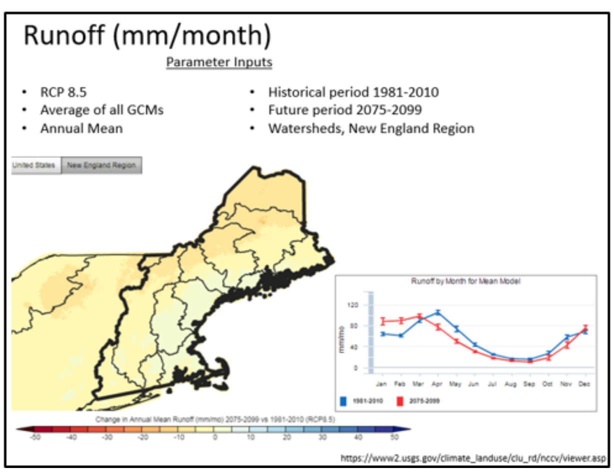
9


Snow (mm)
Parameter Inputs
• RCP 8.5
• Average of all GCMs
• Annual Mean
• Historical period 1981-2010
• Future period 2075-2099
• Watersheds, New England Region
Snow by Month for Mean Model
Change in Annual Mean Snow (mm) 2075-2099 vs 1981-2010 (RCP8.5)
https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp

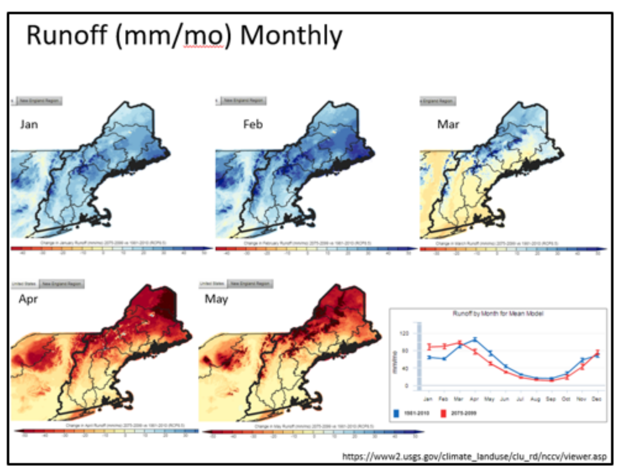
10


Snow (mm) Monthly
Jan
Feb
Mar
Apr
May
https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp

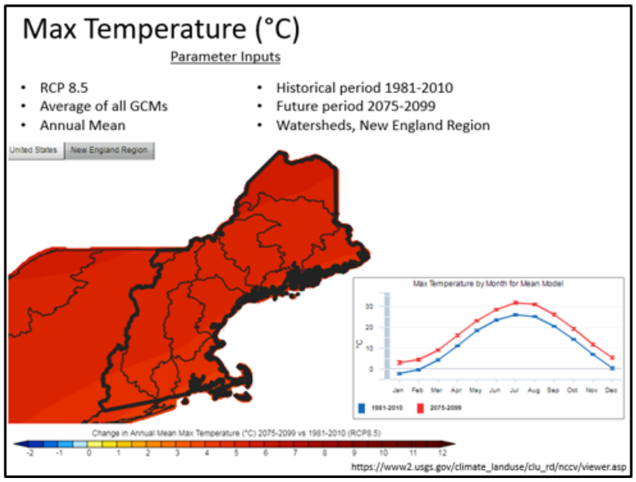
11


Runoff (mm/month)
Parameter Inputs
• RCP 8.5
• Average of all GCMs
• Annual Mean
• Historical period 1981-2010
• Future period 2075-2099
• Watersheds, New England Region
Runoff by Month for Mean Model
Change in Annual Mean Runoff (mm/mo) 2075-2099 vs 1981-2010 (RCP8.5)
https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp

12


Runoff (mm/mo) Monthly
Jan
Feb
Mar
Apr
May
https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp

13



Max Temperature (°C)
Parameter Inputs
• RCP 8.5
• Average of all GCMs
• Annual Mean
• Historical period 1981-2010
• Future period 2075-2099
• Watersheds, New England Region
United States
New England Region
Max Temperature by Month for Mean Model
°C
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1981-2010
2075-2099
Change in Annual Mean Max Temperature (°C) 2075-2099 vs 1981-2010 (RCP8.5)
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp

