Agenda Item H.2
Attachment 1
September 2022

DRAFT Western Regional Action Plan to Implement the NOAA Fisheries Climate Science Strategy in 2022 - 2024

Editors: Toby Garfield and Rich Zabel

Prepared by the Northwest Fisheries Science Center, the Southwest Fisheries Science Center and the West Coast Regional Office

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

National Marine Fisheries Service
November 2021 - DRAFT for public comment

DRAFT Western Regional Action Plan to Implement the NOAA Fisheries Climate Science Strategy in 2022 - 2024

Editors: Toby Garfield and Rich Zabel

Prepared by the Northwest Fisheries Science Center, the Southwest Fisheries Science Center and the West Coast Regional Office

ABOUT THIS DOCUMENT

This is a draft plan for public review and comment. Comments submitted will be considered when drafting the final document. Implementation of the plan is contingent on available resources.

Table of Contents

Executive Summary

Changing climate and oceans are affecting the nation's valuable living marine resources and the many people, businesses and communities that depend on them. Warming oceans, melting sea ice, rising seas, extreme events, and acidification are impacting the distribution and abundance of species, and the structure of marine and coastal ecosystems in many regions. These impacts are expected to increase and there is much at risk.

To prepare for and respond to climate impacts on marine and coastal resources, the 2015 NOAA Fisheries Climate Science Strategy (NCSS) identified seven key objectives to increase the production, delivery, and use of climate-related information needed to fulfill the agency's mandates (e.g., fisheries management, protected resources conservation) in a changing climate. Beginning in 2016, NOAA Fisheries developed Regional Action Plans (RAPs) to implement the NCSS in each region based on regional needs and capabilities.

The initial Western Regional Action Plan (WRAP) was released in 2016 and focused on implementing the NCSS in the California Current Large Marine Ecosystem over three to five years. Substantial progress has been made since 2016, but more remains to be done to accomplish the objectives of the NCSS. This draft updated WRAP builds on previous efforts and describes proposed actions in 2022-2024 to continue to implement the NCSS and provide decision makers with information to prepare for and respond to changing conditions in this region.

The goals of this draft WRAP are to coordinate climate science activities through improved communication among the Northwest and Southwest Fisheries Science Centers and the West Coast Regional Office, support climate and ecosystem models, and help examine climate related indices and the data collected by the many ship-based surveys. This effort will also incorporate a variety of other goals and objectives including development of the integrated ocean modeling and decision support system proposed in the NOAA Climate, Ecosytem and Fisheries Initiative.

The 2016 WRAP had seven planned actions, and significant progress has been made on four of these actions. Work on the four activity areas will continue and future actions will emphasize the remaining three areas: (i) establish a framework for strategic planning of climate work, originally conceived as the NMFS West Coast Climate Committee (WC^3) and Program (WCCP), (ii) build scientific expertise within the Centers to address ongoing and expected changes, and (iii) review, coordinate, and standardize existing data-collection efforts and analyses to bring climate indices and projected trust species' responses into management applications. A number of ongoing and anticipated actions are listed below with the NCSS objectives they address, to illustrate the range of planned and proposed climate-related science.

Informing Management (NCSS Objectives 1-3)

- Develop and deliver the California Current Integrated Ecosystem Assessment (CCIEA) Ecosystem Status Report to the Fishery Management Council
- Develop Management Strategy Evaluations for select species (sablefish, swordfish, sardine, albacore, coastal pelagic species)
- Conduct Climate Vulnerability Assessments (e.g. managed stocks, marine mammals, turtles, habitat)
- Improve the potential to use Adaptive and Dynamic Ocean Management
- Implement the Climate, Ecosytem and Fisheries Initiative
- Address recommendations from the Climate and Communities Initiative and scenario planning

Understanding mechanisms and projecting future conditions (NCSS Objectives 4 & 5)

- Support and strengthen forecasting models (e.g. JSCOPE, Future Seas)
- Conduct salmon climate-driven lifecycle modeling
- Advance ecosystem modeling of the Northern California Current
- Develop spatial distribution/abundance modeling papers (e.g. from the "Location, location, location" project)

Infrastructure and Tracking Change (NCSS Objectives 6 & 7)

- Maintain CCIEA Ecosystem Status Report
- Enhance Strategic Planning and capacity building
    - Data coordination - collection and sharing
    - Standardized reporting

Human dimensions

- Maintain and expand data collection (NCSS Objectives 6 & 7)
- Understand the influence of fishing portfolios on community response to extreme events (NCSS Obj. 5)

Going forward, the WRAP will also support efforts ensuring that fisheries considerations are included as other ocean uses are proposed. Many activities that fall under this umbrella, including human dimension considerations, will allow species management to be considered in light of climate change.

Introduction

Climate change unequivocally represents the most serious threat to our oceanic fishery resources, protected species, and marine and freshwater habitats. It has and will continue to alter the composition, and hence function, of marine and terrestrial ecosystems and has led to shifts in species distributions. It has also created deleterious conditions that can potentially lead to the extinction of many species, particularly endangered and threatened salmon. It has created conditions in the Northern California Current that stimulate marine heat waves, increase ocean acidification, and create new conflict between human uses of the ocean and protected species. All of these will have negative impacts on coastal communities that rely on marine and freshwater resources. Because of our legal mandates to manage and protect the nation's living marine resources it is imperative that NOAA Fisheries study and understand these impacts, the effects on communities, and potential mitigation actions.

Understanding climate impacts on fisheries and fisheries management are long-standing NMFS concerns that have led to multiple efforts addressing different aspects of these impacts. The NOAA Fisheries Climate Science Strategy[1] (NCSS) was designed to provide an organizing structure for these efforts through a set of seven linked and interdependent climate science objectives that start with the science infrastructure and lead to climate-informed reference points. Each Fishery region was requested to develop a plan for implementing the NCSS. In the California Current Large Marine Ecosystem, the two Science Centers, NWFSC and SWFSC, and the West Coast Regional Office collaborated to produce the Western Regional Action Plan or WRAP.

The NCSS draws attention to the need to coordinate climate-related activities within regional ecosystems to enable a national discussion on climate impacts to marine ecosystems and managed fisheries. This provides the forum to review what activities are ongoing; to identify gaps in knowledge, expertise or activities; and to provide guidance and advice on potential future activities and needs. The WRAP has fostered an expanded dialogue between the two Science Centers and the Regional Office. Through review of ongoing activities, identification of knowledge and activity gaps and advice on potential future needs, this group has fostered an ongoing west coast dialog that brings climate science to management and vice versa. The WRAP serves as both the coordination of many programs and a blueprint for future activities.

The 2016 Western Regional Action Plan 1.0[2] provided the west coast blueprint to prepare and mitigate for climate impacts on eastern north Pacific fisheries, managed and protected species, and habitats. To date, WRAP has done a commendable job organizing west coast climate science linked with living marine resources, primarily by hosting a series of climate related workshops and secondarily through conversations between the science centers and the regional office. The NCSS is one of a number of efforts to integrate ecosystem conditions and processes with fisheries science. Other NOAA efforts include: EBFM (Ecosystem Based Fisheries Management), CAFA (Climate and Fisheries Adaptation; formerly COCA), CEFI[3] (Climate,

[1] Link et al. 2015. NOAA-TM-NMFS-F/SPO-155

[2] NOAA-TM-NMFS-SWFSC-565, 2016

[3] NOAA Climate, Ecosystem and Fisheries Initiative Implementation Approach

Ecosytem and Fisheries Initiative), IEA (Integrated Ecosystem Assessment), WCOFS (West Coast Operational Forecast System), DisMAP (Distribution Mapping and Analysis Portal), NAMEs (National Marine Ecosystem Status web portal), CESC (Center Ecosystem Science Committee), HI-EBFM (Human Integrated EBFM Research Strategy), DFO/NMFS Climate and Fisheries Collaboration, and various applicable laws and executive orders. Ultimately, these efforts need to operate synergistically for advancing shared science and management goals under changing conditions. Long term success will require inter-center (i.e., CCLME-wide) collaboration to capture and manage the ecosystem and its various components at the scales they operate.

The NCSS team recently completed a synthesis of Regional Action Plan accomplishments between 2016 – 2020[4]. The West Coast chapter to this synthesis lists our accomplishments and highlights areas needing additional attention. WRAP 2.0 (this document) will highlight the continuation of successful efforts, examine areas where progress has stalled, and identify opportunities for expanding the use of climate science in management applications.

From its inception, the WRAP has been connected and, when possible, integrated with the other west coast efforts to embed climate change considerations into the science and management of harvested species, protected species and habitats. In particular, the WRAP has collaborated with the California Current Integrated Ecosystem Assessment (CCIEA), the EBFM Western Region Implementation Plan (WRIP), and the Pacific Fisheries Management Council's (PFMC) Fishery Ecosystem Plan (FEP). The proposed Climate, Ecosytem and Fisheries Initiative (CEFI) aims to enhance and bring many of these elements together through enhanced model development and the creation of a national ocean modeling framework and regional Fisheries and Climate Decision Support Systems (FACSS). The WRAP identified activities to date have included working with both Centers on developing ocean, fisheries and human dimension indices that are used in the annual IEA Ecosystem Status Report (ESR) given to the PFMC. These will be foundational elements for the CEFI FACSS toolbox to support targeted research to understand impacts, identify risks and evaluate best management strategies.

