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NOAA Technical Memorandum NMFS

NOVEMBER 2016

WESTERN REGIONAL ACTION PLAN (WRAP), NOAA FISHERIES CLIMATE SCIENCE STRATEGY

NOAA NW/SW Fisheries Science Centers

NOAA-TM-NMFS-SWFSC-565

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Western Regional Action Plan (WRAP),

NOAA Fisheries Climate Science Strategy

November 2016

NW/SW Fisheries Science Centers

http://www.nwfsc.noaa.gov/

http://swfsc.noaa.gov/

ABSTRACT

The Western Regional Action Plan (WRAP) outlines efforts underway to increase the production, delivery, and use of the climate-related information required to fulfill our mission. As part of the NOAA Fisheries Climate Science Strategy (NCSS), the WRAP conforms to a nationally consistent framework that guides efforts by NOAA Fisheries and partners to address the agency's climate-related information needs. The WRAP identifies strengths, weaknesses, priorities, and actions to implement the NCSS on the U.S. West Coast over the next 3–5 years.

DISCLAIMER:

This regional action plan is a guidance document and the actions identified are subject to final agency decisions and available resources. None of the recommendations contained in this guidance are binding or enforceable against any public or private party, and no part of the guidance or the guidance as a whole constitutes final agency action that could injure any person or represent the consummation of agency decision making. This guidance does not change or substitute for any law, regulation, or other legally binding requirement and is not legally enforceable.

ACKNOWLEDGEMENTS:

The WRAP development is definitely a community effort between the two west coast Science Centers and the Regional Office and acknowledges the active participation of many of the individuals who contributed significantly to the effort. In addition, constructive input was provided by many non-governmental agencies and the general public.

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1. EXECUTIVE SUMMARY

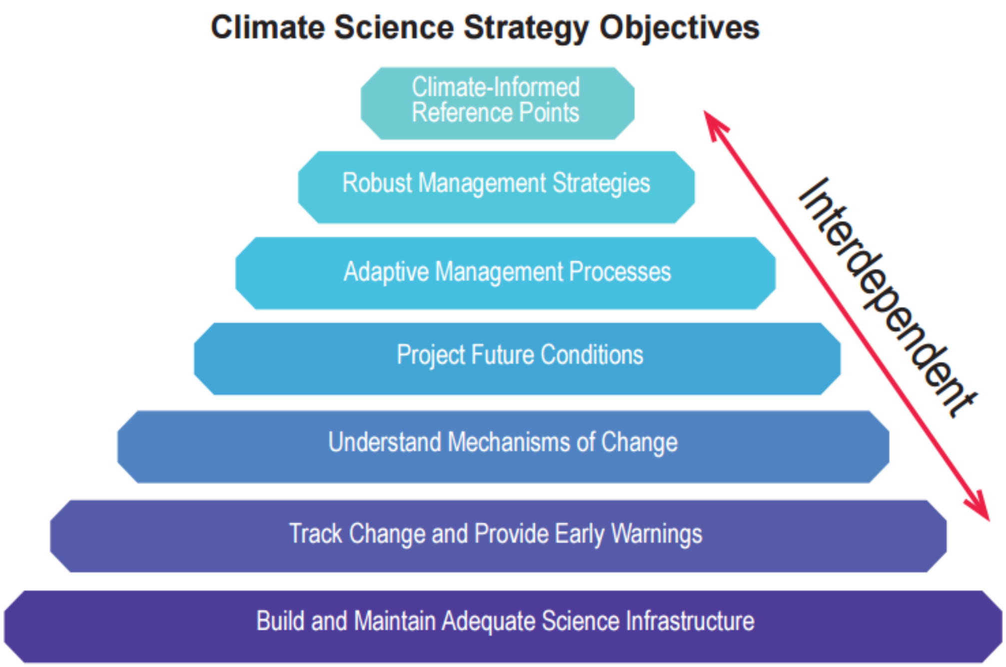
The California Current Large Marine Ecosystem (CCLME) along the West Coast of the United States, Canada, and Mexico is characterized by some of the most dramatic annual, interannual and decadal variability in basin-scale physical forcing and changes in marine food web structure in the world. Likewise, the watersheds and estuaries tributary to the CCLME also experience large variations in response to climate variations across the same wide range of time scales. Superimposed on this natural climate variability are growing pressures we now know have arisen from anthropogenic climate change. Both natural climate variability and anthropogenic climate change can have major, and only partly understood, impacts on freshwater, estuarine and marine food chains, fishery and protected resources, and the coastal and inland communities that depend upon them.

The National Marine Fisheries Service (NOAA Fisheries) monitors, assesses and predicts the impacts of climate variations on the abundance, productivity, life history and distribution of the nation's living marine resources (including anadromous salmonids and sturgeon)[1]. Climate-related changes in the CCLME (ocean to watersheds) are already evident and they are affecting the region's marine and anadromous fish, invertebrates, marine mammals, sea turtles, and seabirds, as well as the people, businesses, and communities that depend on them. Responding to increasing awareness from the public, industry, managers and policy makers, there is a growing demand for actionable information on present climate variability and future climate change in the CCLME. The Northwest Fisheries Science Center (NWFSC) and Southwest Fisheries Science Center (SWFSC)—the Centers—conduct extensive research into resource management and habitat restoration strategies that might ameliorate the impacts of climate change on freshwater, estuarine, and marine ecosystems. This research supports the development of decision-support tools that aim to increase the resilience of coastal and inland communities to the effects of climate variability and change.

The Centers acquire and communicate the scientific information necessary to fulfill NOAA Fisheries' mission to support sustainable fisheries and recover endangered and threatened species and their habitats along the U.S. West Coast and adjacent watersheds. To continue to fulfill this mission, the Centers will explore and develop science-based strategies for sustaining both the nation's living marine resources and resource-dependent, resilient human communities in a changing climate.

[1] See for example: http://www.calcofi.org/ccpublications/ccreports/calcofi-reports-toc/565-crtoc-vol-56-2015.html and http://www.noaa.gov/iea/regions/california-current-region/.

This document, the Western Regional Action Plan (WRAP), outlines present and future efforts to increase the production, delivery and use of the climate-related information required to fulfill NOAA Fisheries' mission and implement the NOAA Fisheries Climate Science Strategy in this region over the next 5 years. As part of the NOAA Fisheries Climate Science Strategy (NCSS)[2], the WRAP conforms to a national framework that guides efforts by NOAA Fisheries and partners to address the agency's climate-related information needs. The WRAP identifies strengths, weaknesses, priorities, and actions to implement the NCSS on the U.S. West Coast over the next 3–5 years, and it contributes to implementation of the NCSS by focusing on building regional capacity and partnerships to address the seven science objectives outlined in the NCSS and illustrated in the pyramid figure below.



The WRAP addresses the NCSS objectives through seven crosscutting actions:

- Establish a NMFS West Coast Climate Committee (WC^3) and Program (WCCP). The Committee will advance the Program by coordinating scientific activities within NMFS, engaging in a sustained discussion on climate-related changes along the U.S. West Coast, refining our approaches to quantifying climate-related signals, and evaluating tools and products to advise management actions.

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[2] https://www.federalregister.gov/articles/2015/08/26/2015-21172/noaa-fisheries-climate-science-strategy

- Build scientific expertise within the Centers to address ongoing and expected changes over the coming decade in climate forcing of the CCLME, neighboring estuaries and watersheds, and the human communities that depend on them.

- Review, coordinate and standardize existing data-collection efforts in response to changing CCLME and social conditions. We will consider different survey approaches, as well as measure and monitor the physical, biological, and social environments in more detail to better understand our changing environment and the responses of species, ecosystems and human communities.

- Use a management strategy evaluation (MSE) framework (that includes multi-species, multi-fleet, and spatial economics models) to identify specific policies that may be limiting under a changing climate. We have initially identified Pacific hake, sablefish, and North Pacific albacore for MSEs, with a focus on identifying mechanistic links, improving management strategies, and developing reference points.

- Develop full life-cycle models for Pacific salmon and sturgeon that are explicitly linked with freshwater, estuary, and ocean habitats in ways that allow for evaluating population responses (e.g., abundance, productivity, distribution, and life history diversity) under different hatchery, harvest, habitat restoration, water management, and climate change scenarios

- Continue the development of the California Current Integrated Ecosystem Assessment (CCIEA) and its Ecosystem Status Reports as tools for implementing ecosystem-based fisheries management (EBFM) while also taking steps to support multi-sector ecosystem based management (EBM). The Centers will coordinate analyses of climate scenarios that include, but are not limited to, multiple Earth System Model runs under a range of greenhouse gas scenarios to enable applying oceanographic and atmospheric projections to a range of population, community, food web, and ecosystem models with both social and ecological endpoints

- Disseminate climate-related science and information, e.g., climate vulnerability analyses, by leveraging existing NOAA Fisheries communications efforts and expertise in the region. Our west coast communications team will assist in delivering climate data and information within NOAA and to existing and new science and management partners. The team will make new and existing climate information readily accessible and useful through novel scientific communications techniques and strategic communication channels

For each of the seven NCSS objectives listed above, the WRAP provides details on plans for making progress under level funding and increased (e.g., an additional ~10%) support. Currently, our workforce is addressing the challenge of climate variability and change. However, we recognize we have gaps in expertise. The WRAP provides the opportunity to realign work, provide training, possibly recruit new staff and strengthen partnerships to fill those gaps. These gaps are noted throughout the WRAP. While the WRAP also describes new activities we would implement with an increase in funding, it is important to recognize that with level funding we may only be able to take incremental steps by realigning personnel and/or suspending some current activities. The WRAP will be assessed through the metrics of 1) the quality of scientific literature in which we publish our results, 2) the strength of our science infrastructure, 3) the rate of recovery of protected species, 4) the development of decision support tools, and 5) recommendations for sustainable fisheries management.

2. INTRODUCTION

This document outlines the joint Western Regional Action Plan (WRAP) for the Northwest (NWFSC) and Southwest Fisheries Science Center (SWFSC)—the Centers—that describes how we will implement the NOAA Fisheries Climate Science Strategy (NCSS; Link et al. 2015) in the California Current Large Marine Ecosystem (CCLME), including the adjacent estuaries and watersheds used by Pacific anadromous species. This Regional Action Plans (RAP) identifies key actions to increase the production, deliver and use of climate-related information to help fulfill NOAA Fisheries' mission and implement the NCSS in this region over the next 3 to 5 years.

The WRAP focuses on *present climate variability* and *future climate change* in the CCLME and West Coast watersheds and estuaries. The CCLME faces dynamic and interacting challenges from a changing climate, ranging from ecosystem services to navigation and security. Extending from Canada to Mexico, the CCLME is used for recreation and commerce, and it supports extensive commercial, tribal, and recreational fisheries for finfish and invertebrates, including sardine, anchovy, hake, halibut, rockfish, salmon, squid, shrimp, tunas, and Dungeness crab. Many protected species, including marine mammals, sea turtles, and birds, inhabit the CCLME or are among the highly migratory species from the broader Pacific Ocean that use the CCLME as a nursery area, migratory corridor, and/or feeding ground. Acknowledging the role the CCLME plays for higher trophic-order organisms that range throughout the Pacific Ocean is key to understanding the potential effects of climate variability and change on our ecosystem.

Physical forcing of the CCLME varies on time scales of days to decades and includes event-scale changes in winds, seasonal cycles, and multi-year scales associated with the El Niño Southern Oscillation (ENSO), warming–cooling cycles associated with the Pacific Decadal Oscillation (PDO) and spin-up/spin-down cycles of the Subarctic and North Pacific gyres, referred to as the North Pacific Gyre Oscillation (NPGO). Seasonal and longer time scale variations in cool season precipitation and temperature also have profound impacts on annual snowpack and subsequent snowmelt runoff into West Coast watersheds. Superimposed on this natural variability is anthropogenic climate change.

While "climate change" is viewed by many as a slow process that may not affect society and the environment for 30–50 years into the future, NOAA's National Marine Fisheries Service (NOAA Fisheries) has observed many challenges and changes to our managed species' population abundances, productivity, and distribution resulting from impacts of recent climate variability in the CCLME (see Appendix A). By "climate variability" we refer to seasonal, interannual, and decadal variability in physical forcings that drive freshwater, estuarine, and marine biological responses associated with basin-scale oscillations such as the PDO, the NPGO, and the ENSO, as well as to the local-regional impacts from seasonal variability in temperature, precipitation, stream flow and temperature, and upwelling (e.g., see Fig. 3). Both climate change and climate variability have major, and only partly understood, impacts on freshwater, estuarine and marine food webs, fishery and protected resources, and the resource-dependent communities.