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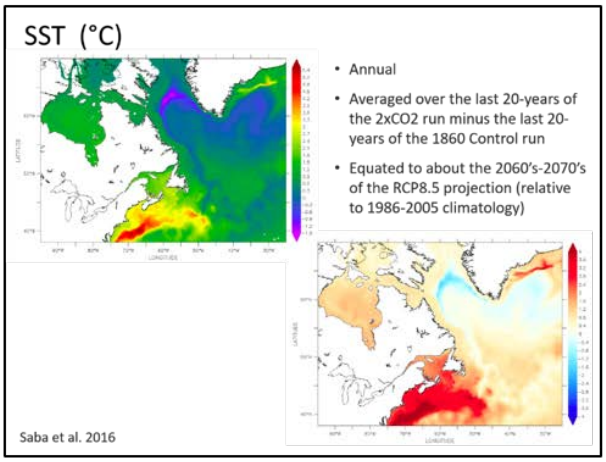
Appendix 11. High-resolution projection provided by Saba *et al.* (2016) to help with the consideration of non-uniform, enhanced warming and enhanced rainfall in the Gulf of Maine. Included are two different color palettes for ocean temperature change, and Saba *et al.* note that the graphics depict:

"CM2.6 deltas for precipitation (seasonal), air temperature (seasonal), SST (annual), and bottom ocean temperature (annual). These are averaged over the last 20-years of the 2xCO2 run minus the last 20-years of the 1860 Control run, which may be equated to about the 2060's-2070's of the RCP8.5 projection (relative to 1986-2005 climatology). The precipitation units are in mm/season. Air temperature and ocean temperature are in degrees C."

Seasonal breakdowns are as follows:

- Fall = September, October, November
- Winter = December, January, February
- Spring = March, April, May
- Summer = June, July, August

1



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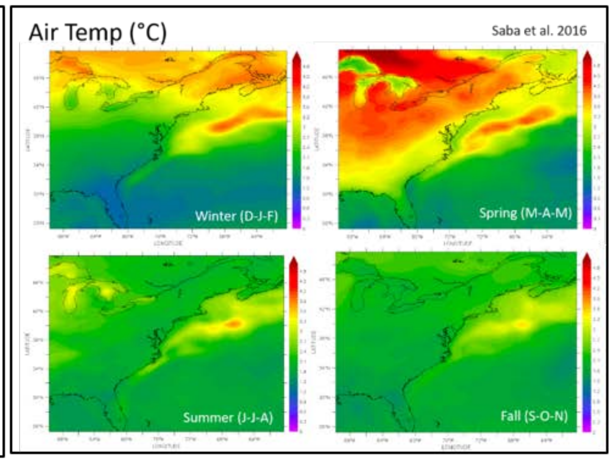

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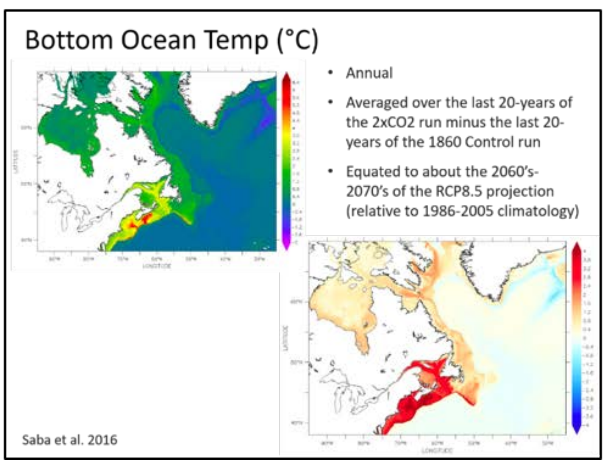