Funding resources bear mention. Over the past decade, Fisheries budgets have either held steady or decreased. The agency has requested permanent funding to begin building the infrastructure required to execute the programs coordinated in the WRAP, but progress is incremental, at best, and it will take time to build programs to scale. Much of the available funding for climate science has been temporary funds; permanent staff are largely yet to be hired, but will be critical as programs advance. To date, increasing scientific expertise and impact have been met with temporary affiliate staff hiring through contracting agencies, National Research Council (NRC), or via Cooperative Institutes. The progress that is being made with support of these affiliates has been excellent; however, this means that the human capital 'infrastructure' and expertise upon which much of the work has been done is currently largely temporary, and the agency will need to plan for a transition to more permanent staff for the WRAP objectives to be fully realized. Ongoing research will need to be transitioned into operational scientific products to support managers and decision makers and this requires sustained oversight by qualified federal staff. In addition to these challenges at the Centers, the Regional Office must build a similar permanent

[4] NCSS 5-year Progress Report (Peterson et al. 2021)

capability and capacity to facilitate the use of climate science in management programs. Supporting the science-to-management interface will be critical as the products outlined in the WRAP are developed and implemented and constituencies for them grow. Efforts to include these new capabilities have been requested for future budgets.

Going forward, WRAP-led coordination will promote data standards and metrics for gauging progress, connect projects with appropriate models, and engage social scientists with other programs to understand climate change impacts on Coastal Communities. The overall goal is to ensure, through expanded communication, that climate and ecosystems activities across the US West Coast are aligned.

Higher Level Activities

We will begin by expanding upon the aforementioned higher-level activities and then discussing some of the specific projects we plan to promote in the next three years.

Coordination
The WRAP strives to improve communication across climate projects and better coordination with the WCRO. Beginning in FY22, the Region and Centers will prioritize twice-yearly joint meetings between the Centers' WRAP team and the Region's Climate Team. The focus of these meetings would be to: review WRAP research progress and review and prioritize tool development to address WCRO climate science needs.

The CCIEA team has produced a 3-year plan. WRAP is coordinated with the IEA 3-year plan and we propose a joint workshop addressing the coordination of the portfolio of the various NOAA Ocean Surveys along the West Coast.

Better coordination with other regions, particularly Alaska. We had a joint workshop scheduled with the Alaska Fisheries Science Center to discuss our efforts and look for avenues to collaborate. We will convene this workshop in the next year or so, depending in part on COVID-19 restrictions.

Support
Ocean and Ecosystem Models. Many WRAP projects combined environmental data (e.g. from an ocean model such as ROMS) with a statistical (e.g. species distribution model, mechanistic model) or an ecosystem model (e.g. Atlantis, or EcoTran) to assess the impact of climate change on a target species. WRAP will support the development of these models by providing a forum for sharing information on the data inputs needed by these models, dissemination of model outputs and the application of the models to longer time scales and broader geographic coverage. We will attempt to ease the burden on individual projects by promoting a common modeling platform for west-coast scientists. This includes working to support common remotely-sensed data streams (e.g. integrated chlorophyll measurements), ROMS from academic partners, and the development of MOM6 and WCOFS by Oceanic and Atmospheric Research (OAR) and National Ocean Survey (NOS) line offices.

Species distribution models have been used to examine historical patterns of habitat use for long-term citing efforts but also to provide near real time information on where species are most likely to be (e.g. EcoCast, WhaleWatch). With funding efforts from NOAA's Climate Program Office, skill at seasonal forecast and decadal projection scales are being explored so these models can be both tactical, and proactively used for planning. These offer spatially-explicit products to support climate-ready management, but rely on stationarity between species-environment relationships to ensure future skill. Operationalizing and continued validation of these tools are critical to ensure their utility as part of a broader management portfolio.

Assessment

What data are we collecting? There are numerous fisheries-directed CCLME research surveys hosted by the two Centers. The data from these surveys need to be collected and processed in a consistent manner that will allow use of the data to plan for climate change adaptation coastwide. Most of the effort goes into using the data for stock assessments; thus, not much planning has been directed to climate variability and change analyses. The NWFSC is currently conducting a center-wide review of their ocean surveys; the SWFSC will shortly initiate a similar comprehensive review. Following completion of these two analyses, we will conduct a workshop to review, coordinate, maintain, and standardize existing observational efforts. Wells et al (2020) present strategies for identifying data gaps and building the relevance of a research program for management applications. Surveys, modeling efforts, and monitoring programs to evaluate for their relevance to advancing WRAP objectives include: CalCOFI, RREAS, JSOES, Newport line, Trinidad line, Prerecruit-NCC, CPS, sea lion, cetacean ecosystem assessments, SHSTM, National Water Model, NorWeST, NANOOS, SCCOOS, CeNCOOS, West Coast National Marine Sanctuaries, etc.

Support of the Climate Fisheries Initiative

We note that the activities listed above would support the goals of the Climate, Ecosytem Fisheries Initiative (CEFI) that have been developed and proposed as part of the 2021-2022 Federal budget. This NOAA-wide Initiative would "implement the initiative to deliver and support the regional hindcasts, nowcasts, forecasts, and projections needed across the temporal (near-real-time, subseasonal-to-seasonal, seasonal-to-decadal, and multi-decadal) and spatial scales (U.S. coastal and ocean ecosystems) required to effectively fulfill NOAA's stewardship missions in a changing climate". While still in the initial planning stages, the initiative calls for permanent funds to support new permanent employees within each living marine resource management region. These positions would include ocean modelers at each science center to run regional ocean models and serve as a conduit for model output to center scientists, as well as multiple positions to advance regional Fisheries and Climate Decision Support Systems (FACSS). Hires within the FACSS would be focused on advancing analyses and tools to support management, and would include a regional coordinator as well as multiple scientists with a range of expertise as needed (e.g., population dynamics, management strategy evaluation, ecosystem modeling, economics and social sciences). FACSS would also work to transition and maintain research analyses into operational science products for IEAs, stock assessments, protected species toolboxes, and other science products that inform managers and decision makers. NMFS activities would also be supported by the involvement of other NOAA line offices (especially

OAR and NOS) in CEFI, particularly through their roles in ocean modeling, training, data management and dissemination. If funded, the CEFI's additional resources would present an opportunity to align the CCIEA Ecosystem Status Reports, risk analyses, MSEs, and protected species needs, with WRAP planning efforts to build a holistic long-term strategy for climate-ready fisheries science.

NMFS has partnered with other line offices, particularly OAR and NOS through the CEFI, to develop community models for both short- and long-term forecasting and to develop decision-support tools for fisheries management in this changing environment.

Key Needs/Actions

In the following sections, we will focus on projects that we plan to implement over the next 3 years. We will begin with an evaluation of the progress we have made on the original WRAP plan.

Update on project status and management needs from the original WRAP

The original WRAP had seven planned actions. Significant progress has been made on specific applications within four areas: (i) management strategy evaluations (MSE) that include climate projections, multiple species, multiple fleets, spatial distribution changes and economic models, (ii) full life-cycle models for Pacific salmon that are explicitly linked to climate projections and management actions, (iii) development of the California Current Integrated Ecosystem Assessment (CCIEA) and its Ecosystem Status Reports (ESR), and (iv) dissemination of climate-related science and information, e.g., climate vulnerability analyses and other communications. These project areas will continue or expand over the next 3 years as an ongoing component of NMFS science and management.

The other three planned action areas have been initiated to varying extents, but do not have completed products to date: (i) establish a framework for strategic planning of climate work, originally conceived as the NMFS West Coast Climate Committee (WC^3) and Program (WCCP), (ii) build scientific expertise within the Centers to address ongoing and expected changes, and (iii) review, coordinate and standardize existing data-collection efforts and analyses to bring climate indices and projected trust species' responses into management applications.

The two Centers and the Regional Office have created internal climate committees; the SWFSC created the Center Ecosystem Science Committee (CESC), the NWFSC created the Climate Change and Ocean Acidification Network, the Science Centers provide liaisons to the Regional Office's cross-divisional Climate Team, and the Regional Office provides liaisons to the WRAP team. To date, there has been some coordination across these committees, but there hasn't been a common directive that integrates across committees to reduce duplication of effort and to ensure that common goals can be addressed. There needs to be further collaboration among regional and national climate groups as to the need and benefit of creating a stronger climate tie between the entities.

The West Coast Regional Office has identified management applications pertinent to managing trust resources under climate change (see appendix 2). Some of the applications identified by the region include:

1. Tools to assess the resilience of habitat areas being considered for species' protection and reintroductions; including how human interaction with freshwater habitat may change under climate change.
2. Incorporation of climate change impacts into streamflow, temperature and salmon habitat suitability projections at a variety of scales and time-steps.
3. Tools to assess climate change impacts on the range, distribution, phenology, disease, and abundance and productivity of protected and managed species in bays and estuaries.
4. Tools to assess how our changing climate, changing ocean physical states, chemistry, and changing ocean productivity may affect: species' interactions in ecological communities over time; the availability of habitat to our species, compression or expansion of habitat; and the availability of fisheries-targeted species to fishing communities.
5. Evaluation of the potential for extreme-weather and climate events, hypoxic zones, drought and flooding conditions, and sea-level rise to affect human communities, including ocean industries such as fisheries and coastal aquaculture.