Ecosystems in West Coast watersheds, estuaries and the CCLME respond strongly to changes in physical forcing. For example, populations of small pelagic fish go through extended periods of high and low abundance. In recent times, eastern Pacific sardine and anchovy populations have been out of phase during extended periods of relatively high and low abundance, but the longer paleorecord shows that, in general, sardine and anchovy population fluctuations are positively correlated. In concert with the PDO, U.S. West Coast coho and Chinook salmon post-smolt survival rates vary in parts of the CCLME over an order of magnitude between "good" and "poor" years. Market squid landings are closely associated with El Niño, plummeting during all moderate-to-large events, and then rebounding a year or two later. Also during El Niños and warming ocean conditions, Pacific hake migrate farther north, loggerhead turtles are more abundant in the CCLME, and subtropical species such as tunas, opah, and wahoo are more commonly found throughout the CCLME. The distribution and abundance of marine mammals within the CCLME also varies markedly as ocean conditions change. Likewise, certain harmful algal blooms (HABs) are more severe in warmer years. Exploited and protected populations are important as predators and prey, affecting taxa ranging from plankton and forage fish to marine mammals, sea turtles, and seabirds. As such, organisms of the CCLME affect biogeochemical cycles and, in turn, are affected by changes in ocean chemistry and climate. In essence, climate variability and change are strongly intertwined with the CCLME's health and services.

In recent years, we have witnessed oceanographic conditions that are notably anomalous even for this region. These extremes, like a "climate change stress test," are perhaps early signs of how future changes to the CCLME and West Coast estuaries and watersheds will manifest and how these changes will affect ecosystems – including human communities – reliant on these waters historically rich in natural resources.

Some of the climate-driven oceanic changes observed to be occurring or expected to change in the future in the CCLME due to anthropogenic climate change include: a) timing of the onset, duration, and strength of coastal upwelling, b) changes in atmospheric wind patterns that drive ocean circulation, including changes in transport in the California Current that affect the lower trophic levels of the food web, c) increased water column stratification as observed during marine heat waves (including those associated with El Niño events), d) more frequent occurrences of hypoxia, e) pH-related declines in aragonite saturation, which are likely to impact lower, middle, and upper trophic levels of the food web, and f) rising coastal sea level.

Freshwater environments will also experience increased stresses due to changes in physical forcing. The major stressors occurring now or expected to affect watersheds are g) increased average air and stream temperature, h) an increased fraction of annual precipitation falling as rain rather than snow, i) a contraction in the snow accumulation season that also comes with reduced springtime mountain snowpack, and j) more natural runoff and stream flow in winter and less snowmelt runoff in spring. Rising temperature alone increases annual water deficits that drive drought stress and moisture content in vegetation. Increasing water deficits on the landscape leads to substantial negative impacts on forests by making them more vulnerable to pests, pathogens, and wild fire. Because snowpack serves as a critical natural reservoir for fresh water in many West Coast watersheds, reduced snowpack typically increases human conflict over already fully or over-allocated freshwater resources. Without management actions that mitigate or resist climate change impacts in freshwater habitats, these changes are very likely to diminish the productive capacity of many West Coast watersheds for Pacific salmon and steelhead.

Estuaries experience climate change forcings from the atmosphere, the ocean and the tributary freshwater environments. Changes in estuarine systems due to rising coastal sea level, warming temperatures and altered stream temperature, stream flow timing and volume will cause multiple stresses on anadromous species through habitat modification, changes in primary and secondary production, altered species composition and food-web structure, and changes in fish metabolism.

In this section, we first present a brief overview of the CCLME and broadly identify major climate-related pressures on our living marine resources. We briefly summarize the unusual marine heat wave event and extreme El Niño we experienced from 2012–2016. These events have provided us with insight into what the CCLME's response may be in the future under similar warming events. As such, this five-year "climate change stress test" (described in greater detail in Appendices A and B) will be used in framing our Action Plan. In Section 3, Assessment, we address the seven NCSS objectives, describing our current capacity and efforts to conduct climate science supporting the management of our living marine resources, as well as overarching strengths, weaknesses, and opportunities. Section 4 outlines the comprehensive Action Plan for the next five years, assuming stable funding, as well as the scenario of a 10% increase in current funding levels. Section 5 describes metrics to be used in assessing the quality of our output and outcomes. Finally, because making science usable and useful requires effective collaborations with and dissemination to a wide range of stakeholders outside the Centers, we describe our overall Outreach and Engagement strategy in Section 6.

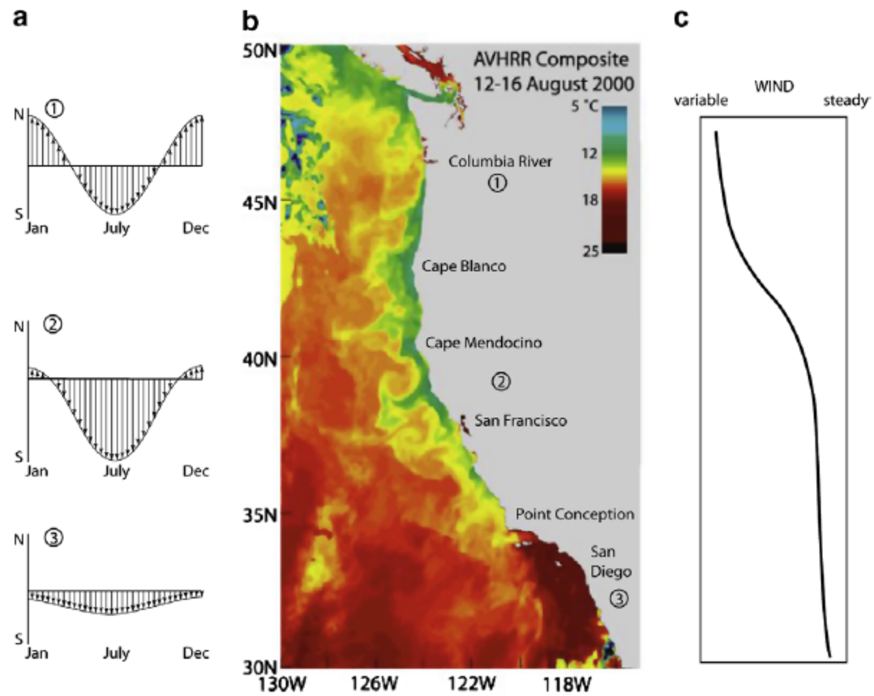

Figure 1. Winds and sea-surface temperature in the California Current System (CCS). (a) Seasonal variation of alongshore winds in three regions of the CCS; (b) sea-surface temperature from August 2000; (c) variability of wind forcing as a function of latitude. From Checkley and Barth (2009).

2.1 The California Current Large Marine Ecosystem

Globally, the CCLME is one of four highly productive eastern boundary upwelling systems that are driven by equatorward winds (Figure 1). Superimposed on the seasonal wind pattern are significant natural seasonal, interannual, and interdecadal forcing fluctuations that generate impacts in ocean biogeochemistry, marine food webs, and fisheries (Strub et al. 2013). The scale and patterns of the variability are changing and, as such, these upwelling systems are vulnerable to climate-driven changes in ocean acidification (OA), hypoxia, harmful algal blooms (HABs), and the dynamics of forage fishes and their predators and prey. In turn, these biogeochemical responses to climate forcing impact ecosystem services important to humans.

A host of fish, bird, turtle, and mammal species are resident or migrate annually to or through the productive waters of the CCLME (Figure 2), in most cases feeding on the ecosystem's lipid-rich food chain. Migrants include ~2M metric tons of hake and sardine from the waters off southern and Baja California, several hundred million juvenile salmon from U.S. West Coast rivers, millions of seabirds from as far as New Zealand (sooty shearwaters) and Hawaii (Laysan and black-footed albatrosses), tens of thousands of gray whales from Baja California, critically endangered leatherback sea turtles coming from nesting beaches in the far western Pacific, endangered loggerhead sea turtles hatched on nesting beaches in Japan, millions of albacore tuna from the north Pacific, and recovering populations of eastern North Pacific humpback, blue, and fin whales. Residents of the CCLME include green turtle foraging aggregations in southern California, California sea lions, killer whales, and other diverse marine mammal species. The prey resources of the CCLME are critically important to these migrants and residents; thus, any physical process that disrupts the food web may result in declining growth and survival rates, changes in behavioral patterns and/or distribution, and mismatches in phenology between predator need and prey availability.

There are approximately 560,000 pinnipeds of six different species that are resident breeders on islands and along the U.S. West Coast. The animals range in size from 6 kg for newborn pups of northern fur seals to greater than 1,000 kg for adult male northern elephant seals. Added to the resident pinnipeds are another approximately 445,000 northern fur seals that migrate from the Bering Sea into the California Current each winter, which brings the total to nearly a million pinnipeds that use the CCLME just within U.S. waters.

Large populations of seabirds are resident breeders on islands along the Pacific coast from Washington through California. They rely on prey from the CCLME during nesting and the non-breeding season. Common murres, rhinoceros and Cassin's auklets, pigeon guillemots, western and California gulls, and Pelagic and Brant's cormorants, all together numbering hundreds of thousands of birds, nest on offshore rocks and islands. Smaller numbers of rarer species, such as Ashy storm petrels, Xantus murrlets, and Brown pelicans, also breed on California islands. These birds, like many of the pinnipeds, are central place foragers and function as sentinels of the marine productivity of the CCLME. Oceanographic processes that disrupt the food web of the CCLME may result in declines in the status of these protected species.

Figure 2. The California Current Large Marine Ecosystem (CCLME) is a dynamic, diverse environment in the eastern North Pacific Ocean spanning nearly 3,000 km from southern British Columbia to Baja California, and includes the U.S. Exclusive Economic Zone, the coastal land-sea interface, and adjacent terrestrial watersheds. Taken from http://ecosystems.noaa.gov/WhereIsEBMBeingUsed/WestCoast.aspx.

Climate impacts on freshwater and estuarine systems

There are many micro-climates in US West Coast states that are a product of large scale wind and weather patterns, proximity to the Pacific Ocean, and the complex topography of the region. Sharp local climate gradients are especially evident moving west-to-east from the cool, moderate, and moist maritime climate found in low-elevation coastal watersheds to the arid, continental climates in the interior that are shielded from maritime influences by high terrain. Clearly defined wet and dry seasons form an important general pattern for salmon-bearing watersheds in Western US States, with seasonal changes in the position and activity of Pacific storm tracks bringing a distinct wet season from fall through spring and a dry season in summer, with a longer dry season at lower latitudes. Windward (western) slopes of the high terrain receive substantially more precipitation than the leeward (eastern) slopes, with some of the wettest locations in North America found on the west slopes of the coastal mountains and Cascade Mountain range (Figure 3). In contrast, dry desert conditions are common in the lee of the Cascade and Sierra Mountain Ranges. High elevation terrain in Western States typically collects an abundant snow pack over the course of the winter season, and snowpack serves a critical water storage function for many western watersheds.

Because of the region's complex topography and sharp climatic gradients, the region's hydrology ranges between snowmelt dominant runoff produced in the coldest basins (interior and high elevation), rainfed runoff produced in the warmest basins (typically coastal), and mixed snowmelt-and-rainfed runoff basins that occupy intermediate climate (and elevation) zones. Of the region's largest watersheds -- the Columbia, the Klamath, and the Sacramento/San Joaquin River Basins – the Columbia Basin has the greatest snowmelt influence, though many tributaries are characterized by mixed snowmelt-and-rainfed runoff. The Sacramento/San Joaquin Basin is similarly composed of a mix of snowmelt dominant and mixed snowmelt-and-rainfed tributaries, while the Klamath Basin is the warmest of these large basins with most tributaries characterized by mixed snowmelt-and-rainfed runoff or rainfed runoff.

In cool and wet years, the Columbia River Basin and high elevation tributary basins to the Klamath, Sacramento and San Joaquin Rivers experience an especially large snow pack and abundant snowmelt runoff in late spring and early summer. Basins that are too warm to collect substantial snowpack instead deliver increased runoff in winter when the precipitation falls. Periods of high runoff typically deliver more turbid and higher volume discharge into rivers, estuaries and the coastal ocean, at least to the extent that this runoff is not captured in storage reservoirs. Storage reservoirs and water conveyance systems (pipelines, aqueducts, canals, pumping facilities, etc.) are extensive in the Western US, and their existence and operations play integral roles in the habitat used by most anadromous fish in the region.

Prominent patterns of natural climate variability for the Pacific Basin as a whole are associated with systematic changes in Western States climate (Redmond and Koch 1991, Mantua et al. 1997) and hydrologic responses (Cayan and Peterson 1989, Cayan 1996). For example, El Niño periods favor relatively warm-dry winters in the northwest US and cool-wet winters in the southwest US, while tropical La Niña periods favor the opposite patterns. Similarly, twentieth century variations in the Pacific Decadal Oscillation favored relatively cool-wet northwest and warm-dry southwest winter climate in the periods ~1890-1924, 1947-1976, and 1999-2013, and the opposite winter patterns during 1925-46, 1977-1998, and 2014-2016.

Estuaries experience the combined influences of atmospheric forcing from above, oceanic forcing on their marine side, and watershed forcing where runoff and stream flow enters from their tributary basins. For small coastal lagoons, wet periods can lead to extended periods with breached sandbars that allow the lagoon to drain and bring in marine waters, while dry periods can lead to extended periods where sand bars block the estuary and allow the lagoon waters to expand with freshwater inflows, however meager they might be. In perennially open estuaries, high runoff periods contribute to increased estuarine circulation, reduced salinity, and increased turbidity, all factors that can impact the biogeochemistry of the estuary.