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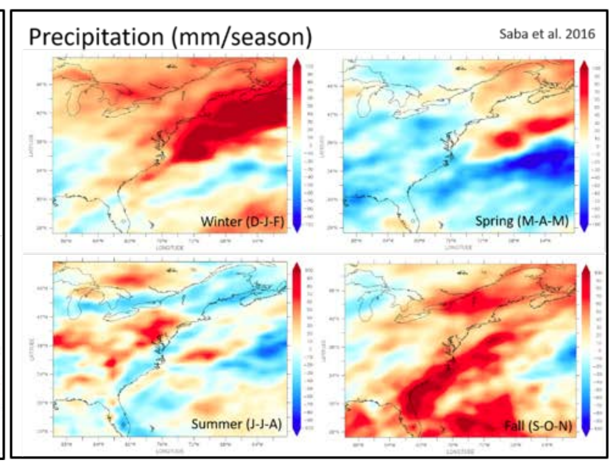
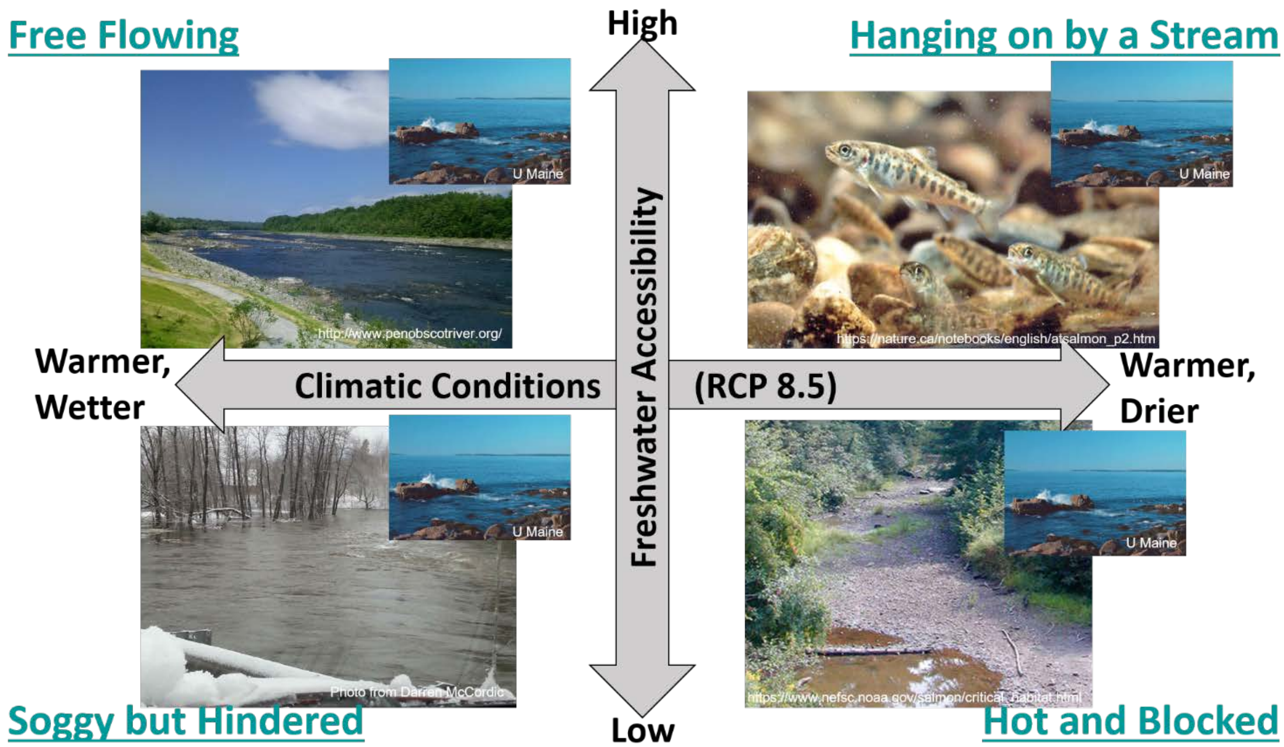


Appendix 12. Pictorial representation of scenarios.



Appendix 13. Full transcripts of workgroup Scenario Development worksheets. Note: Participants were encouraged to think as broadly and unrestrained as possible, therefore, what is recorded here includes thoughts that are not fully formed and do not necessarily represent agency views.