Ongoing efforts that will continue

There are numerous WRAP-related efforts bringing climate science into management considerations. These include the CCIEA ESR, six separate MSEs, climate vulnerability assessments, adaptive management strategies, ecosystem forecasting models and life-history analyses. There is diverse funding for these analyses; the WRAP provides the forum for integrating these efforts.

Informing Management

California Current Integrated Ecosystem Assessment -- Ecosystem Status Report

The CCIEA focuses on providing ecosystem data and interpretation to the Pacific Fishery Management Council. Since 2014 an annual ESR has been presented to the full council. During the year, the CCIEA works with the Council's Science and Statistical Committee, and its subcommittees, to review and validate ecosystem indices to build into the report. The report has evolved each year to emphasize trends that may impact the managed resources and impacts on the fishery communities. Three recent examples are the development of new indices to monitor upwelling, marine heatwaves, and habitat compression in the CCLME. In 2016-17, the Council conducted a Fishery Ecosystem Plan (FEP) initiative that provided a coordinated review of the ESR's indicators and other information and analyses to better tune the ESR's contents to the Council's ecosystem science information needs. The FEP is currently being updated. Tommasi et al. (2021) examines the potential for connecting ecosystem models and analysis to management needs articulated under that Council initiative.

MSE efforts:

Management Strategy Evaluations remain an important tool for fisheries management in a changing environment. These efforts will continue to inform management options.

Sablefish

The NE Pacific sablefish MSE work is ongoing, with main focal points being the collaborative development of the technical MSE tool and engaging stakeholders in the MSE process. Recently, the Pacific Sablefish Transboundary Assessment Team (PSTAT), in collaboration with the Northwest Fisheries Science Center (NWFSC), Alaska Fisheries Science Center (AFSC), Canadian Department of Fisheries and Oceans (DFO), Alaska Department of Fish and Game (ADF&G), Pacific Fishery Management Council (PFMC), and North Pacific Fishery Management Council (NPFMC), held a public workshop (April 27-28, 2021) to solicit feedback on the ongoing range-wide sablefish management strategy evaluation. The NE Pacific sablefish workshop report is available at *pacificsablefishscience.org*, and provides a synthesis of workshop feedback that will be considered during both Phase I (MSE management procedures, through 2023) and Phase II (future research, in 2023 and beyond). A primary goal for Phase I of the PSTAT research project is to learn about sablefish dynamics across the NE Pacific and provide the best scientific advice to regional managers. Phase II priorities, which are dependent upon available funding and resources, include incorporating climate considerations into the operating model. Climate considerations for Phase II are supported by ongoing range-wide review and analyses of climate-recruitment relationships and spatio-temporal variation in recruitment that will set the stage for climate related hypotheses to be explored via MSE.

Swordfish

Building upon our real-time prediction tools in EcoCast, the Future Seas project (https://future-seas.com) focused an MSE on the drift gillnet swordfish fishery in the California Current. For rare and broadly distributed bycatch species, dynamic closures are likely to be most effective when used with other tools (e.g. Smith et al. 2021a). In the next phase of development, the model ensemble will be expanded to include a multispecies age structured population model for the forage assemblage and the Atlantis ecosystem model to generate projections of ecosystem state.

Sardine

An ongoing sardine MSE aims to explore issues of climate resilience and multi-species management on the sardine (and other CPS) fisheries. To date, we have assessed the potential impact of a shifting sardine distribution on sardine landings, and identified the important influence other CPS landings and the seasonal annual catch limit (ACL) allocation scheme have on this impact (Smith et al. 2021b). Bioenergetic, individual-based, and spatial age-based models of sardine are currently being refined for use as operating models in MSEs. A second CAFA funded project building upon Future Seas will focus on forage species to improve climate-ready information for decision makers.

Albacore

Two MSEs have been developed for albacore. The first examines scenarios for the entire North Pacific stock, and was completed in collaboration with the ISC albacore working group (ISC 2019). The final report will be available later in 2021. The second was part of the Future Seas project, and linked species distribution models (Muhling et al. 2019) with albacore biomass to derive indices of albacore availability, and predict port-level landings. These models were informed by a network analysis of the albacore fleet (Frawley et al. 2020) and are being combined with fishing community level social vulnerability indices to assess climate impacts on albacore dependent communities.

Coastal Pelagic Species

Phase II of the Future Seas project (2020-2023) will develop a climate-informed ecosystem MSE framework focused on coastal pelagic species. This work will assess the performance of current and alternative management strategies under a changing climate, shifting forage species composition, and varying predator populations. The MSE framework will use an ensemble of spatially explicit and climate-informed operating models including Atlantis, a multispecies model (MICE), and a sardine single-species model (SPM). To assess performance of explicit economic objectives, the operating models will be coupled to economic models to represent the fisheries dynamics and to develop socio-economically explicit performance metrics.

Climate Vulnerability Assessments

Climate Vulnerability Assessments are ongoing for 61 Fishery Management Plan stocks, marine mammals, turtles, and habitat assessments.

Adaptive management

Dynamic ocean management (DOM)

Adaptive management approaches use expert assessment to fine-tune management approaches during a management cycle to allow for timely intervention. A drawback of such approaches, however, is that they require expert elicitation to translate new information into management decisions, which can slow the process but also can be extremely successful when done rapidly. DOM utilizes real-time environmental and ecosystem data to enable managers to make rapid fisheries management decisions based on changing ocean conditions. On the west coast we have one DOM control rule, Temperature Observations To Avoid Loggerheads (TOTAL) (https://coastwatch.pfeg.noaa.gov/loggerheads/) and two DOM modeling approaches (EcoCast and WhaleWatch) (https://coastwatch.pfeg.noaa.gov/ecocast/) (https://coastwatch.pfeg.noaa.gov/projects/whalewatch2/) to address human-wildlife conflict.

New DOM tools are being developed to inform the risk assessment and mitigation program for whale/fixed gear entanglement on the west coast, aiming to provide information on real-time environmental conditions (e.g. habitat compression index, HCI), real time forage and whale distributions, and information on fleet effort and economics to conduct a more thorough trade-off analysis. These DOM tools are climate-ready as they respond to changing ocean conditions as long as stationarity between species and the variables used to describe their habitat remains. The tools are being tested with seasonal forecasts and downscaled climate projections to provide multiple time-scales of decision-relevant projections for the US West Coast.

Forecasting models

On seasonal timescales (1-12 months), there are several efforts to develop west coast ocean forecasts for fisheries applications. Downscaled ROMS forecasts for the CCLME have been run for a retrospective period (1982-2010) to enable a multi-decadal skill assessment and explore the potential for ecological forecasts. Forecast skill is dependent on ocean state (sea surface temperature (SST), sea surface height (SSH), bottom temp, and stratification tend to have good skill), time of year (winter/spring are best, fall is worst), and lead time (generally lower skill at longer lead times). SST forecasts are being evaluated for potential application to the TOTAL (Temperature Observations to Avoid Loggerheads), which currently is based on observations but could provide additional lead time based on forecasts. Prospects for additional applications are being explored, and those with the most potential will be targeted for further development and transition to real-time application. Longer term forecasts will be part of our collaboration with OAR and the development of MOM6.

J-SCOPE

WRAP efforts to develop seasonal forecasts of ocean conditions will continue to benefit from JSCOPE (JISAO Seasonal Coastal Ocean Prediction of the Ecosystem), a partnership led by Dr. Samantha Siedlecki (Univ Connecticut) and involving scientists from the NMFS, ESRL, PMEL, and academia. JSCOPE produces short-term (6 to 9 month) forecasts of oceanographic conditions off of Oregon, Washington and Vancouver Island, using oceanographic models and forcings derived from downscaled simulations from the NOAA Climate Forecast System (Siedlecki et al. 2016). Outputs include 3-D, high-resolution predictions of temperature, pH, oxygen, and chlorophyll. These outputs yield seasonal forecasts of distribution of key species such as sardines, hake, and larval Dungeness crab (Kaplan et al. 2016, Malick et al. 2020, Norton et al. 2020). Ongoing work involves seasonal forecasts of catch rates and meat quality of Dungeness crab, in collaboration with state and tribal agencies. Dungeness crab, hake, and sardines are typically among the highest-ranking species in terms of West Coast fishery landings or revenue. These seasonal forecasts are tailored to annual decision-making processes, as fishery managers grapple with climate variability and shifts in stock location, quality and abundance.

Understanding mechanisms and projecting future conditions

Salmon freshwater-marine cumulative effects, ecosystem models and cost effectiveness of recovery actions

Biophysical models that link parts or all of a salmon's life-cycle to climate and salmon habitat have been developed and are now regularly used to support freshwater habitat management for West Coast salmon. For instance, biophysical models are now used to evaluate consequences of reservoir storage, water release alternatives, and future weather and climate on the early life-stage survival rates for ESA-listed Winter Run Chinook salmon in California's Central Valley (see https://oceanview.pfeg.noaa.gov/CVTEMP/). Likewise, habitat-linked life cycle models have been developed and used to evaluate the consequences of climate change and habitat restoration alternatives for salmon in Washington's Chehalis Watershed and the Snake River Basin. Both the NW and SW Fisheries Science Centers are putting increased effort into better understanding and modeling of "carry-over" effects of climate-influences on salmon from one habitat and life-stage to the next. These models essentially follow salmon from freshwater to estuary to ocean and back to estuary and freshwater. Model scenarios explore how different management actions (e.g. habitat restoration, dam removal, reservoir release alternatives, etc.) might be used to mitigate negative impacts of climate change.