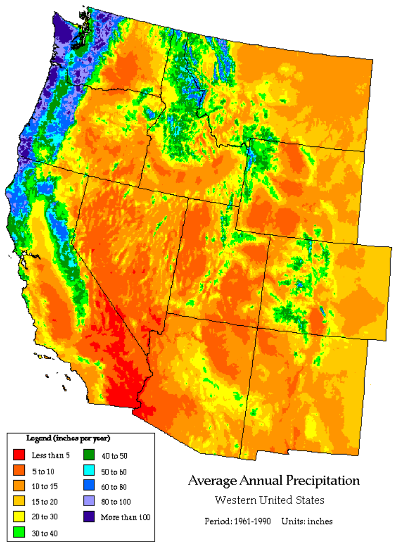

Figure 3: Annual mean precipitation in the Western US (based on PRISM data from 1961-1990). Image obtained from the Western Regional Climate Center (http://www.wrcc.dri.edu/pcpn/westus_precip.gif)

Climate impacts combine to affect the whole ecosystem, from the mountainous origins of the streams that flow to the Pacific to the open ocean far from shore. Especially affected are the anadromous fish (salmon, lamprey, eulachon, and sturgeon) whose habitats span the entire region. Spawning regions in small mountainous streams, rivers that flow through inland valleys, and estuaries that range from large (the San Francisco Bay Delta and Puget Sound) to the smaller coastal estuaries and short coastal lagoons that are seasonally closed by sand bars (especially in California)—all are impacted by climate variability. In the West Coast States, the massive degradation and loss of freshwater, floodplain, and estuarine habitats, coupled with intensive human use of freshwater resources, have greatly increased the vulnerability of anadromous fishes to climate impacts (NRC 1996; ISAB 2007; Lindley et al. 2009).

The combined effects of climate impacts on rivers, streams, estuaries, and the ocean lead to cumulative impacts on the full life-cycle of anadromous fish populations. For instance, the warm phases of the PDO and ENSO typically bring warmer and drier winters to the Pacific Northwest, with reduced snowpack and stream flow that tends to reduce freshwater habitat quantity and quality for salmon. Warm phases of the PDO and ENSO also favor a warmer, and a more subtropical, marine food web in the CCLME that includes leaner and smaller zooplankton. This constitutes an overall less-favorable food web for Pacific salmon early marine growth and survival. In contrast, cold phases of ENSO and the PDO have been especially favorable for Pacific Northwest (PNW) salmon productivity and abundance, because they foster high productivity in freshwater (cooler temperatures, more precipitation, abundant snowpack, and an abundance of cold water in streams and estuaries) and marine habitats (colder, increased nutrients, and a more subarctic/boreal food web that includes a larger, lipid-rich zooplankton community), leading to increased early marine growth and survival.

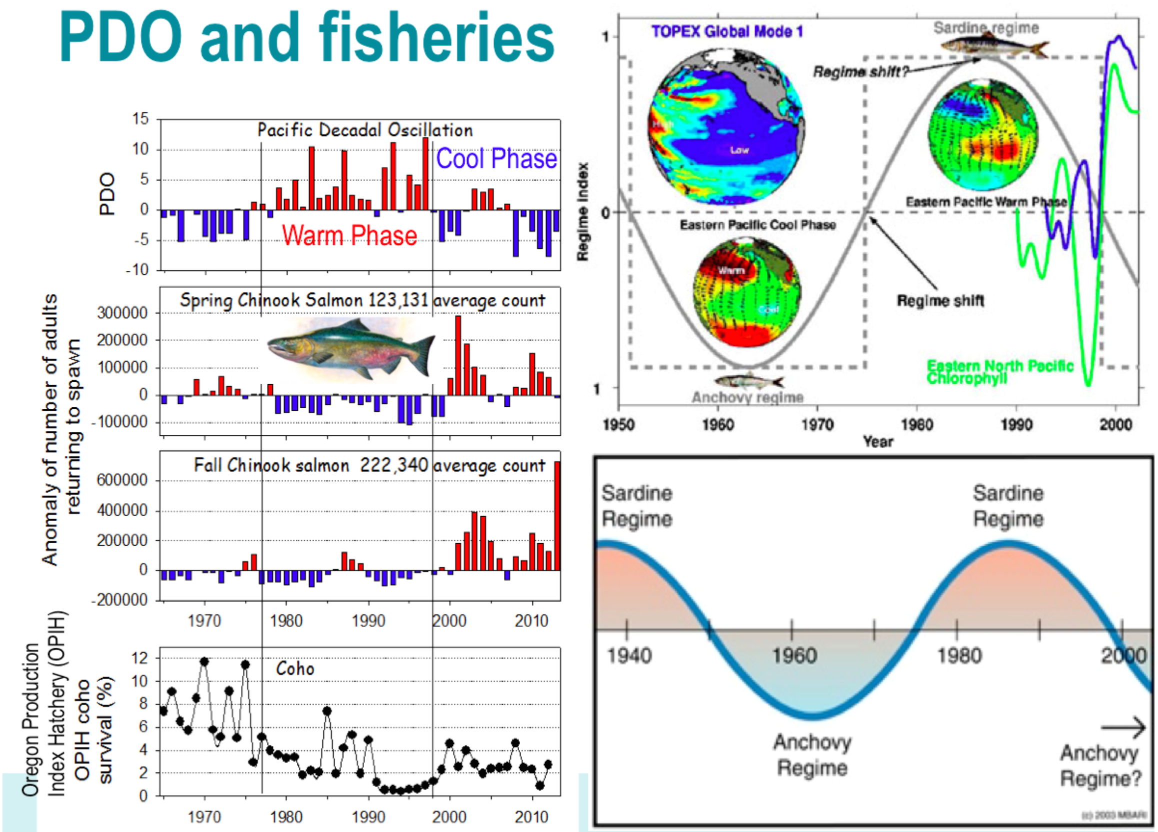

Figure 4. Pacific Decadal Oscillation (PDO) from the 1950s to present, and its recent correlation to fluctuations with salmonids and small pelagics in the CCLME. Annual spring Chinook salmon and fall Chinook salmon counts at Bonneville Dam on the lower Columbia River.
[Panels adapted from Chavez et al. (2003), http://www3.mbari.org/news/news_releases/2003/nr01-chavez.html, and http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ca-pdo.cfm.]

Expected Impacts of Climate Change in the CCLME

Longer-term (anthropogenic) climate change is likely to affect our ecosystem and fisheries through effects of increased temperature on organisms' metabolisms and life history, altered freshwater food webs, northward shifts in ocean isotherms leading to northward shifts in species' distribution and/or phenology, and increased upper-ocean stratification that will tend to inhibit the upward transport of nutrients into the euphotic zone and the downward mixing of dissolved oxygen. Reduced nutrient concentrations alone will reduce plankton production. Decreased dissolved oxygen concentrations would affect respiration, potentially limiting the favorable habitat for finfish, shellfish, and other benthic organisms on the continental shelf. A reduced aragonite saturation state (lower pH) would increase mortality of shell-forming mollusks. Potential changes in wind-driven upwelling would impact all of the biogeochemical processes described above. These climatic effects will interact with existing pressures on the ecosystem (from urbanization to fisheries removals to hydropower) to produce cumulative impacts that are not necessarily predictable from considering climate alone.

Climate warming, by itself, will raise freezing levels and cause an increased fraction of annual precipitation to fall as rain rather than snow, and increase evaporative demand. Mountain snowpacks will decline in all but the coldest (highest elevation and/or inland) basins as snow accumulation seasons start later and end earlier in the year. More rainfed runoff will come in winter, and less snowfed runoff will come in late spring and early summer. Watersheds that have historically had mixed rainfed-and-snowfed runoff hydrology will transition to rainfed systems, while snowfed runoff basins will trend toward mixed rainfed-and-snowfed runoff hydrology. Water temperatures will also rise in lakes, streams, and estuaries. Summer low-flow and winter peak-flows are likely to intensify in many watersheds. Increasing water deficits on the landscape will likely cause substantial negative impacts on forests by making them more vulnerable to pests, pathogens, and wild fire. Increasing sediment inputs to watersheds due to post-fire rain-events could become a growing issue of concern for spawning and rearing habitat for anadromous fish. Without management actions that mitigate or resist this collection of climate change impacts in freshwater habitats, these changes are very likely to diminish the productive capacity of many West Coast watersheds for Pacific salmon and steelhead (Mantua et al. 2010, Beechie et al. 2010).

Near-term, observed climate variability is signaling that the climate changes in sometimes surprising ways, such as delayed upwelling in summer 2005; the exceptional marine heat wave covering much of the Northeast Pacific Ocean during 2013–2015 (the so-called “warm blob” Bond et al. 2015) with its widespread ecological impacts, including the largest west coast harmful algal bloom ever recorded; and the extreme tropical El Niño in 2015–2016, the third such “Super El Niño” in 40 years. As well, increased temperatures due to climate change are likely to impact the number of female sea turtle hatchlings produced on nesting beaches, because the sex of sea turtles is influenced by their environment (warmer temperatures produce more female hatchlings). Therefore, the population dynamics of sea turtles using foraging grounds in the CCLME may be subject to alteration or destabilization.

2.2 The 2012-2016 “Climate Stress Test” for the West Coast

Recent climate extremes provide “natural experiments” which allow us to study their impact on food chains, ecosystem structure, and fisheries, and may offer previews of anthropogenic climate change impacts projected for the latter part of the 21st century. The resulting extreme freshwater, estuary, and ocean conditions represent a climate change stress test on the living marine and anadromous resources (and their different habitats) managed by NMFS. We view this “stress test” as a unique opportunity to better understand the impact of climate on the CCLME from summit to sea (see Appendix B).

Other important socioeconomic changes will likely interact with the regional effects of anthropogenic climate change to shape the future of the CCLME (see Appendix C).

3. ASSESSMENT AND ACTIONS: MEETING THE NCSS CHALLENGE

The NCSS recommends that the Regional Action Plans highlight the strengths, weaknesses, opportunities, and challenges related to living marine resource (LMR) science and management in the face of climate change. The NCSS's seven objectives are:

Objective 1: Identify appropriate, climate-informed reference points for managing LMRs.
Objective 2: Identify robust strategies for managing LMRs under changing climate conditions.
Objective 3: Design adaptive decision processes that can incorporate and respond to changing climate conditions.
Objective 4: Identify future states of marine, estuarine, and freshwater ecosystems, LMRs, and LMR-dependent human communities in a changing climate.
Objective 5: Identify the mechanisms of climate impacts on LMRs, ecosystems, and LMR-dependent human communities.
Objective 6: Track trends in ecosystems, LMRs, and LMR-dependent human communities, and provide early warning of change.
Objective 7: Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates under changing climate conditions.

Because they possess elements that are tightly interrelated and there is a strong interdependency between them, we assess our capabilities (in Section 3) and present our Western Regional Action Plan (Section 4) in overarching terms. We point to specific NCSS objectives in Table 4.

3.1 Strengths

The Centers combine multiple strengths to address the challenges inherent in providing the scientific information necessary to manage LMRs in the California Current under a changing climate. Strengths include existing infrastructure and information and substantive steps taken in understanding the CCLME, including study of "natural experiments," or applying the "climate stress test" that the 2012–2016 West Coast climate extremes offer. Scientists who work at our Centers are also working to address climate impacts and implement ecosystem-based fishery management (EBFM) in other ecosystems (e.g., in Antarctica), and their experience can be leveraged for application in the CCLME.

Existing observations and time series (Objectives 6 and 7)

The U.S. West Coast is home to the longest fisheries–oceanography time series in the nation (the California Cooperative Oceanic Fishery Investigations,[3] CalCOFI), has some of the highest levels of marine mammal survey effort and broadest marine mammal taxonomic coverage in the world (Kaschner et al. 2012), and has a number of other long- and medium-term data collection efforts that sample many physical, chemical, biological and ecological parameters and socioeconomic

[3] http://calcofi.org/index.php

components of our system (Table 1). These studies underpin much of our understanding of how the CCLME and related ecosystem services function and respond to climate variability. In addition to the NOAA-led observations and time series, we also have the advantage of long-term monitoring efforts from other agencies, both state and federal. These tend to be relevant to the management of anadromous fishes and other species, and include time series of salmonid abundance, water quality, stream flow, and temperature. In total, these data sets are the key elements to detect trends in abundance and distribution of species, patterns of environmental conditions, and sustained changes in the human communities that depend on the CCLME and its constituent species.

This work is supported by a physical infrastructure that includes: modern research vessels and aircraft; the exploration and use of advanced technologies, including satellite and airborne remote-sensing platforms and a range of animal tags and tag-detection systems, such as satellite-based acoustic tags and receivers, passive integrative transponder (PIT) tags, and antennae arrays; glider arrays and moorings; our state-of-the-art laboratories (molecular genetics, hormone assays, stable isotopes, etc.) and the unique world-class Ocean Technology Development Test Tank at our La Jolla lab. Our infrastructure also includes rapidly developing and improving data management systems for the full range of data collected.