In your scenario: **Scenario Name: Free Flowing**

<table>
<tr><td colspan="3">Main regional climate features:</td></tr>
<tr><td colspan="3">• As expected, and other changes
• + ocean temp increase at depth
• + ocean stratification, productivity
• + location (feeding, migration routes)
• + sea level rise
• + limited droughts</td></tr>
<tr><td colspan="3">Notable non-climate features and developments:</td></tr>
<tr><td colspan="3">• Hydropower market collapses; non-hydro dams a public safety risk
• Incentives for dam removal, fish passage advancement (including fish-friendly turbines)
• Growing populations (cooler than southern NE) → more development e.g. roads, impervious areas, forest clearing, groundwater withdrawal, communications, connectivity (water temp, stream flow)
• Increased land conservation for riparian buffers
• Invasive species (fish)
• Diseases
• Change in community structure in Gulf of Maine (predation)</td></tr>
<tr><td colspan="3">Significant events and developments:</td></tr>
<tr><td>2020 – 2050
• Increased appreciation of sea-run fish
• Hatchery program ends
• Barriers removed
• Human population increase</td><td>2050-2075
• Human population decreases</td><td>2075-2095
• Human population decreases</td></tr>
<tr><td colspan="3">What are the main changes in conditions/impacts on salmon:</td></tr>
<tr><td>Watershed?
• Better access to cold water habitat
• Natural spawning, rearing, emergence
• Hydrologic processes restored
• Habitat divergence
• Faster development, earlier emergence (life history)
• Local pride in salmon runs, sea-run fish stories
• Diversify the portfolio
• Potential for local adaptation</td><td>Transition?
• Earlier outmigration
• Faster travel times
• Better conditioned smolts
• Predators</td><td>Marine?
• Predators
• Diet changes/ growth rates (?)
• Harvest unknown

What if we see non-uniform enhanced warming in the Gulf of Maine and cooling and/or less warming off Greenland? Any additional/ different effects?
• Temperature wall</td></tr>
</table>

In your scenario: **Scenario Name: Hanging on by a Stream**

Main regional climate features:

- Flow
  - Increase in winter, decrease in spring, summer and fall
- River temperature
  - Increase in winter, spring, summer and fall
  - River temperature change higher than estimated temperature change
- SST
  - Gulf of Maine much warmer
  - Labrador Sea decreases
  - Greenland coast warmer
- Accessibility increases

Notable non-climate features and developments:

- Accessibility increases
- Social/political willingness
- Increase in alternative energy sources (instead of dams)
- If population increases – could make scenario worse
- If population decreases – could make scenario same/worse
- Increases in diadromous fish community, more diverse system
- Fishing?

Significant events and developments:

2020 – 2050	2050-2075	2075-2095
• Political schedule • Otero et al. 2014 conclusions • Are they applicable to US stocks?		

What are the main changes in conditions/impacts on salmon:

Watershed?	Transition?	Marine?

• Egg/fry
  o Decrease S (smolt?)
  o Increase rate of development
  o Greater exposure to temperature variability
• Parr
  o In a big picture sense, could be a wash
  o Concern over increasing temperature
  o Production may focus in upper watershed
	• Smolt
	  o Shift and decrease migration window
	  o Increase migration with fewer dams
	  o Decrease predation mortality
	  o Larger mismatch between freshwater-estuary-marine
	  o Mismatch with photo-period and temp
	  o Survival?
		• Gulf of Maine
		  o Concern of increase in mortality via temperature
		  o Changes in ecological community
		• Labrador
		  o Awash
		  o Ecological changes a la Mills et al.
		• Greenland
		  o Increase in temperature
		  o Increase in migration distribution to preferred habitat
		  o Changes in ecological community
		
		What if we see non-uniform enhanced warming in the Gulf of Maine and cooling and/or less warming off Greenland? Any additional/ different effects?