Life cycle modeling has largely focused on climate impacts and management actions in the freshwater life stages, with improvements in climate projections for stream temperature, stream flow, and salmon responses. We will continue this work in numerous locations, including the Central Valley, California, the Columbia River Basin, and other locations such as the Chehalis River Basin, Puget Sound, and California's coastal watersheds. A looming gap is application of these tools to management actions and climate impacts in the marine environment.

The goal of the salmon case study is to bridge the gap between recent projections of severe declines in threatened salmon due to climate change (e.g. Crozier et al. 2021), and a better characterization of potential management responses to mitigate declines in marine survival. Salmon marine survival depends on some combination of bottom up (nutrient-based) and top down (predator-driven) species interactions, and salmon life history. Thus, the WRAP project will parameterize ecosystem models to test hypothesized species interactions across multiple salmon life histories. We will test a large set of conceptual models previously proposed using a combination of existing ecosystem models and statistical models that focus on key species interactions. We will compare yearling spring/summer Chinook, subyearling fall Chinook from different regions, and coho life histories by varying the body size, timing, and spatial distributions driving predator/prey interactions.

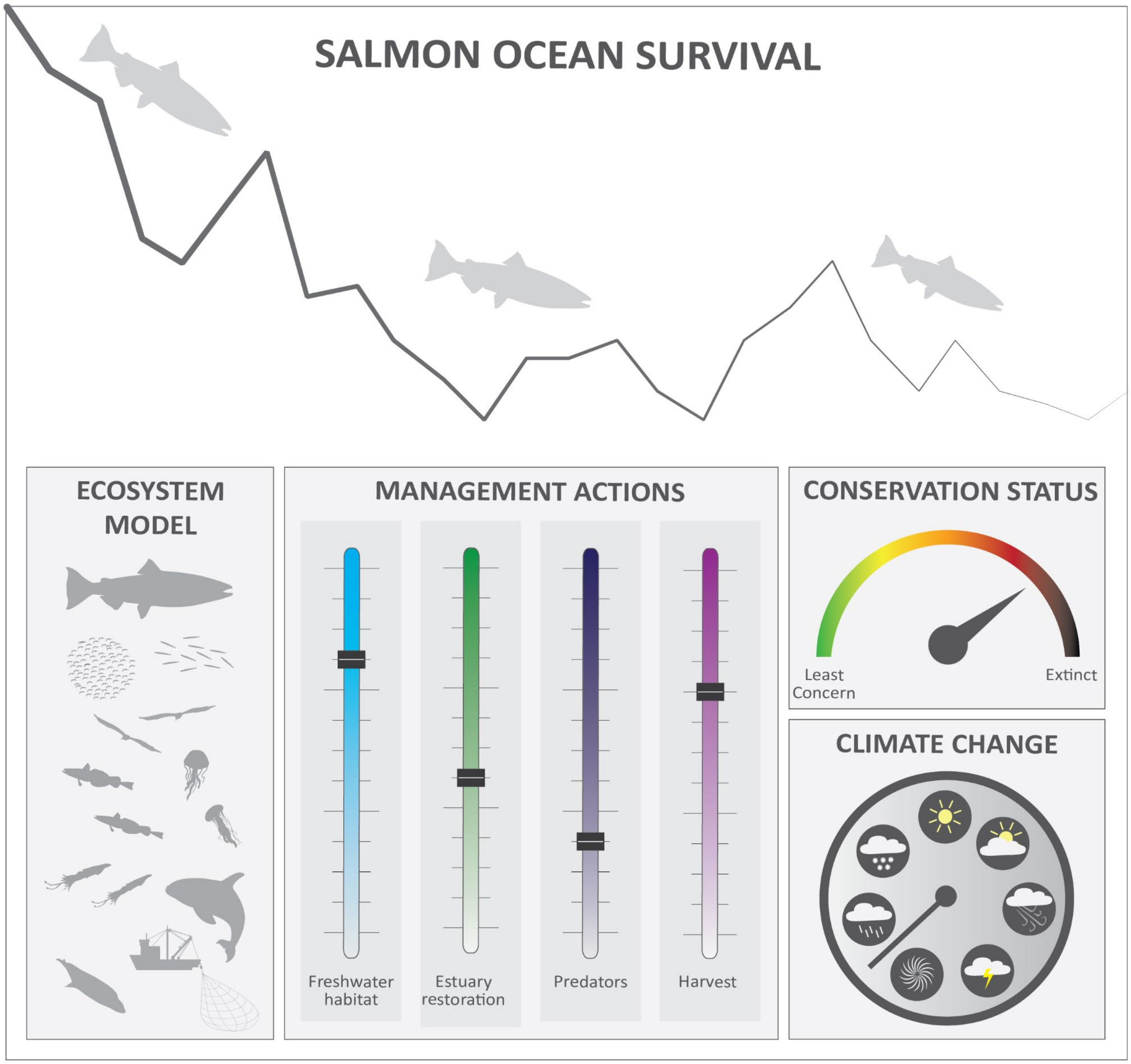


Figure 1. Major features of salmon case study. Statistical models project that warmer oceans will drive salmon population declines (top panel). We will use ecosystem models (left lower panel) to compare alternative hypotheses regarding the mechanisms driving the observed correlation, and assess the potential for management levers to mitigate those drivers (middle lower panel). The model will account for a variety of climate effects in freshwater and the ocean (bottom right) with the goal of avoiding population extinction (middle right).

Expanding EBFM to better reflect needs of protected species, we will test model sensitivity to at least five types of management actions: predator control actions, such as culling of sea lions, changes in management of target fisheries stocks that interact with salmon (forage species and fish predators), habitat actions in the Columbia River estuary, and freshwater "carry-over" effects associated with dams, habitat actions and climate impacts in freshwater. The models will compare ecosystem characteristics under historical and future ocean conditions using ROMS projections from multiple global climate models, and changes in spatial distribution and abundance of forage fish, mammals, and other species in the California Current using results from other projects (e.g., the COCA Forage Project and MICE models focused on marine mammals). Improved parameterizations of ecosystem models will then be available for multi-model comparisons in other management strategy evaluations.

Finally, we will examine the human impacts of decreasing salmon runs. Billions of dollars have been spent over the last fifty years on a variety of measures to promote recovery of these populations, and billions more will almost certainly be spent in the next few decades. Although there is no fixed budget or limit on what is spent to promote recovery, resources are not unlimited, and fully restoring the natural river system and habitat has been considered too costly and impractical. There is considerable uncertainty about the effectiveness of alternative actions for promoting recovery, both in absolute terms and in terms of cost-effectiveness. Climate change exacerbates this uncertainty as it will undoubtedly change the absolute and relative effectiveness of different recovery actions. Despite this uncertainty examining the relative effectiveness and cost effectiveness of alternative recovery actions can be useful for informing recovery planning. Targeting recovery investments cost-effectively can advance recovery objectives and other objectives related to ecological restoration, including advancing human well-being and equitable distribution of costs and benefits. This analysis will also help identify where it is most valuable to target research and data collection to reduce uncertainty. In this project we will compare a wide range of actions intended to promote recovery of salmon and steelhead in the Columbia River Basin and evaluate relative return on investment of those actions in terms of increasing average returns of threatened and endangered salmon and steelhead populations. Where possible, we will evaluate how effectiveness of actions may be impacted by climate change. We will also evaluate the distribution of costs and benefits associated with applying different actions and how that influences equity and political feasibility of particular approaches.

Location, location, location

The “Location Location Location” WRAP study and workshop in March 2020 focused on species distribution shifts under climate change. A substantial part of the workshop focused on more fully testing the performance of different methods for species distribution models (SDMs) under projected future changes in ocean conditions. The Future Seas Team provided dynamically downscaled earth system models to define scenarios of ocean conditions under climate change (Pozo Buil et al. 2021). Stephanie Brodie, with assistance from James Smith, led much of the discussion around performance testing of the SDMs, drawing from Brodie, et al. (2019). Next steps that support WRAP and climate science on the West Coast will focus around development of the following papers 1) The primary paper, which advances best practices for projecting species distribution shifts under climate change, including quantifying sources and magnitude of uncertainty through time (Stephanie Brodie, lead) 2) Testing the use of fishery dependent data in SDMs and its impact on model performance and predictive skill (Melissa Karp, lead) 3) Estimating shifts in biogeographic distributions of fishes from 1951-present between Punta

Eugenia, Baja California and San Francisco, California, inferred from the CalCOFI and IMECOCAL survey programs (Andrew Thompson, lead).

New Initiatives

While robust EBFM is a short-term objective, other developing potential ocean uses, principally wind and wave energy and offshore aquaculture, are shifting management strategies to the more comprehensive Ecosystem Based Management (EBM). The goal is to ensure that fisheries surveys, fisheries management, protected species and habitat are properly considered during the permitting phase of other ocean uses. The WRAP will work with other initiatives to ensure that these competing usages are included in the FACSS. The WRAP Salmon case study will begin this process by developing an end-to-end model and evaluate management alternatives with a protected species explicitly in mind.