Finally, these data sets have supported the initial development of ecosystem indicators, through the California Current Integrated Ecosystem Assessment (CCIEA)[4]. These indicators span a range of ecosystem components, from oceanographic to harvest-related to predators of commercially fished species, chosen to reflect areas that might be affected by a number of stressors to the system, including climate change. The indicators are presented to the Pacific Fishery Management Council (PFMC) on a regular basis within an annual ecosystem status report.[5]

Studies addressing or incorporating climate drivers (Objectives 5 and 6)

One of the most active areas of climate-related research at the two Centers involves identifying the mechanisms by which climate affects the status of our LMRs (including anadromous fish) and anticipating the impacts of ongoing climate variability and change.

Correlations between climate-related or environmental drivers and species or population responses have been found for planktonic species, pelagic fishes, some groundfish, salmonids, marine mammals, and turtles, among others (Table 2). Key to these studies have been the long-term data collection efforts (above and Section 6) that allow the evaluation of statistical associations between potential climate drivers and the conditions of species or the ecosystem; for example, the CCIEA is using statistical approaches to estimate the relative risks that climate drivers pose to LMRs and human systems, and to identify threshold values at which climate impacts increase drastically. In addition, we support active laboratory research into the

[4] http://www.noaa.gov/iea/CCIEA-Report/
[5] http://www.pcouncil.org/ecosystem-based-management/annual-state-of-the-california-current-ecosystem/

mechanisms of climate-related water-quality impacts (e.g., ocean acidification, hypoxia, temperature) on marine and anadromous organisms, as well as genetics and genomics that will give us insight into how species adapt to changing conditions. Similarly, stable isotope analysis allows us to track changes in diet and foraging location, and hormonal analysis provides insight into nutritive condition, reproductive state, and stress response in marine mammals as well as sex ratio (for sea turtles) in relation to changes in climate.

In collaboration with other NOAA line offices and academic partners (see below), we are developing two types of knowledge required to make informed projections about the future of LMRs in the CCLME and anadromous fish populations in West Coast watersheds: 1) a mechanistic understanding of biophysical links, and 2) future scenarios (or projections) for properties of marine and freshwater habitats. We are also engaged in studies to integrate these two pieces in coupled biophysical models of varying complexity. At one end of the spectrum are expert-based rapid climate vulnerability assessments[6] for protected species and Fishery Management Plan (FMP) species. At the other end of the spectrum are "end-to-end" models that link physics to fish and fisheries. For anadromous fish, the Centers are developing a variety of linked life-cycle models for Pacific salmon and sturgeon that are explicitly linked with freshwater, estuary, and ocean habitats in ways that allow for evaluating population responses (e.g., abundance, productivity, distribution, and life history diversity) under different hatchery, harvest, habitat restoration, water management, and climate change scenarios. Under the aegis of the CCIEA, an effort is underway to use output from global climate models (GCMs), regional ocean modeling systems (ROMS), and ecosystem models (e.g., Atlantis), to project broad-scale biological and physical conditions in the California Current, including the likely future suitability of habitat for salmonids and cetaceans, the frequency and intensity of HABs, short-term (6- to 9-month) forecasts of sardine distributions, fluctuations in forage biomass, and the impacts of ocean acidification. These research themes require enhanced modeling capabilities.

These types of studies provide one of the primary and most direct ways that management decisions can be informed by NOAA climate and fisheries science. In fact, the U.S. West Coast has the only temperature-dependent fishery closure rule for the protection of an endangered species: to protect loggerhead turtles, the closure of the swordfish drift gillnet fishery east of 120°W is triggered when ENSO events bring on anomalously high sea surface temperature (June, July, and/or August during forecasted or realized ENSO years). It also has one of the only harvest control rules that include an explicit climate/environmental trigger: allowable Pacific sardine harvest rates are mediated by an ocean temperature consideration. Similar control or decision rules based on other types of observations (e.g., the successes or failures of key predator species) are presently being developed by our scientists working in other ecosystems, and the lessons learned from these efforts are likely transferable to the CCLME. We have conducted a variety of studies aimed at identifying the impact of direct anthropogenic activities on listed species under

[6] https://www.st.nmfs.noaa.gov/ecosystems/climate/tools/assessing-vulnerability-of-fish-stocks

climate change, as well as studies identifying the restoration activities that are most robust and effective under a changing climate (Table 3). This kind of work has underlain the recent policy guidance for incorporating climate change in Endangered Species Act (ESA) decision-making. Finally, as an important contribution to developing more robust strategies for managing species under climate change, both Centers are engaged in expanding Management Strategy Evaluations (MSEs), with initial efforts focused on sablefish, hake, and North Pacific albacore, under alternative climate scenarios.

Collaborations and relationships (Crosscutting all NCSS objectives)
The Centers have robust collaborations and relationships with academics and others who use our science. In particular, the Cooperative Institute for Marine Ecosystems and Climate (CIMEC, a collaboration between NOAA and several California universities including the Scripps Institution of Oceanography and the University of California at Santa Cruz), the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) based at the University of Washington, and the Cooperative Institute for Marine Resource Studies (CIMRS) at Oregon State University provide ready and critical access to a broad range of academic expertise relevant to climate change studies. Other collaborators include San Diego State University, NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), Earth System Research Laboratories (ESRL), and the Pacific Marine Environmental Laboratory (PMEL), the three West Coast Integrated Ocean Observing Systems (IOOS) – CeNCOOS, NANOOS and SCCOOS – among others. Similarly, cooperative efforts with Australia's CSIRO (Commonwealth Scientific and Industrial Research Organization) and PICES (the North Pacific Marine Science Organization) have built our capacity to address ecosystem-relevant questions. In the U.S. West Coast region in general, climate, hydrologic, and oceanographic research is strong, with readily available climate (e.g., temperature, precipitation, stream flow, and snow storage), oceanographic, and biogeochemical characteristics (e.g., pH, O_2, and nutrient levels) of our freshwater, estuarine, and marine systems. Our established network of researchers will enable us to continue to move forward with climate-relevant research.

The Centers also have strong relationships with the West Coast Region (WCR), the PFMC, and the Pacific States Marine Fisheries Commission in matters of fisheries, and the International Whaling Commission (IWC), the US Marine Mammal Commission, and the Pacific Scientific Review Group (PSRG) for marine mammals. The existing West Coast Climate Team, consisting of representatives from the WCR and the Centers, is a regular and robust forum for exchange of information bridging research and policy developments and science needs. The PFMC has been receptive to ecosystem approaches in general, including our CCIEA and supporting work, and is actively seeking input and engagement on ways to incorporate climate information into decision-making. The ongoing communication channels and cooperation we have with these groups inform our research agenda on science needs, provide a venue to transmit the information we develop, and ensure that our science and data products are used appropriately in management.

3.2 Weaknesses

While our Centers have many strengths and efforts aimed at climate research supporting management of NOAA trust resources, we also face a number of challenges in meeting the goals of the NCSS.

Infrastructure: people (Objectives 4, 5, and 7)

Meeting the scientific challenges of the coming changes in climate while simultaneously fulfilling the full range of other obligations will tax our current human capacity. Designing studies, analyzing data, developing climate and regional ocean models, providing interpretations, and working with policymakers to develop, implement, and use the range of products and tools, are a few of this effort's necessary human functions. **Our current staffing is not sufficient to fulfill the emerging needs of the decision-makers[7] seeking scientific advice related to climate impacts and other changes in the CCLME**. In fact, we currently lack sufficient time and capacity to process samples or to systematically analyze the data from completed surveys. We will continue to make progress in climate science for the CCLME, but our human capacity, which has declined since 2012, is already limiting the rate and extent of what we can do, and is exacerbated by the retirement of key personnel with expertise in ocean ecology at both Centers. CIMEC, CIMRS, and JISAO are sources for highly qualified expertise, but additional funding is required to fully utilize these collaborations.

Infrastructure: observations (Objectives 5, 6, and 7)

While the ship-based surveys and other data sets that we maintain are critical components of our current efforts, there are weaknesses as well as strengths in our work. First, several of our surveys (including the Newport and Trinidad Head Oceanographic Lines, the BPA-funded Salmon Ocean Program, and all of the marine mammal and turtle surveys) do not have stable funding, inhibiting our ability to count on these important data sources in the long term. Second, many of our surveys and data collection efforts do not occur on spatial and temporal time scales that allow us to resolve links between climate drivers and species, population, or ecosystem responses. Third, many of our key data sets for salmon in the watersheds are dependent on our state and tribal partners, which have also experienced human capacity challenges. Fourth, we know the genetic or demographic population structures of only a few species, limiting our ability to determine responses to stressors. Nearly all of our observation efforts were initiated and grew in response to particular problems, and took place at different times, meaning that coordination and standardization between surveys is limited; fully compatible data collection efforts would increase our power to detect change, ascribe mechanistic causes, and project the future. Finally, the vast majority of our observations stop at our national borders, while the ecosystem processes and species distributions in our system do not; we do not currently collect a comprehensive picture of the entire CCLME.

[7] Including the WCR, the PFMC, tribes, the IWC, the PSRG, the U.S. Marine Mammal Commission, and state and local resource agencies.

Social science (Objectives 5 and 6)

Social science is an essential element of managing natural resources in an ecosystem framework. While both Centers have strong expertise in fisheries economics and have begun to develop their social science capacity in other disciplines, there are not yet long-term data sets of human factors that would help us to identify links between coastal communities and the natural and regulatory environment. This limits our ability to include appropriate human responses in MSEs, as well as to predict likely human responses to management actions. Overall, 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. The Southeast Region's Five Year Review of Red Snapper[8] provides a helpful example of how the Centers might begin to incorporate community social vulnerability indices in fisheries management plans, which can be tied directly to climate variability and change, as well.

Determining mechanistic links at appropriate scales (Objectives 6 and 7)

Determining how climate factors drive oceanographic, hydrographic, and other environmental processes, and how these, in turn, drive biological (including potential evolutionary responses to climate stressors), ecological, and human responses, is perhaps the single most important element for making progress on all the Objectives identified in the NCSS. We have made progress in some areas (Table 2); however, we do not fully understand which components of climate are tied to vital rates, species' distributions, ecosystem structure, and more. The Centers need to maintain monitoring capability, utilize new laboratory analytic techniques, and enhance their modeling capability to fully investigate these linkages. Improving qualitative and quantitative descriptions of these interactions will be essential to model development, identifying appropriate biological reference points, and developing management strategies that will be effective in the face of our changing climate. The absence of a quantitative understanding of mechanistic links—particularly under evolving climate conditions—also limits our predictive capacity. Hence, while the drought and warming conditions witnessed in the past four years (2012–2016) may be the norm decades in the future, without verified mechanisms of impact from climate to environment to ecology and biology, the uncertainties in our projections of the future CCLME will remain considerable.

Laboratory capacity (Objectives 5 and 7)

Our physical infrastructure to gather information about population structure, food habits and food web structure, and ecosystem structure is uneven, and in some areas is insufficient to meet current or future needs. While the Centers enjoy state-of-the-art laboratory facilities in some locations, there are aging structures in others. As such, sample processing is limited in parts of the region.

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8 http://gulfcouncil.org/docs/amendments/Red Snapper 5-year Review FINAL.pdf

"Random Acts of Kindness" approach (Crosscutting all NCSS objectives)
A strength is that the Centers have dedicated and talented personnel who are approaching the scientific issues around climate change with vigor. However, to date, most of our work has not been systematic, has been funded opportunistically (often by non-NOAA sources), and is thus dependent on individual interest, available resources, and personally fostered collaborations. Obviously, these are important components of any research program. Greater region-wide coordination could ensure that priority areas are treated more thoroughly and we could direct resources more strategically. This WRAP, the Climate Vulnerability studies, and the CCIEA are all steps toward a better-structured inclusion of climate factors in our mission.

3.3 Opportunities
This combination of strengths and weaknesses affords us a number of opportunities as we move forward:

West Coast Climate Program development (Crosscutting all NCSS objectives)
Treating our climate-relevant research as an integral component of our programs affords us the opportunity for more targeted, coordinated efforts aimed at areas of particular scientific or management importance. It also provides the opportunity for more focused approaches to MSEs and the ability to more quantitatively integrate our understanding of the various ecosystem components end-to-end.

Realign the workforce to confront change (Objectives 4, 5, and 7)
Currently, our workforce is nobly attacking the challenge of climate variability and change. However, we suffer gaps of expertise, or too little capacity in some areas of expertise, and have the opportunity to reorient work, provide training, and recruit, as possible, staff to fill those gaps. Particular areas of importance include the social sciences, modeling and statistics, expertise in the interpretation and handling of oceanographic and climate projections, laboratory skills (including processing plankton samples), diet and similar secondary data collection efforts, the development and implementation of novel methods in 'omics, stable isotope analysis, aging via skeletochronology, hormone analysis, and others. In addition, we can build interdisciplinary and cross-organization collaborations across our divisions, Centers, other NOAA line offices, agencies (state and federal), and international boundaries with the climate, ecological, socio-economic, and fisheries science communities. However productive these partnerships, they are no substitute for obtaining new, in-house expertise that can serve to initiate new, and strengthen existing, collaborations.

Determining appropriate scales for science and management (Objectives 4, 5, and 6)
Scientific exercises, such as finding statistical associations between climate drivers and a population's response, and management efforts, such as regulations intended to reduce impact to climate-sensitive species, need to be conducted at the appropriate scales. To date, out of necessity, we conduct many of our scientific efforts at the scale of the coast or of political

boundaries (e.g., states). However, some processes occur at more local or regional scales, others at ecosystem scales, and many fishes, marine mammals, sea turtles, and seabirds are likely to have population structures that do not correspond to our political or geographical boundaries. Ensuring that our efforts are targeted at appropriate scales will increase our efficiency and effectiveness.