In your scenario: **Scenario Name: Soggy but Hindered**

<table>
<tr><td colspan="3">Main region climate features:</td></tr>
<tr><td colspan="2">• Warmer and wetter
• Higher winter/lower spring streamflow
• River temp increases
• Warmer Gulf of Maine</td><td>• Greenland – slower rate of warming? Cooling?
• Possible increase frequency of winter scouring (REDDS)
• ? wetter = groundwater levels increase = higher base flow = decrease temp
• ? change in stratification and timing – impacts on estuary</td></tr>
<tr><td colspan="3">Notable non-climate features and developments:</td></tr>
<tr><td colspan="2">• Politically prioritizing hydropower over dam removal
• Low incentives to improve fish passage
• ? change in human population
• Policy = ESA necessary
• Funds available for continuation of hatcheries</td><td>• New developments in captive rearing, stocking practices
• Loss of public advocates (salmon clubs/tribes)
• Increased impacts aquaculture
• Mixed stock fisheries change</td></tr>
<tr><td colspan="3">Significant events and developments:</td></tr>
<tr><td>2020 – 2050
• New administration?
• ESA still useful?
• NAO/AMO shift? – buys us a decade, slows warming for X yrs and salmon increase dramatically
• Plethora of re-licensing opportunities (remove dams/improve passages)</td><td>2050-2075
• NAOA/AMO shift? – unfavorable for salmon</td><td>2075-2095
• End of current recovery plan</td></tr>
<tr><td colspan="3">What are the main changes in conditions/impacts on salmon:</td></tr>
<tr><td>Watershed?
• Lower spring streamflow = decreased survival (because increased predation during smolt migration)
• Advance smolt migration (~ possible match - mismatch)
• Decrease flows can lead to missed smolt window and revert to Parr (male)
• Thermal barriers to adult migration
• Increase harmful algal blooms/red tide</td><td>Transition?
• Prey mismatch?
• Predator mismatch?
• Increase in harmful algal blooms/ red tide
• Decrease flows can lead to missed smolt window and revert to Parr (male)
• Thermal barriers to adult migration</td><td>Marine?
• Continued poor survival in marine environment
• Prey mismatch?
• Predator mismatch?
• Increase harmful algal blooms/red tide

What if we see non-uniform enhanced warming in the Gulf of Maine and cooling and/or less warming off Greenland? Any additional/ different effects?
• Increase in sea lice/disease?</td></tr>
</table>

In your scenario: **Scenario Name: Hot and Blocked**

Main region climate features:

- Light snowpack (if any)
- Earlier spring runoff
- Warmer streams
- More disconnect due to low flow conditions
- No/light ice
- Flashier summer precip
- Gulf of Maine warmer
- Less fresh at surface
- More saltwater intrusion
- Ocean acidification (pH decrease in ocean)

Notable non-climate features and developments:

- Human population increase = decrease in water quality/ increase in storm water
- Increase in technology for fish passage (ladders, trucks)
- Increase energy development in ocean/estuaries
- MMP = increase suburban
- PMB = increase urban
- More nitrogen discharge (runoff)

Significant events and developments:

2020 – 2050

- Ducktrap River extirpated
- Salmon genebank opens
- NMFS loses FPA challenges
- Increase in offshore wind, tidal energy, and offshore aquaculture
- Squid fishery shifts north
- Pink salmon arrive in Gulf of Maine waters
- Oil and gas in Gulf of Maine
- Great white shark population explosion brings seal population relief

2050-2075

- Portland population ≥ 500,000
- Bangor population ≥ 100,000
- OTEC

2075-2095

- Dennys River becomes perennial stream
- Portland population ≥ 3,000,000

What are the main changes in conditions/impacts on salmon:

Watershed?

- Water cycle flatter and shifted – earlier leads to earlier out migration
- Fewer/less access to cold water refugia – decrease survival of parr and adult, decrease reproductive success
- Less stable winter conditions (egg survival)
- Increase in invasive species and disease
- Adult overwintering?

Transition?

- Mismatch with other species and food (smolt survival consequences)
- Adult overwintering?
- Changes to salinity regime and location of mixing zone = squeeze habitat availability (dam effect)

Marine?

- Earlier, poor condition
- Narrower suitable habitat (vertical water column and spatial distribution decrease)
- New predators and prey = shifts
- Increase ocean development = ocean survival and migration decrease
- Shifts/new fisheries increase bycatch mortality

What if we see non-uniform enhanced warming in the Gulf of Maine and cooling and/or less warming off Greenland? Any additional/ different effects?

- Shift in marine distribution

Appendix 14. Full transcripts of workgroup Generating Options worksheets. Note: Participants were encouraged to think as broadly and unrestrained as possible, therefore, what is recorded here includes thoughts that are not fully formed and do not necessarily represent agency views.

