	Council *Atlantic Salmon (*Salmo salar*) Conservation and Management in a Changing Climate: The U.S. Approach to Insert a Climate Focus into Ongoing Salmon Conservation Efforts*	CNL(23)59 Agenda item 7a)

*Atlantic Salmon (*Salmo salar*) Conservation and Management in a Changing Climate: The U.S. Approach to Insert a Climate Focus into Ongoing Salmon Conservation Efforts*

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Introduction:

This paper describes the U.S. approach to integrate climate planning into existing Atlantic salmon management actions with the goal of promoting and enhancing climate resilient populations. This paper highlights a five-step approach that we are using to advance climate mitigation ideas into tangible climate actions. The approach has helped inform climate-focused recovery actions that were integrated into the Final Recovery Plan for Endangered Salmon (USFWS & NMFS 2018), coalesced scientist and managers around a shared vision to mitigate climate impacts on salmon, and provided the foundation to integrate climate measures into continued strategic planning efforts, regulatory measures, and proactive restoration actions.

The five-step approach starts with developing a national level climate strategy and culminates with the development of species specific science and management actions (Figure 1).

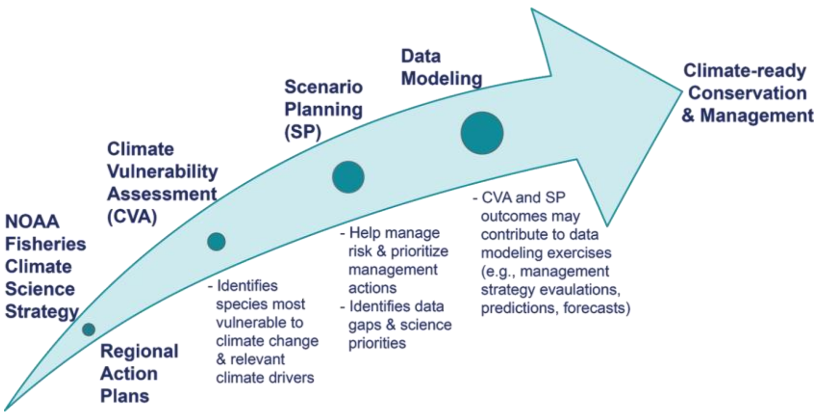

Figure 1. *The five-step approach used to advance climate mitigation ideas into tangible climate actions (see Borggaard et al. 2019)*

These five steps are designed to complement and build off of each other as the focus becomes more regional. NOAA Fisheries' National Climate Science Strategy outlines a process to guide the five regions of the United States (e.g., Northeast, Southeast, West Coast, Alaska and Pacific Islands) in the development of Regional Action Plans. This includes approaches for integrating climate change into resource management and highlights activities such as conducting Climate Vulnerability Analyses and Scenario Planning exercises. Results from the Climate Vulnerability Analysis and Scenario Planning direct and inform science and modeling that can inform the development of climate-ready conservation and management actions. The following sections walk through each of these steps, detailing how they advanced the consideration and inclusion of climate science into management actions for Atlantic salmon.

National Climate Science Strategy and Regional Action Plans:

The NOAA Fisheries National Climate Science Strategy (the "Strategy") and the Climate Science Regional Action Plans (RAPs) provide a national and regional approach to guide climate-smart resource management and implementation. The goal of these efforts is to increase the production, delivery, and use of climate-related information to support science, stewardship, and management of living marine resources (Link *et al.* 2015).

The Strategy identifies national-level climate objectives that are needed to inform management and stewardship (Link *et al*. 2015). The Strategy provides the goal posts for developing RAPs. The RAPs are five-year plans that identify priority science and management needs and specific actions to implement the Strategy in the five U.S. regions. The Northeast U.S. RAP (Hare *et al.* 2016; Saba *et al.* 2022) identified a number of regional climate planning and management actions, including Climate Vulnerability Analyses and Scenario Planning, both of which inform climate considerations within our overall management structure for Atlantic salmon.