Human Dimensions

Social science is an essential element of managing natural resources in an ecosystem framework. Information about the interaction between climate drivers and human elements of the system, including commercial and recreational fisheries, changes in aquaculture production or seafood pricing, patterns of hydropower generation, agricultural and human demands for water, patterns and dynamics of human well-being, and so forth, is needed to support management of our marine and anadromous resources. Both science centers have strong expertise in fisheries economics and the NWFSC employs two social scientists focused on human dimensions of fishery management and impacts on fishing communities. However, our ability to predict how climate change will impact fishers and fishing communities is limited both by a lack of data to understand impacts of climate change and climate variation retrospectively and because many other factors (e.g. technology, markets, demographics) may drive changes in coastal communities as or more strongly than climate change. Data on fishery landings and revenues can be attributed to vessel owners or port of landing providing information about fishery dependence. However, there are not yet long-term data sets of human factors that can clearly identify links between coastal communities' well-being and the natural and regulatory environment. There are extensive data from sources such as American Communities Survey, the Bureau of Economic Affairs, Bureau of Labor, etc. at the municipal or county level. This information is used to understand vulnerability to climate and other stressors at the community level, but it is not clear how well it reflects the individuals within those geographies that participate in fishing, particularly for large urban areas. This limits our ability to include appropriate human responses in MSEs, as well as to predict likely human responses to management actions over long time frames. A longitudinal survey of fishing vessel owners along the West Coast was conducted in 2017 and 2020 and will be conducted every three years going forward. This survey may provide a means to better understand how welfare of fishing households is impacted by ecosystem changes and to evaluate how well indicators of fishery dependence and social vulnerability at the community level reflect fishing households within them. Existing activities include:

- climate/ocean change impacts on ecosystems and fisheries
- role of diversification and fisheries portfolios in community vulnerability/resilience

- HABs and the Dungeness Crab fishery - mitigation and understanding knock-on effects such as creating increased interactions with whales or changing participation in other fisheries.

Center-wide species-specific research on predicted ocean condition changes will provide some information on potential climate variability impacts for the variety of species and fishery management groups managed on the West Coast. When finalized, these results will be linked to community vulnerability results for the communities where similar species-specific commercial fishing indices are salient. Part of this continued work involves collaborating with biophysical scientists on assessments for Dungeness Crab and Pink Shrimp, still absent in the current set of climate vulnerability assessments (CVAs). Relatedly, this work will support the species distribution modeling (SDM) efforts involved in the NWFSC-led project identifying and predicting climate impacts on groundfish, as well as the PFMC's Climate and Communities Initiative.

Ecological shocks and changes driven by climate are likely to increase inter-annual variability in fishermen's revenue, but variability can be reduced by diversifying fishing activities across multiple fisheries or regions (Kasperski and Holland 2013). Indices of fishery revenue diversification of West Coast and Alaskan fishermen are available going back to 1981 and work is ongoing to understand the role diversification has played in stabilizing income and preventing exit of fishing vessels in response to climate change and shocks over the last 40 years. A focus or research in the next few years is to understand how different types of portfolios of fishing activity including concurrent or overlapping fisheries vs. ones that take place during different seasons impact income variability and persistence in response to climate shocks such as the 2015 marine heat wave and related events such as closures to toxins from HABs. Related work uses network analysis to look at fishery diversification at the community or port level and how this diversification impacts responses and resilience of fishing communities. This retrospective analysis should provide insights into strategies for individuals and fishery managers that may increase resilience of fishers to climate change.

One strong manifestation of climate shocks that is likely to become more common with a warming California Current is an increase in HABs and the subsequent need to close shellfish fisheries due to high levels of domoic acid. NWFSC scientists are taking part in studies to understand how better monitoring and prediction of HABs and toxins in shellfish and changes in management can mitigate impacts of HABs. A primary focus is on Dungeness crab fisheries which are the most important source of income for many West Coast fishers and communities.

Gaps:

- future of floodplains and estuaries for people and fish habitat under future climate extremes, implications for salmon recovery/restoration
- resilience of fishing communities to multiple stressors and compounding climate shocks

Engagement in Management Processes

The Pacific Fisheries Management Council conducted a Climate and Communities Initiative beginning in 2017, and it is scheduled to wrap up in September 2021. The purpose of the initiative is to help the Council, its advisory bodies, and the public to better understand the effects of near-term climate shift and long-term climate change on West Coast fish, fisheries, and fishing communities and identify ways in which the Council could incorporate such understanding into its decision making. The Initiative consisted of 3 parts:

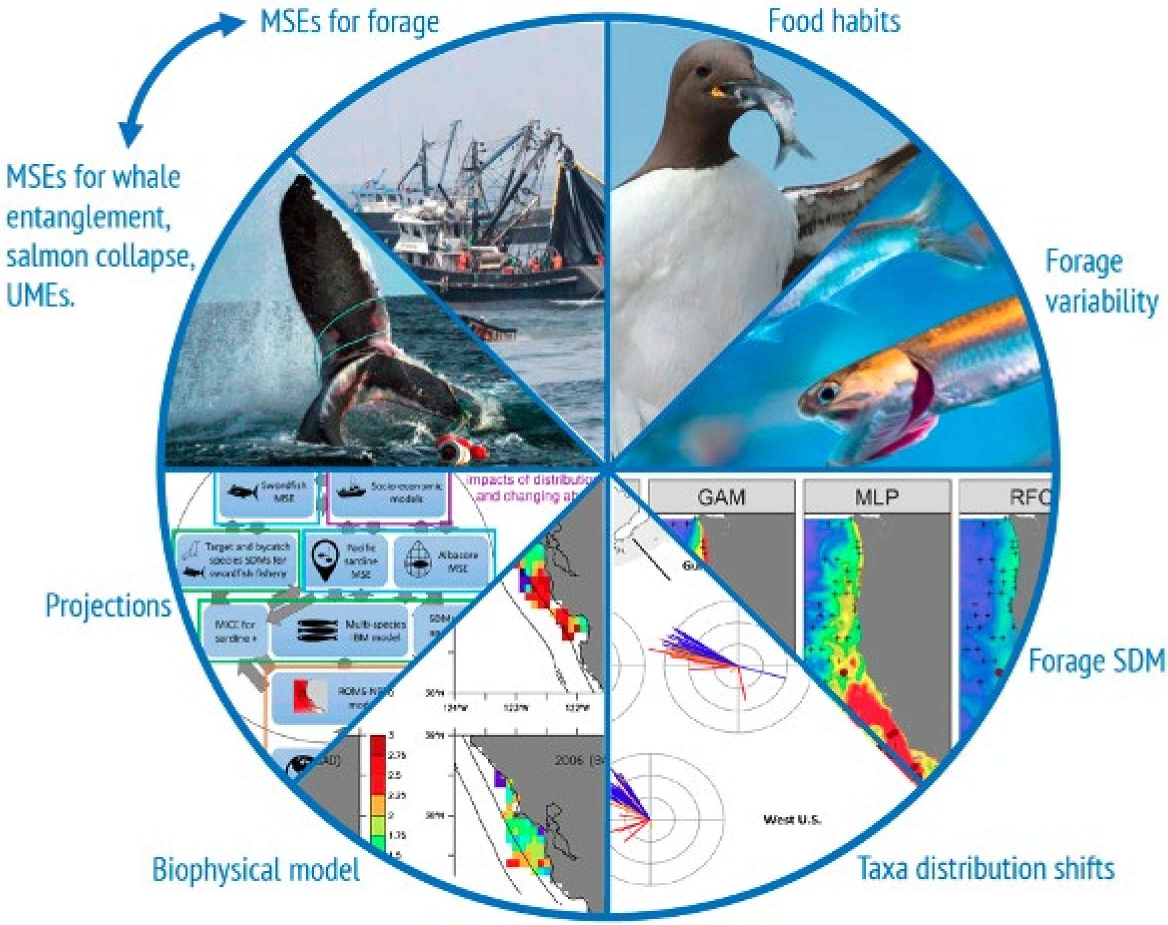
1) A series of informational webinars presented by the NWFSC and SWFSC;
2) A stakeholder workshop;
3) A scenario planning process.

The results of the scenario planning process are summarized in a report on four alternative future scenarios envisioned for the West Coast and a series of recommendations on the science, management processes, and partnerships needed to improve the Council's ability to meet the needs of these alternative futures (report on recommendations due out in September 2021). The efforts of the WRAP team can be used to support several of these recommendations, especially related to enhancing the information available to Council decision makers for federal fisheries management.

Ecosystem Shifts

The Ecosystem Shift project illustrates how independent projects (many listed previously) can be integrated to address the general issues emerging from climate variability and change. This CCLME project illustrates how variable forage availability and associated ecological and socio-economic impacts of predators feeding on alternate prey integrates across the whole ecological landscape. The ultimate goal is to develop a general tool for management strategy evaluation.