Evaluate our full suite of surveys for gaps, integrate, and standardize (Objectives 5, 6, and 7)
Our strong data-collection efforts could be more cohesive and coordinated. A focus on climate variability and change presents the opportunity to evaluate our surveys to understand our ecosystem and detecting changes within it. Revising surveys, as appropriate, to provide some standardized data would give a more comprehensive picture of our system, and identifying gaps helps prioritize where efforts should go in the future. The final aim would be a suite of observation approaches that would provide the most efficient detection of changes in ecosystem or species status and the drivers thereof. Ideally, these would be coordinated with Canada, Mexico, the Pacific Islands, and Alaska, as appropriate.

Indicator development and use (Objectives 1, 2, and 6)
Ultimately, managers use indicators—both quantitative and qualitative—to make and inform decisions. Through our CCIEA efforts, we have begun the development of ecosystem-level indicators and are engaged with the WCR and the PFMC to identify the indicators to be used in their Fishery Ecosystem Plan (FEP). We are in a strong position to continue indicator development through ongoing analyses of observational data and statistical modeling of the ecosystem indicators. The NWFSC provides salmon management advice through 15 ecological indicators that present a picture of ocean condition, in a given year, from the viewpoint of a juvenile salmon, and provide outlooks for good vs. poor salmon returns 1–2 years in the future. Similarly, the SWFSC has been a leader in developing statistical models of cetacean distribution in relation to ecosystem conditions, exploring forecast capabilities at varying time scales (e.g., Becker et al. 2012, 2016), and using loggerhead turtles as clear indicators of shifting species distributions following changes in oceanographic conditions. Finally, our collective modeling skills will pursue forecast capabilities through various numerical models with the goal of building both near-real-time indicators and eventually informing Biological Reference Points.

Data management (Objectives 6 and 7)
Ongoing effort to improve and enhance data management, including our efforts with implementing Public Access to Research Results[9] (PARR), could provide increased ability to analyze existing data sets and use our long-term data for the full range of scientific activities called for in the NCSS. Maintaining and upgrading the NWFSC's bioinformatics computer cluster will make it available to researchers at both Centers and allow us to increase our

[9] http://docs.lib.noaa.gov/noaa_documents/NOAA_Research_Council/NOAA_PARR_Plan_v5.04.pdf

efficiency in deciphering the bounty of information from genome sequencing; however, this will not be possible without an individual on staff with detailed knowledge and skills in bioinformatics. Similarly, we have bioinformatics expertise and access to computer clusters and supercomputers at UC Santa Cruz, UC San Diego, and the University of Washington. Collaborations with their world-class bioinformatics and computer science people and labs should continue to be strengthened. Ongoing efforts to improve management of and access to other data collected by the Centers are also critical.

Meet the needs of policymakers and natural resource managers (Objectives 1, 2, and 3)

In addition to strictly scientific activities, it is important that we work closely with those who rely upon the information we generate (see Appendices D and E). In particular, we will need to work with a full range of stakeholders to ensure that our products and tools address questions of concern and relevance. Ensuring that we maintain capacity for liaison activities between science and management is critical; doing so will continue to keep Regional Office staff aware of new research and information, keep the Centers' staff aware of emerging climate-related management issues and related needs for scientific information, and facilitate cooperative approaches to working on those issues. Similarly, ensuring that we can continue periodic updates about expected climate effects on all our trust resources, including habitats and human communities, is important ongoing guidance that both the WCR and the PFMC have requested. Because our management obligations span marine, estuarine, and freshwater systems, ensuring that targeted research continues in all three arenas, including integrated studies across the three habitats, will also be important.

Table 1. NWFSC and SWFSC observation efforts for tracking trends in the CCLME and its dependent LMRs and human communities.

Effort	**Scope**	**Data Types**					
		Fish Distribution	*Fish Abundance*	*Biological Oceano-graphy*	*Physical Oceano-graphy*	*Socio-economic Information*	*Marine Mammal, Turtle, and Seabir*
West Coast Bottom Trawl Survey	Coastwide, annual (spring/summer, summer/fall)	x	x	x	x		
Joint Hake/Sardine Survey	Coastwide, plus Canada (summer)	x	x	x	x		
CalCOFI	113-station survey, San Francisco to San Diego (winter, spring)	x	x	x	x		x
CalCOFI	75-station survey, Southern California Bight (summer, fall)	x	x	x	x		x
Coastal Pelagic Species	San Francisco to San Diego* (spring)	x	x	x	x		
BPA Plume survey	Washington and Oregon June (May, September)	x	x		x		
Newport hydrographic line	Off of Newport, Oregon (biweekly)			x	x		
Trinidad hydrographic line	Ssimilar to Newport survey (monthly)			x	x		

Rockfish recruitment and ecosystem assessment survey	Coastwide (annual, late spring)	x	x	x	x		x
Economic Data Collection Program	Groundfish IFQ program (annual)					x	
West Coast Fishing Community Vulnerability Index	Every five years (2005–2015)					x	
Vessel Monitoring System	Coastwide, coverage varies based on fisheries targeted					x	
West Coast Groundfish and At-Sea Hake Observer Program	Coastwide, coverage varies based on fishery					x	
Fishermen logbooks	Coastwide, coverage varies based on fishery					x	
PacFin Fish Tickets	Coastwide					x	
Cetacean & ecosystem assessment surveys	U.S.–Mexico to U.S.–Canada border, seaward to 300 nautical miles (target frequency every 3–4 years)			x	x		x
Gray whale abundance	Shore-based survey captures						x

	species-level information across global range, Bering Sea to central Baja California, Mexico						
Marine Mammal Strandings	U.S. West Coast						x
Pinniped abundance, demography & diet surveys	U.S. West Coast (abundance); Channel Islands (diet and survival)						x
Coastal bottlenose dolphin abundance surveys	Southern California Bight						x
Harbor porpoise abundance surveys	U.S. West Coast shelf habitat (target frequency every 3–5 years)						x
Green turtle ecological surveys	Southern California						x
Leatherback turtle abundance & ecological surveys	U.S. West Coast (abundance); central California (ecology)						x
Loggerhead turtle abundance & ecological surveys	Southern California						x

Southern California Bight Hook and Line Survey	Southern California Bight (annual)	x	x				
OCNMS subtidal surveys	Scuba surveys in OCNMS (summer)	x	x				
Elwha nearshore surveys	Beach seines in the Strait of Juan de Fuca (March–September)	x	x		x		
Salmon tagging programs	North Pacific	x	x	x			
Puget Sound eelgrass community surveys	Quarterly scuba surveys	x	x				

*Adaptive management was applied to the spring 2015 Coastal Pelagic Species cruise, and sardine sampling was into Washington State.

Table 2. Examples of identified mechanisms of climate impacts in the California Current Large Marine Ecosystem.

Taxon	**Mechanism of Impact**	**Selected References**
Salmonids	Freshwater: flow and temperature are basin-scale drivers of juvenile survival, smolt survival, and susceptibility of returning adults to disease; in addition, changing temperature and flow profiles are associated with adaptive change in life history traits. Marine: marine survival and growth of juvenile salmonids are associated with climate variability affecting upwelling and zooplankton assemblages, including krill.	Crozier et al. (2008) Zabel et al. (2006) Peterson (2009) Wells et al. (2012)
Invertebrates	Ocean acidification leads to changes in growth, survival, and calcification of invertebrates, especially calcifiers. Oceanographic conditions determine zooplankton assemblages.	McElhany and Busch (submitted) Hooff and Peterson (2006) Fisher et al. (2015)
Sablefish	Oceanographic conditions drive recruitment strength.	Schirripa, and Colbert (2006)
Humboldt Squid	Climate-driven ecosystem interactions in the California Current	Stewart et al. (2014)
Groundfish	Meta-analysis of common patterns and climate drivers of groundfish growth using commercial fishery composition data.	Stawitz et al. (2015)
Groundfish	Meta-analysis of climate drivers of recruitment strength.	Stachura et al. (2014)
Groundfish	Estimation of common trends in recruitment for U.S. West Coast groundfishes.	Thorson et al. (2013)
Ecosystem	Spatial ecology of krill, micronekton, and top predators in the central California Current: Implications for defining ecologically important areas	Santora et al. (2011, 2012)
Across Taxa	Relative magnitude of cohort, age, and year effects on growth of exploited marine fishes (where year effects could be due to climate)	Thorson and Minte Vera (in press)
Sardines	JSCOPE model that predicts sardine distributions based on ROMS model outputs	Kaplan et al. (201)
Rockfish	Variability in rockfish recruitment and ecosystem structure	Ralston et al. (2013), Wells et al. (2008)
Cetaceans	Physical and biological oceanographic parameters predict species-specific distribution, abundance, and trophic interactions.	Forney et al. (2012), Becker et al. (2012)
Leatherback Turtles	Basin-scale climate oscillations drive leatherback abundance in nearshore feeding habitat off central California.	Benson et al. (2007)
Loggerhead Turtles	Sea surface temperature predicts presence in U.S. waters.	Allen et al. (2013)
Green Turtles	Warmer temperatures may produce more female sea turtle hatchlings, which then recruit to foraging aggregations in Southern California, producing further female-biased sex ratios.	Allen et al. (2015)

Table 3. Examples of efforts providing advice about specific management activities that will be robust to climate variability and change impacts.

Taxon	Management Activity	Selected References
Salmonids	Water diversion: impacts of diversion become more intense under climate scenarios. Habitat restoration plans: guidelines for accommodating climate change impacts on streamflow and temperature to habitat restoration activities. Advice on salmon returns to the Columbia River based on 15 indicators of ocean conditions. Life cycle modeling: improved simulation of ocean survival under changing physical, chemical, and biological ocean conditions. Effects of flood control projects on salmon migration.	Walters et al. (2013) Beechie et al. (2013) Peterson et al. (2014). http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ Boughton et al (2013)
Protected species (marine mammals, turtles)	Bycatch avoidance under climate change	Lewison et al. (2015)
Sardines	Temperature-dependent harvest control	Jacobson and McClatchie (2013) Lindegren and Checkley (2013)
Fishing Communities	Fisheries diversification reduces revenue volatility.	Kasperski and Holland (2013)
Groundfish	Methods for calculation of reference points for groundfish given decadal scale variability in recruitment.	Haltuch et al. (2009)
Marine Mammals	Sustainable take thresholds for human-caused mortality determine fisheries management actions.	NMFS (2016)
Loggerhead Turtles	Fishery closure triggered by sea surface temperature threshold.	Allen et al. (2013) and NOAA (2007)
Green Turtles	Current sex ratio baseline information will be informative for predicting climate warming conservation concerns for sea turtles, and sex ratio information for each sea turtle species is vital for inferring population status and the survivorship of each sex.	Allen et al. (2015)

4. ACTION PLAN: MEETING THE CHALLENGE OF THE NCSS

For the initial 3 to 5year period of climate science efforts, the NCSS recommends that the Centers engage in the following activities:

- *Maintain existing ocean observation programs*

- *Conduct climate vulnerability analyses for all managed LMRs*
- *Strengthen the Centers' ecosystem status report*
- *Develop capacity to conduct MSEs on the effects of climate change on management targets, priorities, and goals*
- *Develop socio-economic indicators and supporting research describing effects of climate change on human LMR-dependent communities*
- *Identify climate-related issues of concern for species in our region*
- *Identify barriers to producing, delivering, and incorporating climate-related information into LMR management*
- *Identify major gaps in the research useful for generating data to inform LMR management under climate change*
- *Conduct regional assessments of strengths, weaknesses, opportunities, and challenges related to species science and management in the face of climate change*
- *Work internally and with academic, agency, and tribal partners to continue developing the modeling capacity needed to generate state-of-the-art hindcasts, nowcasts, projections, and future scenarios for West Coast freshwater, estuary, and marine habitats*
- *Work internally and with academic and agency partners to continue developing the coupled biophysical modeling systems needed for ecosystem forecasts and scenarios (from relatively simple single-population and life cycle models under altered climate conditions, to state-of-the-art end-to-end physics, to fish and fisheries modeling systems)*

This section lays out our plan to advance these activities, both with level funding (largely by realigning existing programs and re-directing staff), and with increased support (here we assume an additional ~10%). Specifically, this is a description of our approach to provide the necessary science for managing our living marine resources under climate change. The general strategies we have identified as core, and crosscutting, are:

- Establish a West Coast Climate Committee for science issues.
- Develop a West Coast Climate Program.
- Build scientific expertise.
- Review, coordinate, maintain, and standardize existing observational efforts.
- Continue the development of the CCIEA.
- Conduct MSEs.
- Disseminate new climate-related LMR science and information through existing U.S. West Coast NOAA Fisheries programs, e.g., climate vulnerability analyses and related communications efforts.

These approaches are described below with additional details in relation to the seven NCSS objectives (Table 4).