If you knew this scenario was the future, what actions would you take now / within 5 years? **Scenario Name: Free Flowing**

<table>
<tr><td>Research:
Salmon? Climate? Social Science?</td><td>Management (Non-Dam):
e.g., stocking strategy, mixed stock fisheries, water withdrawals etc.</td><td>Other?</td></tr>
<tr><td>• More temperature monitoring for resilience
• Thermal imagery (seeps)
• Further barrier assessment/ground truthing
• Tracking salmon in wild (what are they telling us about habitat?) → Assess and identify climate resilient habitats
• Overlay stocking with habitat
• Social science – other values
• Increased stream flow gauging
• Smolt survival/fitness
• Suitability mapping in marine environment
• Changes in marine community structure/productivity
• Connecticut lessons learned
• Undammed rivers as an index (Canada)</td><td>• Land conservation of priority habitats
• Regulate/protect riparian buffers
• Floodplain protection
• Strategy for stocking →mature reproduction
• Fishing regulations
• Minimize harvest and bycatch
• Regulate water withdrawals
• Water quality/storm water regulations</td><td rowspan="3">• Integration with land use planning
• Find conservation role models/spokespersons/success stories
• Targeted communications campaign (data stories, infographics)</td></tr>
<tr><td>Dams/Other Barriers:
Location dam removal? Alternatives?</td><td>Relationships/Collaborations:
Other partners? Other initiatives?</td></tr>
<tr><td>• Identify priority barriers for removal/passage
• Find pathways to removals (safety, liability, buyouts)
• Remove high priority barriers
• Improve FERC relicensing process →removals, effective fish passage
• DOT replacements (emergency, non-emergency)</td><td>• TNC (assessment, barriers, land conservation)
• SHEDS
• Improve state-federal relations
• Improve federal-federal (FERC)
• Collaborate
  o Utilities
  o DOT
  o Recreational community (fishing)
  o Environmental orgs
• Canada (research, exchange info temperature, tracking, climate)</td></tr>
</table>

If you knew this scenario was the future, what actions would you take now / within 5 years? **Scenario Name: Hanging on by a Stream**

Research: *Salmon? Climate? Social Science?*	**Management (Non-Dam):** *e.g., stocking strategy, mixed stock fisheries, water withdrawals etc.*	**Other?**

• (A) Life history specific quantitative thresholds (e.g. temp) synthesis and analysis → Pursue gaps as needed
• (B) Range-wide analysis of habitat features at various time horizons (e.g. temp, Q)
• (C) Social science study to better market dam removal
• (D) Build-out analysis
• (E) Better marine spatial demography [existing, projected], predator/prey relationships
	• (1) Complete overhaul of hatchery management to produce:
	  ○ A. Maximum survival in wild
	  ○ B. climate resilience
	• Spatial alignment with A+B+C and 1+2
	• (2) Reduce mixed stock fisheries mortality
	• (3) Analyze build-out analysis (D) in light of A+B+1
	• (4) Develop/implement BMPs to improve precip infiltration
	• (5) Continually monitor change in fishery dynamics (keep fishing and bycatch mortality low)
	• (6) Increase multidisciplinary collaboration and "boundary spanner" people	

Dams/Other Barriers: *Location dam removal? Alternatives?*	**Relationships/Collaborations:** *Other partners? Other initiatives?*	
• Barrier removal prioritization that integrates A & B above as factors change IDs "must have" removals • Implement C (above) on a project-by-project basis to successfully remove dams	• Improve/change joint management structure • Maximize/increase efficiency NGO collaboration • Build relationships with entities whose climate resilience concerns run in same directions as ours e.g. DOTs, tribes, others • Targeted outreach to decision makers e.g. politicians, dam owners	

If you knew this scenario was the future, what actions would you take now / within 5 years? **Scenario Name: Soggy but Hindered**