The figure below shows the specific aspects of the project that could be integrated: 1) diet analyses, 2) variability in forage availability, 3) forage distributions, 4) shifts in those forage distributions, 5) development of biophysical models for examining the system responses to varying climate and forage retrospectively, 6) future states, and 7 and 8) development of MSEs to mitigate negative effects of predators seeking alternate prey. While a number of these individual projects are funded, our goal, in the context of WRAP, is to secure funding to develop a gap analysis and modeling framework focused on the integration of these projects. The MSEs we will hope to examine could include management directly on forage (e.g., reduce fishing on CPS or groundfish to promote greater juvenile abundance), management on competing predators (e.g., fishing hake to decrease demand on forage), or on predators directly (e.g., culling).



More generally, the goal of this project is to demonstrate that ecological surprises can be contextualized into greater topological conditions rather than treated as idiosyncratic issues. If treated as such, we can take a broader approach to developing management strategies.

The collaborators on this project have made great strides toward achieving the project goals.

1. Food Habits. Using S&T funds, SWFSC has successfully developed and begun beta testing a relational database of food habits for 157 elasmobranch, teleost fishes, cephalopod, and marine mammal predators across the CCLME which will provide a knowledge base for the following components.

2. Forage Variability: Using data from a number of surveys, we have identified a number of environmental characteristics that affect directly and indirectly the spatiotemporal availability of forage as well as variability in the assemblages. Using S&T funds, we initiated work on understanding drivers of the recruitment dynamics of CPS. Finally, the Future Seas project (see above) will investigate drivers of forage species variability.

3. Forage SDM: Great strides have been made to define species distribution models for sardine and anchovy with work progressing on Pacific mackerel, market squid, Pacific herring, and jack mackerel. Parametrization of these models comes directly from survey data. Forage ecosystem indicators will be developed from these SDMs to inform predator and fishery dynamics and their interactions.

4. Taxa distribution shifts: See "Location Location Location" above.

5. Biophysical model: Given the goal of the project to identify spatiotemporal variability in predator-prey interactions, we are focusing on an agent-based approach to examine the role of the environment on predator and forage dynamics. This will be done by building on previously developed models for predators (i.e., central place feeder, migratory feeder, transitory feeder), prey (i.e., anchovy, juvenile rockfishes, krill) and salmon. This model directly uses data from the Food Habits database including diets and diet sizes.

6. Projections: See swordfish MSE as an example.

7. We envision potential MSEs related to managing hatchery practices, freshwater dynamics, fixed gear fishing regulations, forage for predators and the management of competing predators to reduce associated ecological and socio-economic impacts of predators feeding on alternate prey.

8. Future Seas in phase 2 will develop an MSE using the multispecies and ecosystem models described above to compare performance of current and alternative, including assemblage-based, catch rules in meeting management objectives given potential future impacts of climate change on the forage assemblage.

Ongoing/Future Activities and Metrics

We compiled a table of ongoing and future projects under WRAP (Table 1). We also considered metrics for measuring progress.

Table 1. Planned WRAP activities for the next 3 years (2022-2024).

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
Four WRAP-sponsored workshops	Ocean Modeling				
	Ecosystem Modeling				S&T RAP
	Decision Support Tools				S&T RAP
	location, location, location	complete three manuscripts	Kaplan/Brodie	manuscripts	S&T RAP
Ecosystem Indicator Monitoring	California Current Integrated Ecosystem Assessment (CCIEA)	Annual Ecosystem Status Report to the PFMC	Harvey/Garfield	Report and oral presentation to Council	IEA funds and base funds
	Upwelling indices	extend application of upwelling indices	Jacox	Web delivery of indices	base funds
		Marine Heatwaves (MHW)	Leising	Automated web delivery	base funds
		Habitat Compression Index (HCI)	Santora/Schroeder	manuscript	CA state funds and IEA funds

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
Climate-informed MSEs	Sablefish	Complete NE Pacific wide review of climate driven recruitment processes for sablefish, and build out a framework for doing so once the first interation of the technical MSE tool has been built and the first iteration is complete (likely during 2023).	Haltuch	Manuscript, Framework for integrating climate-recruitment impacts in the MSE, presentations to both fishery managers, stakeholders, and scientists. Second iteration MSE tool that explicitly incorporates climate.	The review paper is supported by salaried NMFS and DFO staff, and travel funding from HQ. Future climate driven MSE is unfunded and will not move forward until funding for either a graduate student or post doc has been obtained.
	Hake	Hake	Hastie / Johnson		
	Future Seas Phase I: Swordfish, sardine and albacore		Jacox/Muhling		CPO
	Future Seas Phase II:		Tommasi		CPO

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
	Coastal Pelagic Species				
	Sardine	Sardine bioenergetic modeling, individual-based, spatial age-based models	Tommasi		
	Albacore	Entire North Pacific stock	Tommasi	Final report 2022	
	Social consequences for albacore fishery	Spatial distribution models to predict port-level landings, social vulnerability indices	Tommasi		
Outreach	Climate Vulnerability Assessments	Marine Mammals	Noren		
		Fishery Management Areas	McClure/Haltuch	Manuscript	Supported by NMFS staff.
Real-time Fisheries Management	Dynamic ocean management	Continue development of management options	Hazen/Bograd	manuscripts and web tool	NASA/base
	anticipating IUU vessel disposition	develop tools for vessel interception	Welch	web-based tool	OLE
	Whale entanglements	Refine tools for the CA State RAMP program	Santora/Samhouri/ Hazen	Manuscripts and web tool	RO funding / OPC funding
	Bycatch reduction leatherback and loggerhead turtles	DOM and TOTAL	Hazen/Robinson	web-based tool	NOAA BREP & NASA

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
Forecasting Models	J-SCOPE	Annual prediction of WA/OR coastal O2 and OA			
Forecasting Models	Central Valley Temperature Mapping and Prediction (CVTEMP)	Seasonal forecasts of river temperature impacts on salmon in the Sacramento River to guide water project operations	Danner	Manuscripts and web tool	NOAA, USBR, California Department of Water Resources
Climate-driven life cycle modeling of Pacific Salmon	Snake River spring/summer Chinook salmon	Expand salmon responses to climate change within this population group (marine trophic interactions, phenology and growth carryover effects); add new climate forcing models from Future Seas ROMS model outputs, estuary effects	Crozier	Manuscript, results communicated to WRC, presentations, use in Biological Opinions and EISs	
		Develop similar models for other populations		Presentations and initial results	
	Sacramento River winter-run Chinook salmon LCM	Predict response of population to changing water project operations under climate change; include carry-over effects from freshwater to ocean	Lindley/Danner	Inclusion of analyses in biological opinions; manuscripts	USBR
Ecosystem modeling of northern California Current	WRAP Salmon case study	Complete end-to end ecosystem model simulations and scenario exploration of climate	Crozier	Publications using EcoTran, publications on qualitative network	S&T, NOAA Base funds

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
		change and management actions, multi-model comparison		model and statistical model, presentations to NOAA staff and partners/stakeholde rs on management implications	
	Salmon recovery return on investment under climate change	Compare return on investment of alternative salmon recovery tools taking into account impacts of climate change	Holland	Tech memo and journal publication comparing ROI of salmon recovery actions and recommending areas where more research on effectiveness would be most valuable	NOAA base funds
Spatial distribution/abundance modeling	Salmon ocean distribution modeling	Develop similar models for other populations	Shelton	manuscripts	NOAA base funds
	Groundfish	use downscaled climate projections (Future Seas ROMS model) to predict changes in distributions of groundfish species adequately sampled by the NWFSC trawl survey, how those distributional shifts interact with current	Samhouri/Harvey/ Kaplan/Norman	Manuscripts, results communicated to PFMC and DFWs, presentations	This work funds one postdoc, supported by the Packard Foundation, for 2.5 years, with 1.5 years remaining. All

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
		harvest management using the Atlantis ecosystem model, and how they may impact west coast fisheries and fishing communities.			other funding is contributed in kind by N/SWFSC, WRO, and academic colleagues. We are actively seeking additional forms of support.
Human Dimensions					
			Hunsicker		
Strategic Planning and capacity building	Center Ecosystem Science Committee (SWFSC)		Garfield	Manuscripts on Ecological Indicators	NOAA. base funds
	Climate and Ocean Acidification Network (NWFSC)		Crozier		
	West Coast Region Climate Team (WRC+centers)		Schott		

Planned actions from WRAP 1.0	Project	RAP 2.0 goal	Contact person:	Metrics -- SMART	Funding source
	Climate, Ecosystem and Fisheries Initiative oceanographic modeling		New FTE TBD	Base funds if approved in FY22	
	Coordination of data-collection efforts and data sharing	Meet with Ocean Surveys Working Group to ensure climate needs accounted for	Hunsicker, Crozier	Meeting with Ocean survey team in FY22	
		Coordinate through DFO/NMFS climate work group	Crozier	DFO/NMFS Action Plan to be completed Fall 2021	
		Incorporate climate needs into Salmon Science Strategic Plan	Crozier	Completion of SSPT strategic plan	
	Standardize data collection and reporting	Organize a workshop	All	Identify the players who need to participate	

References

Brodie, S., J.T.Thorson, G. Carroll, E.L.Hazen, S. Bograd, M.A. Haltuch, K.K. Holsman, S. Kotwicki, J.F. Samhouri, E. Willis-Norton and R.L. Selden. 2019. Trade-offs in covariate selection for species distribution models: a Methodological comparison. Ecography (43): 11-24. doi: 10.1111/ecog.04707

Chasco, B., B. Burke, L.C. Crozier, R.W. Zabel. 2021. Differential impacts of freshwater and marine covariates on wild and hatchery Chinook salmon marine survival. Plos One 16: e0246659.