Establish a NMFS West Coast Climate Committee and Program (Crosscutting all NCSS objectives)

We consider the development of a NMFS West Coast Climate Program (WCCP), steered by a West Coast Climate Committee (WC^3) on science, as essential for systematically addressing the critical need to provide climate science in support of effective management of our LMRs and the human communities that depend upon them. Effective implementation of the WCCP will require an increase in resources if the Centers are to be able to meet this challenge and to continue to conduct the full range of work that we currently do in support of fisheries management and protected species protection and recovery.

The WCCP will be steered by the WC^3. The WC^3 will be composed of NWFSC and SWFSC scientists, potentially including scientists who are current members of the West Coast Climate Team. The Committee will: 1) advance the WCCP and the scientific activities identified above, 2) engage in a sustained discussion on climate-related changes along the U.S. West Coast, 3) refine our approaches to quantifying climate-related signals, 4) engage constituents on science issues and 5) with the West Coast Climate Team, evaluate tools and products to advise management actions. Two staff, one from each of the Centers, will serve the additional role of liaison between the Centers to ensure effective communication and coordination. The Committee will also periodically brief and consult with Center and Region leadership. The exact staffing needs and commitments required by the Centers and the Regional office are important details that will be fleshed out based on funding decisions related to the Committee.

Because there are common or similar climate issues in neighboring regions and other ecosystems, the Committee will periodically coordinate with NMFS science centers in the Pacific Islands and Alaska, and with Center staff who work in other ecosystems, to share recent research findings and identify any areas for collaboration to increase efficiency or leverage capacities. Through the Committee and Center/Region leadership, we will coordinate with the PFMC. Additionally, the Committee will engage other Western Region laboratories, e.g., PMEL and ESRL from NOAA's Office of Atmospheric Research (OAR), and other agencies including BOEM, USGS, and NASA, as appropriate and as resources allow, to ensure broader discussion and inclusion of needed capabilities not available in NMFS.

- *Level funding*: The WC^3 would be established from the existing Center/Region climate team and will serve to steer a NMFS WCCP. However, the development and implementation of programs and new research approaches would not be possible without realigning staff, thereby affecting existing programs negatively.
- *Additional funding*: The WC^3 could direct yearly, staff-driven workshops (in the style of the National Center for Ecological Analysis and Synthesis—NCEAS—workshops) targeted at making significant progress on one or more key and immediately relevant questions underlying the NCSS objectives. These workshops would include, but not be limited to, staff from the Centers, and could be energized by hiring and appointing

postdocs. Themes could include topics such as changing ocean conditions (e.g., warming, acidification, hypoxia, HABs, changes in the watershed) and broader ENSO/PDO variability, climate vulnerability assessments for U.S. West Coast fishing communities, application of downscaled Earth System models to the CCLME, etc. Additional funding would also allow building capacity to enhance observations, modeling (especially oceanographic projections under climate change, foundational to so many other analyses yet currently funded by piecemeal grants), laboratory studies of climate-related effects on vital rates and the production of additional products to better inform decision-making and climate change literacy of constituents, as noted below.

Build scientific expertise (Objectives 4, 5, 6, and 7)
It is safe to say that the coming decade will not be "business as usual" in most areas of our science and management. Climate variability and change will affect the species NOAA manages through changes in the environment, resulting in changes in their populations' distribution and abundance, and even at the organismal level—in their phenology, their ability to adapt to the ocean's evolving biogeochemistry, etc. Similarly, climate variability and change alters the lives of people, the actions of fishing vessels, and the conditions within coastal communities. As such, it will be necessary to increase our in-house capabilities.

- *Level funding*: We can redirect staff, structure retirement succession planning, and change programs at the expense of existing efforts. Retraining would still be needed, requiring modest investments. Attention could be given to analyzing existing data (as it would be unlikely that we can add new measurements/sensors in the field with level funding) to tease out trends, mechanistic drivers of population, species, vessels, human communities, and ecosystems associated with past climate signals (e.g., from CalCOFI, the Newport Line, Cetacean and Ecosystem Assessment Surveys, pinniped abundance and diet time series, turtle abundance and ecology surveys, PacFIN fish ticket, and Vessel Monitoring System data).
- *Additional funding*: Expertise will be built through new permanent hires, together with added infrastructure to measure changes in the atmosphere and ocean and to investigate—in controlled environments—changes in organisms' vital rates in our laboratories and aquaria. In concert, additional modeling and analytical capacity will be implemented so that the updated vital rates can then be used in models, thus more accurately representing current and potential future conditions. New hires would need to be added in a number of areas that could be prioritized according the Centers' existing capabilities and infrastructure, with attention to minimizing duplication and taking advantage of the two Centers working jointly.

Review, coordinate, and standardize existing observational efforts (Objectives 4, 5, 6, and 7)

The recent oceanic conditions in the North Pacific and the CCLME were characterized by significant changes in ecosystem structure at every trophic level, including previously unobserved species, ranging from zooplankton to cetaceans; spatial and temporal shifts in highly migratory and forage species (including turtles and cetaceans) and the location and activity of fishermen; and a highly toxic HAB. It is clear that as we experience different conditions, our survey designs and protocols, as well as the variables we measure, cannot remain static. We need to measure differently and in more detail as we try to keep up with and understand our changing environment and the responses of the species and populations for which we are responsible.

An effort to standardize and coordinate sampling in freshwater habitats would be particularly valuable, as there is an enormous amount of data available from environmental indicators to ecological responses coastwide through local (city, county), municipal (utilities), state, federal, and tribal entities. A perfect example is characterizing the thermal environment of fresh waters. We know water temperature is going to be a large determinant in future abundance and distribution, yet there is no coastwide repository of data that extends beyond a few agencies.

- *Level funding*: We will periodically review our survey designs to allow adaptive sampling as the habitats of the species surveyed change in space and time. This will allow us to better determine the most appropriate suite of surveys to capture needed information for climate science. We will coordinate these reviews with other researchers who are monitoring related ecosystem components and properties. Those partners are not limited to state and federal research agencies and academia: the CCLME spans waters from Mexico's B.C. (Baja California) peninsula to Canada's B.C. (British Columbia), and the behavior of fishermen who operate in the CCLME is influenced in part by ocean conditions and the status of fisheries in Alaska. We will improve cross-regional and cross-boundary collaborations (from B.C. to B.C.) with our Alaska region, Canadian, and Mexican colleagues for surveys and other sampling strategies of transboundary species (e.g., through cross-training of personnel, ensuring interoperability of sampling protocols and datasets, etc.)
- *Additional funding*: Our observational efforts need to be expanded with the advent of new instrumentation such as gliders, AUVs, UASs, and new sensors capable of taking advantage of novel (e.g., genetic, stable isotope/ecogeochemistry, and endocrine) approaches, among others. Moreover, resources are already needed to sustain existing time series and expand observations into regions that have been historically under-sampled. Thus, new funding could be targeted in at least six areas: 1) maintaining existing time series that are not stably funded (e.g., the Newport and Trinidad Head Oceanographic Lines, the BPA-funded Salmon Ocean Program and all of the marine mammal and turtle surveys), 2) acquiring new instrumentation (either autonomous or ship-mounted), 3) developing sensor capabilities and database management strategies in

collaboration with industry and academia, 4) hiring staff to develop in-house capabilities to implement and refine new sampling approaches, 5) developing modeling capacity to conduct observing-system simulation experiments to refine survey design, and 6) building scientific capacity to process and analyze data collected in these observational efforts.

Continue the development of the CCIEA (Objectives 1, 2, 3, and 6)
The CCIEA continues to mature as a tool for implementing ecosystem-based fisheries management (EBFM) while also taking steps to support multi-sector ecosystem-based management (EBM) in the CCLME. The CCIEA collates, synthesizes, and provides information on status and trends of the system (physical and biological), monitors leading physical and biological indicators, and assesses ecosystem vulnerabilities to human uses and natural perturbations, and models conditions and tradeoffs under alternative future conditions and management regimes. Under a changing climate, the potential for qualitative and quantitative inaccuracies is high if statistical trends are simply extended beyond the initial range of conditions. Observations and models are essential to capture changing parameters. Although monitoring and modeling efforts exist across the CCLME, there exist shortfalls that limit our ability to monitor trends and provide early warning of change. **Foremost among these are limited resources to sustain the existing observing network and to expand it to cover critical spatial and temporal gaps (see discussion above on the need to build scientific expertise).**

At the same time, while the Centers have expertise in understanding physical and biological processes in the CCLME, expertise in evaluating the human dimensions of climate change is limited. Full implementation of the CCIEA, including ecosystem-based management of the CCLME, will require research into understanding the potential impacts of climate change on the full range of ecosystem services, from food provisioning to tourism to existence value, including trade-offs among them. The CCIEA team is well-positioned to evaluate the costs and benefits of alternative climate mitigation and carbon emissions reduction strategies in this light. For example, there is considerable potential for 1) renewable energy development off the West Coast (e.g., wind, wave, and tidal), 2) restoration activities to expand blue carbon biogenic habitats (e.g., eelgrass, kelp forests, estuarine wetlands, etc.) to mitigate ocean acidification and other climate impacts, and 3) shifting from terrestrial to marine sources of protein for human consumption in order to reduce carbon emissions. All three of these topics have largely unquantified social and ecological consequences.

Anadromous species using the CCLME, such as salmon and sturgeon, pose special challenges to managers, because their complex life histories make them potentially vulnerable to climate changes in freshwater, estuarine, and marine ecosystems. Sublethal impacts at one life stage and location may have demographic consequences at a later stage or location, and there may be complex interactions between the effects of climate, human activities, and life history diversity. Life cycle models can accommodate and model this complexity, supporting risk assessments and management strategy evaluations for thorny ecosystem management problems, such as management of large water projects and hydropower systems that support multiple anadromous species and that are undergoing clear changes in hydrology.

- _Level funding_: The CCIEA will continue to present information on climate change and other ecosystem considerations to the Pacific Fishery Management Council annually, and will need to transition from a periodically produced documents to more routine contributions through use of web-based tools that can be updated and monitored in near real-time, in order to respond to unexpected conditions or provide early warnings of ecosystem change. The CCIEA should strive for outcomes where an understanding of climate variability and change is used to inform decisions about LMRs. It is also essential that there be improved integration and synthesis of the multitude of monitoring efforts in the CCLME, including those from across NOAA, the Regional Associations of IOOS, state agencies, tribes, and academic partners. The infrastructure exists to provide this framework and integration with partners, although full implementation may require new resources. The Science Centers will continue developing life-cycle models for anadromous species, and bring them into the CCIEA.
- _Additional funding_: Continued improvement of tools for EBM, such as the CCIEA, will provide resource managers with the capacity to adaptively address climate variability and change. Additional resources would hire staff to enhance and improve modeling expertise within our Centers and in collaboration with CIMEC, CIMRS, JISAO, and OAR/GFDL/ESRL. The immediate impact could be a better understanding and improved projections of climate-driven effects on the CCLME, and thus better information to adapt policy to climate change. Additional resources would also allow the Centers to coordinate analysis of climate scenarios that include, but are not limited to, multiple Earth System Model runs under a range of greenhouse gas scenarios, producing oceanographic and atmospheric projections applied to a range of population (including anadromous species life cycle models), community, food web, and ecosystem models with both social and ecological endpoints. Such capabilities will improve understanding of climate change impacts for stakeholders (researchers, policymakers, NGOs, fishing communities, and the general public) in the CCLME.

Conduct Management Strategy Evaluations (Objectives 1, 2, 3, and 4)
Through MSEs that include multispecies and multifleet models and spatial economics models, researchers can identify specific policies that are likely to be resilient to surprises coming from a changing climate and ecosystem. Working with the PFMC, we have identified Pacific hake, sablefish, and North Pacific albacore for the first MSEs. These will identify sampling and management approaches that are robust to uncertainties in our understanding or quantification of mechanistic links, and improve management strategies and reference points.

- *Level funding*: We will be able to initiate MSEs for Pacific hake, sablefish, and North Pacific Albacore. Support for two dedicated MSE experts (one at each Center) has been provided following the Centers' 2015 external review on stock assessment science.
- *Additional funding*: MSEs are likely to become de facto approaches that build on retrospective studies and process-oriented research to identify the mechanisms underlying recruitment variability or other responses (e.g., shifts in spatial distribution, growth, or phenology) to changing climate conditions. An increase in resources would be used to strengthen the Centers' capabilities that presently rely on the minimal dedicated staff mentioned above.

Disseminate new climate-related LMR science and information through existing U.S. West Coast NOAA Fisheries communications efforts (Objectives 1, 2, and 3)
NOAA Fisheries on the West Coast supports a strong cross-Center and Region team of communications specialists. We will engage this expertise to disseminate the science information and products resulting from this action plan. This team will assist in delivering this information to target audiences by partnering with active climate science communities who have existing channels and listserves to reach climate practitioners. In particular, we will coordinate with existing West Coast climate networks like the North Pacific Landscape Conservation Cooperative (LCC) and the NOAA Regional Integrated Sciences and Assessment (RISA) programs. Possible communications strategies include website content, fact sheets or other print media, press releases and other media engagement, listserv announcements, and podcast and/or video production. We will also seek collaborations with existing communication experts in our region (e.g., UW's eScience institute and data visualization lab: http://escience.washington.edu/about-us/, https://idl.cs.washington.edu/).