<table>
<tr><td>Research:
Salmon? Climate? Social Science?</td><td>Management (Non-Dam):
e.g., stocking strategy, mixed stock fisheries, water withdrawals etc.</td><td>Other?</td></tr>
<tr><td>Adaptive Management
Captive rearing
Stocking strategies
Habitat restoration
Assisted migration
Breeding strategies
Better understanding marine survival and factors affecting it (predators and prey)
ROAM project
Investigate bycatch issues
Marine system forecasting
Monitoring (see collaborations)</td><td>Captive rearing all/some parts of life cycle (net pens, streamside, salt-water aquariums)
Gene banking
Continued involvement in NASCO
Review stocking strategies and habitat restoration to get greatest return for money
Manage forage species (marine environment)</td><td rowspan="3">Outreach and education for the public
Political support for research and management programs
Retain strong ESA
$ to everyone
Atlantic salmon license plate
Hydro power royalty
Promote environmental friendly economic development</td></tr>
<tr><td>Dams/Other Barriers:
Location dam removal? Alternatives?</td><td>Relationships/Collaborations:
Other partners? Other initiatives?</td></tr>
<tr><td>Develop new methods to move fish around dams (trucks, pipes, cannons)
Improve existing fish passage technology (rock ramps, fish ways)</td><td>NASCO
Data collection/monitoring (NGOs, citizens, other Fed agencies, tribes, municipal)
Canada – Atlantic salmon joint venture
IYS – International Year of the Salmon (North Atlantic and North Pacific)</td></tr>
</table>

If you knew this scenario was the future, what actions would you take now / within 5 years? **Scenario Name: Hot and Blocked**

<table>
<tr>
<td>Research:
Salmon? Climate? Social Science?</td>
<td>Management (Non-Dam):
e.g., stocking strategy, mixed stock fisheries, water withdrawals etc.</td>
<td>Other?</td>
</tr>
<tr>
<td>• ID climate resilient habitats and focus restoration/protection efforts
• Explore outbreeding options (crosses and releases) (marine survival metric)
• Tagging technologies to support the science
• Will environmental window move beyond the “cold water fish range”?/”mismatch” - phenology effects
• Better understanding of threats/pressures in marine waters (esp 2nd growing season and winter)
• Understanding delay at barriers and ID solutions
• Is there a genetic basis for thermal tolerance that is evident between the different stocks?
• ID cause of increasing estuary mortality and every unsuccessful dam passage (delay? Physical? Stress? Injury?)</td>
<td>• Hatchery – focus on saving as much diversity as possible, retain existing families
• Increase broodstock from small coastal rivers
• Redundant stocking in cold water (upper Kennebec)
• Expand critical habitat designation
• Not taking all adults back to the hatchery → tagging and tracking those fish (outreach link/opportunity)</td>
<td rowspan="3">• Hatchery $/political support
• Privatization of hatcheries
• FWS engagement
• Public buy-in/awareness
• Leverage river herring
• Bringing rest of ecosystem into story
• Flexibility in hatchery and stocking practices →policy implications?
• ID a short term (<10yr) project to find a corporate/large NGO collaboration (LL Bean? Total?)
• Lessons learned from other conservation successes (and failures)</td>
</tr>
<tr>
<td>Dams/Other Barriers:
Location dam removal? Alternatives?</td>
<td>Relationships/Collaborations:
Other partners? Other initiatives?</td>
</tr>
<tr>
<td>• Technology
    ○ Native like fishways?
    ○ Bypass?
    ○ Minimize effects/maximize passage
• Strategic investment in passage and transport options
• “trucking/transport” back up plan
• Ensure fishways can operate in low flow scenarios/flood events
• Management of increasing numbers of river herring, shad, and impacts on collection of broodstock</td>
<td>• NGOs focus effort in climate resilient habitats
• Aquaculture industry (upper KN hatchery facility)
    ○ Marine thermal tolerance
    ○ Sea lice
• Canada – marine research
• IFW – invasives
• USDA – genetics, disease, lice, cold water research facility
• BOEM – research? Threats?
• NPS/Katahdin Woods and Water – new national monument/park – get them to help tell the story of salmon</td>
</tr>
</table>

Appendix 15. Full transcripts of Watershed, and Marine and Estuarine (Transition) workgroups on generating options. Note: Participants were encouraged to think as broadly and unrestrained as possible, therefore, what is recorded here includes thoughts that are not fully formed and do not necessarily represent agency views.