Crozier, L.C., Burke, B.J., Chasco, B.E., Widener, D. L, Zabel, R.W. 2021. Iconic species in peril: Chinook salmon face climate change across multiple life stages. Communications Biology 4:222-235.

Frawley, T.H., B.A. Muhling, S. Brodie, M.C Fisher, D. Tommasi, G. Le Fol, E.L. Hazen, S.S. Stohs, E.M. Finkbeiner, M.G. Jacox. 2020. Changes to the structure and function of an albacore fishery reveal shifting social-ecological realities for Pacific Northwest fishermen. Fish and Fisheries: 280-297. https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12519

International Scientific Committee for Tuna and Tuna-like Species for the North Pacific Ocean (ISC). 2019. REPORT FOR THE FIRST NORTH PACIFIC ALBACORE MANAGEMENT STRATEGY EVALUATION. http://isc.fra.go.jp/pdf/ISC19/ISC19_ANNEX12_Report_First_North_Pacific_Albacore_MSE.pdf

Kaplan, I.C., Williams, G.D., Bond, N.A., Hermann, A.J., & Siedlecki, S.A. 2016. Cloudy with a chance of sardines: forecasting sardine distributions using regional climate models. Fisheries Oceanography, 25(1), 15-27.

Kasperski, S. and Holland, D.S., 2013. Income diversification and risk for fishermen. *Proceedings of the National Academy of Sciences*, *110*(6), pp.2076-2081.

Link, J.S., R. Griffis, S. Busch (editors). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70p.

Malick M..J, Siedlecki S.A., Norton E.L., Kaplan I.C., Haltuch M.A., Hunsicker M.E., Parker-Stetter S.L., Marshall K.N., Berger A.M., Hermann A.J., Bond N.A. and Gauthier S. (2020) Environmentally Driven Seasonal Forecasts of Pacific Hake Distribution. *Front. Mar. Sci.*7:578490. doi: 10.3389/fmars.2020.578490

Muhling et al. 2019. DYNAMIC HABITAT USE OF ALBACORE AND THEIR PRIMARY PREY SPECIES IN THE CALIFORNIA CURRENT SYSTEM CalCOFI Rep., Vol. 60. https://calcofi.org/publications/calcofireports/v60/Vol60-Muhling.pdf

NOAA Climate, Ecosystem and Fisheries Initiative. 2020. https://www.fisheries.noaa.gov/topic/climate-change#noaa-climate-and-fisheries-initiative

NOAA-TM-NMFS-SWFSC-565, 2016

Norton, Emily L., Samantha Siedlecki, Isaac C. Kaplan, Albert J. Hermann, Jennifer L. Fisher, Cheryl A. Morgan, Suzanna Officer et al. "The importance of environmental exposure history in forecasting Dungeness crab megalopae occurrence using J-SCOPE, a high-resolution model for the US Pacific Northwest." Frontiers in Marine Science 7 (2020): 102.

Peterson, J., R. Griffis, P. Woodworth-Jefcoats, A. Jacobs, A. Hollowed, E. Farley, J. Duffy-Anderson, M. Dorn, T. Hurst, J. Moss, L. Rogers, K. Shotwell, T. Garfield, R. Zabel, Y. deReynier, E. Shott, L. Crozier, S. Bograd, N. Mantua, J. Samhouri, J. Quinlan, K. Gore, R. Muñoz, J. Leo, L. Waters, M. Burton, V. Saba, D. Borggaard, M. Ferguson, W. Morrison. 2021. NOAA Fisheries Climate Science Strategy Five Year Progress Report. NOAA Tech. Memo. NMFS-F/SPO-228, 157 p

Pozo Buil M, Jacox MG, Fiechter J, Alexander MA, Bograd SJ, Curchitser EN, Edwards CA, Rykaczewski RR and Stock CA (2021) A Dynamically Downscaled Ensemble of Future Projections for the California Current System. *Front. Mar. Sci.* 8:612874. doi: 10.3389/fmars.2021.612874

Siedlecki, S., Kaplan, I., Hermann, A. *et al.* Experiments with Seasonal Forecasts of ocean conditions for the Northern region of the California Current upwelling system. *Sci Rep* **6,** 27203 (2016). https://doi.org/10.1038/srep27203

Smith JA, Tommasi D, Welch H, Hazen EL, Sweeney J, Brodie S, Muhling B, Stohs SM and Jacox MG (2021) Comparing Dynamic and Static Time-Area Closures for Bycatch Mitigation: A Management Strategy Evaluation of a Swordfish Fishery. *Front. Mar. Sci.* 8:630607. doi: 10.3389/fmars.2021.630607

Smith JA, Muhling B, Sweeney J. 2021. The potential impact of a shifting Pacific sardine distribution on U.S. West Coast landings. Fish Oceanogr. 2021;30:437–454. https://doi.org/10.1111/fog.12529

Tommasi D, deReynier Y, Townsend H, Harvey CJ, Satterthwaite WH, Marshall KN, Kaplan IC, Brodie S, Field JC, Hazen EL, Koenigstein S, Lindsay J, Moore K, Muhling B, Pfeiffer L, Smith JA, Sweeney J, Wells B and Jacox MG (2021) A Case Study in Connecting Fisheries Management Challenges With Models and Analysis to Support Ecosystem-Based Management in the California Current Ecosystem. *Front. Mar. Sci.* 8:624161. doi: 10.3389/fmars.2021.624161

Wells BK, Huff DD, Burke BJ, Brodeur RD, Santora JA, Field JC, Richerson K, Mantua NJ, Fresh KL, McClure MM, Satterthwaite WH, Darby F, Kim SJ, Zabel RW and Lindley ST

(2020) Implementing Ecosystem-Based Management Principles in the Design of a Salmon Ocean Ecology Program. Front. Mar. Sci. 7:342. doi: 10.3389/fmars.2020.00342

Appendices

Appendix 1. Acronyms used in this document and their definitions.

Acronyms	*Definition*
ADF&G	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center
CAFA	Climate and Fisheries Adaptation
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCIEA	California Current Integrated Ecosystem Assessment
CCLME	California Current Large Marine Ecosystem
CeNCOOS	Central and Northern California Ocean Observing System
CESC	Center Ecosystem Science Committee
CEFI	Climate, Ecosystem and Fisheries Initiative
COCA	Coastal and Ocean Climate Applications
CPO	Climate Program Office
CPS	Coastal Pelagic Species
CVA	Climate Vulnerability Assessment
CVTEMP	Central Valley Temperature Mapping and Prediction
DFO	Fisheries and Oceans Canada
DisMAP	Distributed Mapping and Analysis Portal
DOM	Dynamic Ocean Management
EBFM	Ecosystem Based Fisheries Management
EBM	Ecosystem Based Management
ESA	Endangered Species Act
ESR	Ecosystem Status Report
ESRL	Earth Systems Research Laboratory
FACSS	Fisheries and Climate Decision Support Systems
FEP	Fishery Ecosystem Plan
HAB	Harmful Algal Bloom
HCI	Habitat Compression Index
HI-EBFM	Human Integrated EBFM
IEA	Integrated Ecosystem Assessment
IMECOCAL	Investigaciones Mexicanas de la Corriente de California
ISC	International Scientific Committee (for Tuna)
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
J-SCOPE	JISAO's Seasonal Coastal Ocean Prediction of the Ecosystem
JSOES	Juvenile Salmon Ocean Ecosystem Survey
MICE	Models of Intermediate Complexity

MOM6	Modular Ocean Model
MSE	Management Strategy Evaluation
NAMES	National Marine Ecosystem Status web portal
NANOOS	Northwest Association of Networked Ocean Observing Systems
NCSS	NMFS National Climate Science Strategy
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NorWeST	Northwest Stream Temperature (Model)
NOS	National Ocean Survey
NWFSC	Northwest Fisheries Science Center
NPFMC	North Pacific Fisheries Management Council
NRC	National Research Council
OAR	Oceanic and Atmospheric Research
PFMC	Pacific Fisheries Management Council
PMEL	Pacific Marine Environmental Laboratory
RAMP	Risk Assessment and Mitigation Program
RAP	Regional Action Plan
ROMS	Regional Ocean Modeling System
RREAS	Rockfish Recruitment and Ecosystem Assessment Survey
SCCOOS	Southern California Coastal Ocean Observing System
SDM	Species Distribution Model
SHSTM	Salmon Habitat Status and Trends Monitoring
SPM	Single Species Model
SSH	Sea Surface Height
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
TOTAL	Temperature Observations To Avoid Loggerheads
UCSC	University of California, Santa Cruz
WC3	West Coast Climate Committee
WCCP	West Coast Climate Program
WCOFS	West Coast Operational Forecast System
WCRO	West Coast Regional Office
WRAP	Western Regional Action Plan
WRIP	Western Regional Implementation Plan

Appendix 2: WCRO Climate Science Needs, July 2021

This document transmits the WCR Climate Team's summary of climate science needs collected from the divisions and the NOAA Restoration Center during 2020, supplemented by ongoing discussions with the Science Centers. The purpose of this document is to help focus our dialogue with Science Centers, data calls from HQ and others, and to inform the Western Regional Action Plan (WRAP 2.0) to implement the NMFS National Climate Science Strategy. *Importantly, this document will evolve as dialogue with the Centers continues*.