- *Level funding:* We will emphasize science related to climate variability and change in our existing communications plans and activities to targeted audiences, as well as use new NOAA Fisheries-supported web design features to create more integrated U.S. West Coast climate stories and increase access to our climate science products.
- *Additional funding:* We will employ innovative communications techniques such as a dedicated U.S. West Coast climate science web portal, advanced data visualizations, animation, and multi-media storytelling to make NOAA Fisheries climate science easily accessible more audiences.

Table 4. WRAP Action Table and Timeline

Action Name	Funding Scenario	Time Frame	Action Description	POC (name)	Partners
Objective 1: Climate Informed Reference Points					
Conduct MSE analysis of reference points (Pacific hake, sablefish, and North Pacific albacore)	Level	2017–2019	Stakeholders engaged in analysis of effect of alternative harvest (OFL, ABC, ACL) reference points based on long-term stock status under climate change for one species. (Also Obj. 2, 3)	Centers' MSE coordinators	PFMC; Industry and NGOs; academics; state agencies; tribes; climate modelers
Identify climate-relevant ecosystem-level thresholds.	Level	2016–2019	Use CCIEA and associated ecological efforts to identify ecosystem-level reference points. Communicate value of ecosystem reference points.	Centers' CCIEA leads	Industry, management entities, states, tribes, NGOs
Evaluate turtles and marine mammals as climate reference points	Level	2017–2019	Use existing time series data in the CCLME to determine whether higher trophic level species provide robust reference points for climate indicators	SWFSC-MMTD	CCIEA
Evaluate recovery goals for 1–3 protected species	Level/ Increase	2017–2020	Assess appropriateness of established recovery goals, given likely impacts of climate change and results of Climate Vulnerability Analyses. (Also Obj. 2)	NWFSC, SWFSC Species in the Spotlight Teams	WCR, stakeholders, climate modelers
Build socio-economic impact analysis of alternative harvest reference points	Increase	2017–2020	Build socio-economic capacity to evaluate socio-economic outcomes, and likely human behavioral response to alternative harvest reference points and stock trajectories under climate change. (Also relevant to Obj. 3)	CCIEA and WCR	Industry, management entities, states, tribes, NGOs
Objective 2: Robust Management Strategies					
Complete climate vulnerability analysis for ESA and MSA fish species	Level	2016	Identification of most climate-sensitive fish species; information to contribute to prioritization of research and management efforts. (Also relevant to Obj. 3, 4, 6)	Centers' climate vulnerability team	WCR, external federal agency and academic scientists

Complete climate vulnerability analysis for marine mammal and turtle species	Level	2017	Identification of most climate-sensitive marine mammal and turtle species; information to contribute to prioritization of research and management efforts. (Also relevant to Obj. 3, 4, 6)	SWFSC-MMTD, -ERD	WCR, external scientists
Evaluate resilience of restoration activities to climate change	Level	Ongoing	Conduct scientific investigations into the suitability, effectiveness, and resilience of active restoration and other conservation efforts to climate change. (Also relevant to Obj. 3)	NWFSC-FED; SWFSC-FED	Academia, WCR, PFMC, state and international partners
Evaluate surveys and other data collection efforts for ability to detect change	Level	Ongoing	Evaluate current suite of surveys for ability to detect range, abundance and phenological shifts. Identify gaps, build cooperative efforts with Canada and Mexico to fill gaps. (Also relevant to Obj. 1, 5, 6, 7)	NWFSC-FRAM; SWFSC-FRD, -MMTD	State and international partners
Conduct MSE of alternative harvest management strategies for one stock	Increase	2017–2019	Evaluate impact of alternative harvest strategies on stock status under projected climate impacts, engage stakeholders to develop and assess impacts of those strategies. (Also relevant to Obj. 1, 3, 4)	Centers' MSE coordinators	PFMC, industry, academic partners, state mgmt. agencies, tribes, NGOs, climate modelers
Incorporate socio-economics into MSE and other analyses	Increase	2017–2020	Build socio-economic capacity to evaluate socio-economic outcomes, and likely human behavioral response to alternative harvest management strategies and stock trajectories under climate change; build similar evaluations for alternative protected resource management approaches. (Also relevant to Obj. 1, 3, 4, 7)	Centers' CCIEA teams	Industry, management entities, states, tribes, NGOs
Socio-economic analysis of impacts of water supply variability	Increase	2017–2021	Develop models of economic impacts of uncertainty in water supply.	SWFSC-FED	Academics, state agencies (CDFW), federal agencies (USBR)
Model alternative management approaches for achieving recovery of 3–5 protected species	Increase	2017–2021	Model likelihood and time frame of achieving recovery goals for listed species under alternative management scenarios given projected climate	NWFSC-FED; SWFSC-FED, -MMTD	WCR, stakeholders, OAR, climate modelers

			impacts. (Also relevant to Obj. 1, 3, 4)		
Objective 3: Adaptive Management Processes					
Evaluate effectiveness of Dynamic Ocean Management	Level	2018	Scenarios of stock movement and management alternatives in response to climate conditions rather than set areas. (Also relevant to Obj. 2, 4)	SWFSC-ERD, -MMTD; WCR	CCIEA, PFMC, academics, CDFW, US Coast Guard
Maintain scientific liaison capacity	Level	Ongoing	Inform WCR staff of new climate research and activities; ensure that Center staff are aware of WCR activities and information needs. (Also relevant to Obj. 7)	SWFSC-FED; NWFSC-FED	WCR
Build capacity to support Ecosystem Based Management	Increase	2019	Staff positions to use the CCIEA products to create EAFM, EBFM, and EBM capabilities. (Also Obsj. 4, 6)	NWFSC, SWFSC, CCIEA, and WCR	PFMC, U.S. BOR, CDWR, US ACE
West Coast Climate Committee (WC^3) will identify climate-relevant workshops	Increase	2016–2021	The WC^3 will coordinate staff-driven workshops to advise on specific climate variability topics, e.g., warming, hypoxia, HABs, air/ocean exchanges, etc., that impact fishery management. (Cross-cutting to all Objectives.)	NWFSC, SWFSC, PMEL, WCR, ESRL, etc.	CCIEA, PFMC, Academics, WA/OR/CADFW, etc.
Objective 4: Project Future Conditions					
Examine climate-driven future scenarios for U.S. West Coast fish stocks (forage, groundfish, salmon), key predator species and HMS (N. Pacific Albacore), marine mammals, and turtles	Level	2017–2019	Using information from climate models (e.g., from GFDL) to downscale to regional models of ecosystem (ROMS and Atlantis) to estimate the response of CCLME ecosystem components. (Also relevant to Obj. 1, 2)	SWFSC-MMTD and CCIEA	NMFS, OAR, JSCOPE team, Academics, PICES
Examine climate-driven future scenarios for U.S. West Coast hydrology and stream temperature from a freshwater salmon and sturgeon habitat perspective	Level	2017–2019	Use information from partner organizations (e.g., the NOAA-RISA and DOI-Climate Science Center "Integrated Scenarios for Climate, Hydrology, and Vegetation" in concert with USFS "NorWeST" stream temperature database) to evaluate future habitat scenarios for Pacific salmon and steelhead to 2100. (Also relevant to Obj.	SWFSC-FED; NWFSC-FED	DOI Climate Science Centers, RISAs, cooperative institutes at UW and UC

			1, 2, 3)		
Evaluate climate change impacts across the full lifecycles of selected Pacific salmon ESUs	Increase	2017–2020	Use full life-cycle models that integrate vital rates (growth and survival rates) at multiple life stages with freshwater, estuary, and marine habitat conditions under future climate scenarios to 2100. (Also relevant to Obj. 1, 2)	SWFSC-FED; NWFSC-FED	Cooperative CIMEC, CIMRS, and JISAO
Develop models that characterize adaptive evolutionary and plastic responses to climate change impacts across the full lifecycle of selected Pacific salmon and steelhead ESUs	Increase	2017–2020	Apply Integrated Projection Models that integrate vital rates (growth and survival rates, population productivity) at multiple life stages with pedigree information and genetic and phenotypic changes in response to future climate scenarios. (Also relevant to Obj. 1, 2)	NWFSC- CBD	CIMEC, CIMRS, and JISAO
Develop targeted statistical models and numerical simulations to anticipate climate change impacts	Increase	2018–2021	Continue development of statistical tools to determine the impact of climate variability on targeted species; develop numerical simulations to test the statistical analyses.	CCIEA leads from Centers, WCRO	CIMEC, CIMRS, and JISAO, academics
Evaluate vulnerability of coastal communities to climate change	Increase	2017–2020	Examine vulnerability of coastal communities and fisheries to changes in abundance, distribution, and phenology of LMRs, and consequences of climate change. (Also relevant to Obj. 5, 6)	CCIEA leads, WCRO	PFMC, WA/OR/CA DFW, tribes, etc.
Objective 5: Understand the Mechanisms of Change					
Hold two workshops on responses of vital rates in selected marine species to changes in oxygen and pH levels	Level	2017–2018	Quantify range of variability in key vital rate information (respiration, growth, etc.) under expected ranges of climate variability; and use in models (ROMS/ Atlantis). (Also relevant to Obj. 2, 3, 4)	Organizer	NMFS, academics, state agencies, West Coast OAH Panel
Establish functional relationships across a range of pH, dissolved oxygen, and sea-water temperature for selected species/stocks (anadromous and marine) with changing marine and freshwater conditions	Increase	2016–2018	Lab studies to quantify physiological and behavioral responses in selected species/stocks across a range of pH, dissolved oxygen (DO), and water temperature that spans the expected range of future conditions. (Also relevant to Obj. 4) Field studies to collect water	SWFSC-FED; NWFSC-EFSD, -CBD	CIMEC, CIMRS, and JISAO, academics

			geochemistry, plankton, ichthyoplankton, and fish samples simultaneously to quantifying physiological and behavioral responses of selected species across a range of environmental conditions. (Also relevant to Obj. 4, 6, 7)		
Assess sublethal effects of multiple stressors and their population-level consequences	Increase	2018–2021	Quantify physiological, neurological and behavioral responses in selected salmon a range of water quality parameters, temperature, and DO. (Also relevant to Obj. 4, 6, 7)	NWFSC-EFSD; SWFSC-FED, -FRD, -MMTD	Academics (WSU Puyallup), IMR (Norway)
Link changes in water supply and habitat protection actions to economic and social impacts	Level	2016–2019	Develop models of economic impacts and responses to protected fish actions (e.g., changes in water supply, dam removal/fish passage, habitat restoration)	SWFSC-FED	Academics; state agencies (CDFW, CDWR); federal agencies (USBR); WCR
Field, laboratory, and modeling studies to identify likely HABs, invasive species, and changes in species interactions with changing climate conditions	Increase	2017–2020	Identify likely changes in species composition and assemblages, including potential for invasive dynamics. Determine mechanisms by which changed species interactions would affect ecosystem structure and function as well as single species' vital rates.	NWFSC-FRAM, -FE and -CB SWFSC- FRD – FED, and -MMTD	Academics, state agencies,
Objective 6: Track Change and Provide Early Warnings					
Update ecosystem indicators	Level	2016–2021	Build on the CCIEA to aggregate and display in near-real-time on Centers' websites hydrographic and biogeochemical data from ships, gliders, buoys, and remotely sensed data. (Also relevant to Obj. 5) Identify high temporal resolution hydrographic and biological data appropriate for analyzing seasonal and inter-annual ecosystem variability.	CCIEA leads	NMFS, CI, OAR, academics
Improve marine and watershed monitoring	Level	2016–2020	Standardize measurement techniques and indices necessary for tracking watershed environmental and	SWFSC-FED; NWFSC-FED, -CBD	CIMEC, CIMRS, and JISAO

			anthropogenic variability. (Also Obj. 7) Build watershed indices into the CCIEA. The Newport Line has established a table of 16 indicators to provide advice and outlooks on salmon returns to the Columbia and Snake Rivers. A similar set of indices for coastal and Central Valley runs Continue ongoing work to identify conditions most likely to lead to HAB development. (Also Objs. 4, 5)	NWFSC (Newport Line) SWFSC (Trinidad Head Line) NWFSC, CCIEA, Academics, State Agencies	
Integrate ecosystem indicators into management	Increase	2018–2020	Staff positions to use the CCIEA products to create EAFM, EBFM, and ultimately EBM capabilities. Staff positions to increase modeling capability, both in-house and with other NOAA modeling centers. (Also relevant to Obj. 4, 5, 7)	CCIEA	CIMEC, CIMRS, and JISAO
Link changes in management and climate to changes in local economies in fishing communities	Level	2016–2019	Describe historical changes in commercial fishing activity at the community level; identify drivers of change and develop methods to forecast future changes.	SWFSC, NWFSC	Industry, management entities, states
Shore up monitoring enterprise and analysis of existing datasets	Increase	2016–2020	Monitor the critical environmental components of the ecosystem. (Also relevant to Obj. 5, 7) Explore existing data sets and process existing samples to identify associations between environmental conditions and population responses or vital rates. (Also relevant to Obj. 6, 7)	NWFS, SWFSC	NOAA
Objective 7: Science Infrastructure to Deliver Actionable Information					