Watershed group

- Synthesize life history specific quantitative thresholds for all life histories ("what do fish need (all life stages)?")
- Range-wide habitat analysis (based on ID of relevant indicator variables)
    - Existing & projections – where do those conditions occur now and where will they occur
    - Temp, groundwater inputs (proxy), surficial geology, sand and gravel aquifer
- How has fish density changed at specific site and how that relates to temp, elevation, other climate proxies
- Use the above information to inform stocking decisions and habitat restoration options (including barrier removal)
- Identification of research questions/experiments
- Identification of actions to increase habitat productivity (do the things needed to grow more smolts), this may not be just habitat improvements
- Connectivity – getting fish where they need to go

Marine/Estuarine (Transition) group

- Tagging/Tracking salmon in marine environment
    - Purpose: understanding where they are in the marine environment to see if there is something we can do to increase marine survival
    - with focus on understanding impacts from climate change
- Understanding what they did under past conditions (historical)
- Model out to future
- Look at alignment with regime changes in salmon
- Will migration patterns change in light of climate change?
- When is abundance enough to allow diversity to express itself in a meaningful way?
- Need to tag/track the two sea winter (2SW) fish to find out why mortality is higher than for the one sea winter (1SW) fish. What's happening? Where/why are they dying?
- Modelling study where you put fish into variable ocean environments and see what happens with survival
- ROAM - being tested, could be the way to go to sell multi-year tagging information
- Better understanding the knobs that need to be turned to increase survival
    - forage fish management (capelin NAFO management)
    - energetics of forage fish
- Right whale/copepod connection - can we partner and make use of information and resources dedicated to finding out what is happening to copepods that affects NARW and capelin and therefore Atlantic salmon?
- Regional Ocean model system (ROMS) historical reanalysis (best estimate of ocean conditions) from 1958 close to present

    - 7 km resolution
    - Domain: Gulf of Mexico, along US east coast
    - Enrique Curchitser at Rutgers
    - Hindcast - yes
    - Reanalysis in the works → assimilate ocean data
    - Climate change simulations
- Workshop - bring NARW researchers together with salmon researchers and climate scientists/modelers
- Resources - Canada has money for NARW, NOAA fisheries could have money for NARW and could possibly dedicate Atlantic salmon money to a workshop
- ecopath model for Atlantic salmon under varying seal populations - someone the west has started to do this (?)
- Migration model - what happens to survival during migration period under changing environmental conditions
- Estuary → Dan Kircheis
    - incremental effects of dams felt in lower river/marine environment
    - mortality increases with every dam they pass
    - Our survival rates in the estuary are relatively similar to other river systems such as in Canada
    - coevolved diadromous fish community/concept of prey buffering
    - scare cormorants (predator control) - some sort of management efforts in estuary to reduce mortality in the estuary
- "Assisted Living" - rear fish in net pens in ocean
- Way to direct fish through the estuary to avoid predation?

Appendix 16. Recovery Plan climate actions that were informed by the scenario planning effort.

- Increase resiliency of all locally adapted stocks across the DPS by identifying and utilizing vacant habitats, including climate resilient habitats where they exist to create redundant populations.
- Establish and implement a water temperature monitoring protocol in all SHRUs to support efforts to identify climate vulnerable and climate resilient habitats.
- Inventory and prioritize freshwater habitats that provide the best opportunity for salmon recovery, including climate resilient habitats, in all SHRUs.
- Conduct a detailed climate change risk analysis for all locally adapted salmon populations in the DPS to help prioritize actions and develop new ones that are necessary to support climate resilient populations.
- Review and if needed, revisit critical habitat designation to ensure that there is sufficient climate resilient habitats into the foreseeable future necessary to allow for Atlantic salmon survival and recovery.
- Study marine prey base shifts to understand prey production dynamics, energy budgets, and distribution to inform management of forage to minimize impacts of climate change.
- Seek opportunities to enhance resiliency of Atlantic salmon to changing conditions in the estuary and marine environment. Managing for resilience includes: (a) examining interactions of salmon with predators and parasites; (b) conducting smolt, post-smolt, and adult tracking studies to further investigate migration ecology; and (c) continue evaluation of existing marine related data for correlations at U.S., North American, and North Atlantic scales to better characterize the impact of oceanographic changes.
- Investigate and implement alternative hatchery practices that increase survival of hatchery product in the wild and promote resilience to climate variability.