Climate Vulnerability Assessment:

Climate Vulnerability Assessments evaluate the vulnerability of species to changing climate conditions over time, taking into account the species exposure and sensitivity to climate stressors. In the Northeast United States, a climate vulnerability assessment was completed for 82 managed fish and invertebrate species that included exploited, foraged, and protected species (Hare *et al.* 2016). Species vulnerability was determined by the extent that a species abundance or productivity could be impacted by climate change and decadal variability. Exposure variables include factors such as changes in sea surface temperature, air temperature, precipitation, ocean acidification, ocean currents, sea level rise, and salinity. Sensitivity variables include life history attributes such as a species mobility, habitat specificity, prey specificity, spawning cycle, and reproductive strategy. Other sensitivity factors include population size, growth rate, and early life history survival. Upon completion, all species were assigned a relative vulnerability score based on their exposure and sensitivity factors. Atlantic salmon were determined to be one of the two most vulnerable species. Conducting the vulnerability assessment on Atlantic salmon provided a structured framework to document systematically the life history of Gulf of Maine Atlantic salmon as it relates to its exposure to a number of different climate variables. The assessment also laid the foundation for understanding how climate change may affect salmon in the future.

Scenario Planning:

Scenario planning is a structured process used to explore plausible alternative future conditions under different assumptions and to help identify and prioritize potential future management actions with a focus on minimizing risk (Schwartz 1996, Peterson *et al.* 2003). Scenario planning can be an effective tool to identify common science and management actions that can be taken proactively to mitigate the impacts of climate change across multiple plausible future scenarios. After finding Atlantic salmon to be highly vulnerable to climate change, NOAA Fisheries conducted scenario planning to explore what the agency can do to improve U.S. Atlantic salmon population resilience to changing climatic conditions (Borggaard *et al.* 2019). The objectives of the effort were to further understand the challenges of managing Atlantic salmon in a changing climate, identify management actions and research opportunities, and increase collaboration and coordination on climate-related recovery actions (Borggaard *et al.* 2019). Atlantic salmon was the first species on which NOAA Fisheries conducted scenario planning and stemming from its success, scenario planning has been used to inform climate decision-making for many other species. Scenario planning has become a major tool in NOAA Fisheries climate planning portfolio.

The basic approach to scenario planning is to identify two primary but independent drivers impacting the condition of interest (i.e., Atlantic salmon productivity) into the future given changing conditions. These drivers can be visually represented as axes on a graph to form four quadrants, each representing a different plausible future scenario. Guided conversations are then conducted to explore what risks and opportunities each scenario/quadrant provides, what preparations are needed, and what indicators should be tracked over time (Borggaard *et al.* 2019). For Atlantic salmon, the two selected drivers were climate change and connectivity. We selected connectivity as our second axis as it continues to be a high priority threat to salmon survival in the United States (NMFS 2009). A key outcome of this exercise was a number of science questions that were prioritized to understand and mitigate the effects of climate change. Some of these questions included:

- What are the projected future conditions for both freshwater and marine habitats?
- What are the life stage specific environmental thresholds (e.g. temperature, flow, etc.?
- How will Atlantic salmon behavior change in response to a changing climate?
- How will habitat productivity change?
- Where and why are salmon dying in the ocean?
- How will a changing climate further affect survival?
- Are there ways to increase marine survival generally and in light of climate change?

Many of these science questions were tailored into recovery actions that were incorporated into the Final Atlantic Salmon Recovery Plan (USFWS & NMFS 2018).

Science and Modeling:

Since the completion of the Scenario Planning effort we have proceeded to address many of the resulting science questions. We highlight three of those efforts below:

Life stage specific vulnerabilities: The synthesis of Atlantic salmon life stage specific vulnerabilities to climate change helps address our questions regarding lifestage specific environmental thresholds and how U.S. salmon productivity may change in response to a changing climate (Henderson *et al.* in press). Refined understanding of these vulnerabilities is helping to inform short- and long-term conservation planning and management action implementation, as well as identify data gaps where more information is needed.

Baseflow modeling: Baseflow modeling is a tool to help inventory and prioritize climate resilient freshwater habitats (Lombard *et al.* 2021). Water temperature is an important limiting factor of Atlantic salmon abundance based on the therma-maxima of the species (Elliot & Elliot 2010) and baseflow has been shown to be an influential element of water quantity and water temperature, particularly in the summer months (Hodgkins & Dudley 2011). The baseflow modeling effort in Maine helps us identify stream reaches that are richer in cold-water habitat, which can in turn be prioritized for conservation and restoration (Lombard *et al.* 2021). Enhancing access to cold-water refugia is a priority management action to mitigate the impacts of future climate-induced warming stream temperatures.

Impacts of delay at dams: Warming rivers due to a warming climate will likely further increase environmental stressors on Atlantic salmon and increase mortality. Dams can significantly delay passage of upstream migrating adults (Noonan *et al.* 2012; Izzo *et al.* 2016). These delays increase the time that adult salmon spend in warmer waters and increase their migration times.