WCR climate science needs are organized into five subject areas below: freshwater, nearshore and estuaries, oceans, integration across ecosystems and management regimes, and use of climate science. Within these subject areas, we also describe tools that would help the region address climate change impacts on trust resources. Some of these tools may already exist, highlighting the need for continued communication between the Region, Centers, and others (academia, other government agencies, etc.).

In this summary, we did not include references to specific watersheds or species. Our goal is to create a framework that allows us to continue dialogue with the Centers and others, and to focus our efforts on developing tools to address climate change impacts that can be used across large portions of the region.

Climate Change Impacts in the Freshwater Environment

- How can we improve resilience to climate change impacts for salmonids, green sturgeon, and eulachon at a variety of scales? (ecoregion, DPS/ESU, Major population group, population, watershed, etc.)
    - Floodplains and other important habitat types (importance in the future, how these will change, best practices, contribution to resilience and recovery, etc).?
    - Species interactions (invasives, competition, predation, prey availability, etc.)
    - Where are species refuges (areas of suitable habitat, including areas for species reintroductions) likely to be and persist in the future? Unoccupied areas?
- How will human activities associated with rivers and streams interact with climate change to affect anadromous species' populations and our management priorities for those populations?

- ○ How will climate change drive increased human demand for water use in flood-risk management, hydropower, irrigation, municipal and industrial water supply, pollution abatement, and recreation?
- ○ More information about how climate change may exacerbate the effects of stream channelization or structures via acceleration of rates of new construction, repair, or removal/setbacks of structures.
- ○ How might silvicultural practices affect changing stream temperatures and needed stream buffer widths? Which silvicultural practices might mitigate the effects of climate change, and maintain salmonid habitats?

Some science and management tools that we need, or are now using or developing and which should be updated for climate change:

- ● Vulnerability/resiliency analyses at the major population group, population, and watershed scales.
- ● Analysis tools to identify resilient recovery strategies and actions.
  - o Tools to assess the resilience of habitat areas we are considering for species reintroductions--linkages to lifecycle models to help us choose resilient areas that gain the most for the species
- ● Projections and best practices for modeling future stream flows and temperatures
  - ○ Incorporation of climate change impacts into streamflow predictions and projections at a variety of scales and time-steps (from 7-10 day stream forecasts to long term (multi-decadal) daily, monthly, and seasonal flow projections).
  - ○ Best practices for modeling stream flows, temperatures, sediment transport, fish disease outbreaks, and invasive species (informed by reservoir cold water pools, hyporheic flows, ground water, glaciers, etc.) in a changing climate.
  - ○ Irrigation season, duration and volume tracking over time, and its effects on base flow/no flow periods.
  - ○ Impact from sea-level rise and watershed hydrology changes over time on the quantity and quality of large river floodplains, and the population level effects on salmonids from habitat loss/gain. Impacts from cumulative loss of small high elevation flood plains in forested environments.
- ● Analysis tools to evaluate how climate change may alter project impacts on instream habitat, habitat, flows, and water temperatures across a range of eco-regions, and time periods.
  - ○ Decision/analysis support tools for effects analyses for long-term medium-scale projects/structures such as fish passage, levees, other forms of channelization, and long-term water storage and use on listed fish and their habitat in a changing climate.
  - ○ What are key criteria for evaluating the resiliency of cool-water releases from dams and their influence on habitat conditions?

Climate Change Impacts in Estuaries and the Nearshore

- What are the expected impacts of climate change on estuary, associated wetlands, and associated floodplains and nearshore habitat for protected and managed species?
    - o Are these habitat types (and certain features within them) likely to become even more important for protected and managed species (e.g., estuarine floodplains for salmonids, and haul-out areas for pinnipeds) in the future?
    - o Do we have effective tools for valuing these habitats for protection, mitigation, and restoration that incorporate climate change scenarios?
    - o Sea-level rise and coastal inundation projections and their effects on species habitat.
    - o How will the changing climate, ocean acidification, and sea-level rise affect submerged aquatic vegetation, including kelp, in west coast bays and estuaries: wild (native and introduced) and cultured eelgrass and kelp populations? How do these changes influence decisions to conserve and manage these habitats? Can we mitigate with increased restoration of vegetation beds?
    - o How do those effects interact with nearshore human-caused habitat hardening?
    - o How are shifts in kelp forest abundance and distribution affecting marine ecosystems and food webs?

- How will the anticipated impacts from our changing climate on the value of estuarine and nearshore habitats affect the range, distribution, phenology, disease, and abundance and productivity of protected and managed species in bays and estuaries?

- How will these changes alter protected species' interactions with fisheries and aquaculture? How will these changes alter the suitability of the physical and biological environment for fisheries and aquaculture.

Climate Change Impacts in the Ocean

- How will our changing climate, changing ocean physical states, chemistry, and changing ocean productivity (e.g., upwelling and forage availability) affect the range, distribution, phenology, and abundance of protected and managed species? How will those changes affect:
    - o our species' interactions in ecological communities, particularly predator/prey interactions, prey availability to protected and managed species, and predation upon protected species?
    - o the food webs of, predation on, and forage availability for protected and managed species over time?

- o the availability of habitat to our species, compression or expansion of habitat, and links between our species' diet and habitat?
- o the availability of fisheries-targeted species to fishing communities?
- o patterns of bycatch of protected and managed species in fisheries?
- o disease transmission between migratory and shifting populations of protected species?

● What are some of the potential effects of the changing climate and ocean chemistry on the physical environment, particularly: extreme-weather events, hypoxic zones, drought and flooding conditions, and sea-level rise? How will those changes affect human communities, including their effects on fisheries and coastal aquaculture?

The Region and the Centers should collaborate to prioritize particular species, but rough species categories of interest include: longer-lived managed and protected species; highly migratory and far-ranging mammals, turtles, and fish; salmonids that may need access to new habitats; abalone; eulachon; and dominant species of the ocean forage base.

Some of the science and management tools that we are now using, and which could be updated, include:

● Ocean productivity models for salmonids (need upwelling indices, prey indices, information on changes, in water currents, salinity, and density.

● Fish stock assessments, some of which are already targeted for including climate data.

● Models of marine mammal and sea turtle population spatial and temporal distribution under climate change and habitat needs to understand: potential interactions with fisheries and gear, distribution of mammal and turtle prey and prey habitats, and interactions marine mammals may have with other protected species.

● Climate vulnerability assessments need to be completed for finfish species, mammals, and turtles. Will the Centers also embark on climate vulnerability assessments for habitats and fishing communities?

● Projections of Chinook salmon abundance and distribution in the ocean relative to Southern Resident Killer Whale migration and feeding patterns.

● Projections of abundance and distribution of large whales, in relation to shipping lanes and pot and trap fishing gear.

Integration of Climate Change Impacts Across Ecosystems and Management Regimes

● How resilient (e.g. vulnerability assessments) to climate change impacts are our ocean and nearshore species (whales, turtles, shellfish), and recovery strategies and actions, at a variety of scales. See above ocean and nearshore sections.

● Assessments of human coastal community vulnerability to the combined suite of potential effects of climate change, from the physical effects of climate change to the dependence of fishing communities on fisheries resources and their vulnerability to shifts in fish stock availability.

- How do we best integrate the effects of human activities, natural variability, and climate change impacts across species life cycles and ecological communities?
    - Integrated life cycle modeling, starting with salmonids.
    - Tools to assess the potential and resilience of habitat areas we are considering for species reintroductions--linkages to lifecycle models to help us choose resilient areas that gain the most for the species.
    - Changing interactions between human activities and species ranges and distribution (e.g., habitat compression and other metrics).
    - Forage base (bottom-up in addition to top-down) -- how is climate variability and change affecting the abundance, species composition, and distribution of the ecosystem's forage base? What are the expected higher-trophic level impacts of any changes?

Use of Climate Change Science

How do we best distill the climate science that's available to help us manage trust resources under all our statutory mandates (MSA, ESA, MMPA, NEPA, etc.)?

- WCR needs constant ongoing collaboration between WCR and Center scientists on climate science products:
    - The ecosystem status report, developed for use in domestic and international fisheries management.
    - Best practices for use of a variety of climate science, including stream flow projections, and integrating ocean productivity information into the effects of freshwater projects on salmonid life cycles.
    - Periodic updates of climate science-based management tools as needed to incorporate the latest information.
    - Syntheses of expected climate driven changes in freshwater systems across West Coast Region
    - WCR needs continued periodic updates of products that describe potential effects of climate and climate change on managed species throughout their life cycles (Objective 6, NCSS).
    - Best available science for salmon and steelhead for climate analyses in ESA consultations (e.g. updates to species status sections for climate change in biological opinions)
- Update the WRAP so that it addresses science needs, rather than the problems. (For example, whale entanglements and ship strikes are the problem. The science needs are spatial and temporal distribution of mammals related to their pursuit of prey and also impacts of climate change on prey abundance.)