A recently completed study of the impacts of delay and water temperature on the Penobscot River, Maine, concludes that Atlantic salmon that experienced delays below dams of 16 - 23 days lost between 11% and 22% of their fat reserves; this loss could be consequential to spawning success and post-spawn survival (Rubenstein *et al*. 2023). These results highlight the importance of implementing management actions to minimize delays for migrating pre-spawned adult salmon due to dams, particularly in areas with warming waters.

Climate-Ready Conservation and Management:

The fifth element of the climate-ready approach is applying the threat identification, planning, and science from the first four elements to inform conservation and management actions. Here, we provide three examples of how this strategic approach is informing the development of climate-ready conservation and management actions for Atlantic salmon.

Strategic Planning: Improving connectivity at dams and road crossings has been a priority for the U.S. salmon program since 2006. Where dam removal is not possible, we work to improve passage at those dams, both in terms of efficiency and timing. To provide the greatest benefit to salmon and increase their resilience to climate change, we must be strategic in our efforts to restore connectivity by targeting areas that will afford the greatest conservation benefit. The base flow modeling provides us with information we can use to focus connectivity efforts that help ensure access to the most climate resilient areas.

Regulatory Measures: Through the authorities of the U.S. Federal Power Act and the Endangered Species Act, we work to implement measures at hydro-electric dams that are necessary for the protection of endangered salmon, including measures to improve passage rates and reduce delay. Previous studies have quantified the negative impacts associated with dams and the effects on emigration of juvenile salmon to the ocean. The recent study on the impact of delays at dams for adult salmon has expanded our knowledge on the energetic cost of those delays. We will continue to use the best available scientific information to inform the management and regulatory actions implemented at dams, including consideration of climate science and how warming waters can exacerbate existing threats.

Proactive Conservation: Maine's rivers and streams were heavily modified during 100+ years of log drives. Today, these modified rivers continue to be over-widened, straightened, lack habitat complexity, and lack riparian and in-river cover. These factors increase the sensitivity of rivers and streams to warming conditions. Given that there are over 16,000 kilometers of river and stream networks in Maine, new information on life history vulnerabilities and on the current and projected habitat conditions helps to identify where habitat restoration projects are most needed and will afford the greatest benefit to salmon. In addition, this new information helps with identifying what habitat features are needed to afford the most protection to the most climate sensitive life stages.

Conclusion:

The Climate Vulnerability Assessments and Scenario Planning exercises resulted in a convergence of knowledge and ideas to formulate an approach to mitigate the impacts of climate change on Atlantic salmon in the Gulf of Maine. Although both efforts involved salmon experts, they also involved numerous individuals from a wide range of disciplines not previously represented within the salmon program. Of note, the Scenario Planning exercise involved people and agencies not typically involved in Atlantic salmon science and management. These meteorologists, hydrologists, geomorphologists, and ecologists were able to provide meaningful science support to the salmon program in unexpected ways. Although some of the actions and science needs that came out of the Climate Vulnerability Assessments and Scenario Planning had been discussed previously, these exercises helped unify and build partnerships both within the salmon program as well as with other participating entities. These partnerships and the resulting science efforts have contributed valuable information that is being integrated into existing proactive and regulatory management actions. This information has also enabled us to provide better guidance to stakeholders on where and what types of management actions will afford the greatest benefits to salmon now and into the future.

Next Steps:

At present, modeling efforts are continuing to refine our understanding of where climate vulnerable and climate resilient habitats are located and how that may change in light of climate projections. We are also pursuing a Management Strategy Evaluation (MSE). MSEs are a modeling exercise that allows fishery managers to compare different management strategies, taking into account risks and trade-offs, to achieve a specified management objective (Punt *et al.* 2016). By incorporating resource constraints, including uncertainties associated with climate change, into the operating models of an MSE, managers can use the outputs from applying the MSE to identify the best, most effective management strategy to achieve identified conservation and management objectives. Development and use of an MSE is an appropriate next step in determining the most effective strategies to advance our conservation objectives for Atlantic salmon in the face of identified uncertainties related to climate change and other factors. As we build our knowledge base on the current and projected impacts of climate change on salmon and salmon habitat, and increase the tools in our toolbox for managing these impacts, we will need to be strategic in maximizing the limited resources available for conservation.

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