Review designs of CCLME ship surveys	Level	2016–2019	Create a ship survey design review committee to evaluate current data collections, identify gaps, and, if appropriate, develop new data-collection protocols to detect and track changing environmental conditions within the CCLME. (Also relevant to Obj. 5, 6) Include examination of deployment of advanced technologies (autonomous vehicles and drones) in support of survey needs. (Also relevant to Obj. 6)	Survey team (to be formed)	NMFS and OMAO, Mexico
Maintain present observational monitoring capabilities	Level	2016–2021	Maintain existing ecosystem monitoring capabilities to ensure long-term data sets required for climate monitoring	NWFSC, SWFSC	OAR, NOS
Hold workshops on 'omics.	Level	2017	a) Identification of pilot technologies and in-water sampling opportunities. (Also relevant to Obj. 6) b) Fine-scale genotyping can facilitate detection of changes in stock composition, contributions to overall populations in CCLME, and distributions; transcriptomics can facilitate assessment of sublethal stress, nutritional/energetic condition, etc.	NWFSC, SWFSC, OAR MMTD	NMFS and OAR
Improve data management	Level	2017–2021	Increase integration and delivery of data for scientific and management purposes.	NOAA	
Increase laboratory and modeling capabilities	Increase	2017–2021	Enhance the Centers' capabilities by repurposing laboratory space with a focus on improved quantification of organismal response to changing environmental conditions. Hire the personnel needed to staff new analyses programs, including 'omics and	NMFS	Academic, state, private institutions

			other identified laboratory studies.		
Obtain advanced sampling systems.	Increase	2017–2019	Deploy autonomous systems to improve sampling capabilities. Standardize the use of drones and supported instruments. Observe timing and distribution latitudinal migration of CPS, hake, and HMS populations, and examine possible abundance estimates. (Also relevant to Obj. 5, 6)	SWFSC; NWFSC	NMFS, PMEL, academics, Mexico and Canada

5. METRICS

The following metrics will be used to assess the quality of the output and outcomes of the Action Plan. The metrics are categorized according to whether they assess the quality and quantity of the science, the value of the science to management, or the effects on scientific infrastructure. Effort will be made to evaluate and strengthen the metrics over time.

Science quality and quantity:

a. Number of peer-reviewed publications produced that address climate change and climate impacts.
b. Completion of climate-vulnerability assessments and number of species for which vulnerability assessments exist.
c. Species (or populations) for which we have peer-reviewed climate-vital rate relationships.
d. Number of datasets with high-quality metadata available.

Value of the science to management for sustainable fisheries and recovery of protected species:

e. Number of stock assessments and Annual Catch Limits (ACLs) that are climate-informed.
f. Increased proportion of National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) analyses that are climate-informed.
g. Number of CCIEA, State of the California Current Report, Stock Assessment and Fisheries Evaluation (SAFE) reports that incorporate climate information.
h. Number of protected species recovery plan and critical habitat designation analyses that incorporate climate information.
i. Adoption of indicator(s) to inform management.

Science infrastructure

j. Number of long-term monitoring time series maintained.
k. Full-time equivalent (FTE) time (i.e., sum of partial and full FTEs) devoted to climate-related research.

6. OUTREACH AND ENGAGEMENT

The activities proposed in this plan cannot stand in isolation, but will require coordination and communication within and without NMFS. Through strategic engagement with science and management partners we can design approaches and solutions not otherwise realized, align goals, and leverage resources to increase our impact. Management of natural resources on the U.S. West Coast enjoys strong technological knowledge and skills, an integrated network of partnerships, and collectively significant resources. Among the strengths we bring to this effort is a strong history of effective collaboration across the science-management field in living marine resources, as well as active collaborations with top academic, management, and government institutions. As we strengthen and focus our climate science capabilities, we will need to bolster existing partnerships and strategically seek out new collaborations.

Our approach to engagement in support of this plan is three-fold: 1) ensure effective communication and collaboration within NMFS, including among the Centers, the WCR, and with neighboring regions and headquarters offices, 2) strategically nurture existing and new scientific partnerships to advance the activities in this 3–5 year plan, and 3) employ effective communications strategies to deliver new climate science information to our management partners.

Ensure effective communication and collaboration within NMFS
Through recent coastwide scientific collaborations such as the CCIEA program, NMFS has honed coordination across its organizational units. The WCCP and WC^3 will build on these efforts by coordinating with ongoing research with the potential to advance these goals (many already referenced in the Action Plan, above). The agency will also utilize or evolve existing mechanisms—including the West Coast Regional Climate team, the CCIEA network, and monthly nationwide Ecosystem Management calls—to facilitate information sharing, updates, and developments across these related groups.

Nurture existing and initiate new scientific partnerships
As highlighted in the Strengths sections, above, NMFS maintains strong and proven relationships with leading scientific institutions (academic, federal, state, and international) that house some of the best programs and expertise on climate variability and living marine resources. This plan represents a new articulation of NMFS's direction and goals when it comes to climate science, and we will evaluate new partnerships as part of implementing this plan.

We will look to the significant climate science expertise within NOAA, including NOAA's National Centers for Environmental Information, OAR/ESRL/GFDL, NOS/Sanctuaries, the Western Region Climate Services Director, the three Integrated Ocean Observing Systems in the region (IOOS: CeNCOOS, NANOOS, and SCCOOS), the National Center for Coastal Ocean Science (NCCOS) which produce biogeographic assessments, and many other NOAA climate assets across the line offices.

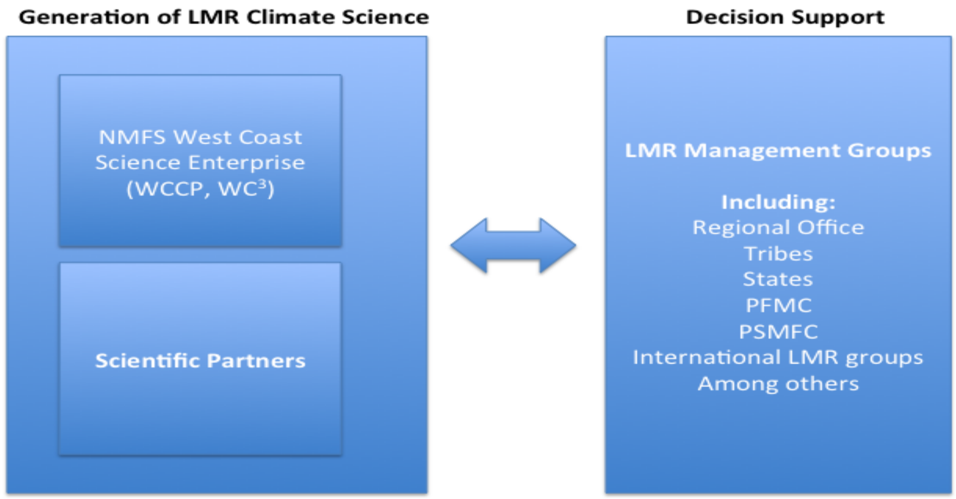
We will look to existing academic collaborators and non-NOAA agencies for synergistic partnerships to achieve the Action Plan activities (see Section 3.1), but will also seek to partner with new organizations that have technologies and approaches that will advance our efforts. For instance, consistent with the CCIEA 2016–2018 Workplan, NOAA scientists will integrate with the international ICES/PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME) to simulate climate change effects on commercial fisheries and conduct climate change-based management strategy evaluations. As another example, there are also opportunities to provide climate risk information to the EPA's Climate Change Impacts and Risk

Analysis project, which aims to contribute to the 2018 United States Global Change Research Program's fourth National Climate Assessment.

Deliver new climate science information to management partners and other users
Ultimately, the scientific advances and new information generated must be delivered to users to be implemented in management decisions. The living marine resources under trust to NOAA are managed variously by our regional offices and fisheries management councils, co-managers including states and tribes, place-based groups like National Marine Sanctuaries and National Estuarine Research Reserves, and are impacted by the activities of many groups, including stranding networks, community environmental groups, environmental NGOs, ocean users and ocean-based industries, and individuals. We will continue to maintain a two-way dialogue and feedback loop with key management partners to ensure science products and information are packaged to best support management decisions.

Given the number of groups involved in living marine resource management, and limited staff time and resources, we must prioritize the key strategic partnerships most likely to result in the greatest impact. These are groups that have direct responsibility for managing the resources, are putting in place mechanisms to manage the resources adaptively, and incorporate science into their decision-making. We know the PFMC and Pacific States Marine Fisheries Commission will be among our key climate science management partners.

Several cross-government and cross-disciplinary groups have formed along the West Coast to inform management of natural resources under a changing climate. These groups can offer lessons learned as well as reach management groups. In particular, NOAA's RISAs and the Department of the Interior's LCCs build a national capacity to prepare for and adapt to climate variability. RISAs focus primarily on connecting science, decision-makers, and LCCs on landscape-scale science-informed management. State Sea Grant organizations also support development and use of climate information as it promotes responsible use of marine resources. All of these groups maintain a network of researchers, managers, and other climate and environmental expertise. The Centers and the WCR can strengthen their partnerships with the two RISAs and the two LCCs located in the western region by disseminating climate science goals, projects, and findings through and with these groups, which may bring insights across the marine-terrestrial-atmospheric divide.



Ecosystems and climate variability see no geopolitical boundaries, and therefore we will continue to engage with a large number of international partners to improve climate-related information with a specific focus on climate-informed biological reference points, climate-smart harvest control rules, MSEs for climate-ready LMR management and climate-smart protected species and habitat consultations. Of particular concern are the species distribution changes that could be a result of climate change.

7. ACKNOWLEDGEMENTS

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DISCLAIMER:
This regional action plan is a guidance document and the actions identified are subject to final agency decisions and available resources. None of the recommendations contained in this guidance are binding or enforceable against any public or private party, and no part of the guidance or the guidance as a whole constitutes final agency action that could injure any person or represent the consummation of agency decision making. This guidance does not change or substitute for any law, regulation, or other legally binding requirement and is not legally enforceable.

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8. WRAP Acronyms

Acronym	Representing
ABC	Acceptable Biological Catch
ACL	Annual Catch Limit
AUV	Autonomous Underwater Vehicle
BC to BC	British Columbia to Baja California
BOEM	Bureau of Ocean Energy Management
BPA	Bonneville Power Administration
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCIEA	California Current Integrated Ecosystem Assessment
CCLME	California Current Large Marine Ecosystem
CCS	California Current System
CeNCOOS	Central and Northern California Ocean Observing System
CIMEC	Cooperative Institute for Marine Ecosystems and Climate
CIMRS	Cooperative Institute for Marine Resources Studies
CPS	Coastal Pelagic Species
CSIRO	Commonwealth Scientific and Research Organization
EBFM	Ecosystem Based Fishery Management
EBM	Ecosystem Based Management
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESRL	Earth Systems Research Laboratories
EWG	Ecosystem Working Group (PFMC subcommittee)
FATE	Fisheries and the Environment
FEP	Fishery Ecosystem Plan
FMP	Fishery Management Plan
FTE	Full Time Equivalent
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
HABs	Harmful Algal Blooms
IOOS	Integrated Ocean Observing Systems
IWC	International Whaling Commission
JISAO	Joint Institute for the Study of the Atmosphere and Oceans
LCC	Landscape Conservation Cooperative
LMR	Living Marine Resources
MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSE	Management Strategy Evaluation
NANOOS	Northwest Association of Networked Ocean Observing Systems
NASA	National Aeronautics and Space Administration
NCCOS	National Centers for Coastal Ocean Science
NCEAS	National Center for Ecological Analysis and Synthesis
NCSS	NOAA Fisheries Climate Science Strategy
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service

NPGO	North Pacific Gyre Oscillation
NPZ	Nutrient Phytoplankton Zooplankton model
NWFSC	Northwest Fisheries Science Center
-CBD -EFSD -FRAMD	Conservation Biology Division Environmental and Fisheries Science Division Fishery Resource Analysis and Monitoring Division
OA	Ocean Acidification
OAR	Oceanic and Atmospheric Research
OCNMS	Olympic Coast National Marine Sanctuary
OFL	Overfishing Limit
PARR	Public Access to Research Records
PDO	Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council
PICES	The North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
PNW	Pacific Northwest
RAP	Regional Action Plan
RISA	Regional Integrated Sciences and Assessments
ROMS	Regional Ocean Modeling System
SAFE	Stock Assessment and Fisheries Evaluation
SCCOOS	Southern California Coastal Ocean Observing System
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
-ERD -FED -FRD -MMTD	Environmental Research Division Fisheries Ecology Division Fisheries Resources Division Marine Mammal and Turtle Division
UAS	Unmanned Aerial System
UME	Unusual Mortality Event
USGS	U.S. Geological Survey
WC^3 or WCCC	West Coast Climate Committee
WCCP	West Coast Climate Program
WCRCT	West Coast Region Climate Team
WCRO	West Coast Regional Office
WRAP	Western Regional Action Plan

Appendix A

Learning from past extremes in the CCLME

Recent climate variability has provided a window into possible future states of the CCLME's marine, coastal, and freshwater ecosystems. It is anticipated that future environmental changes will lead to both range shifts of existing marine fauna and changing ecological structure in terms of predator–prey interactions and food chain structure.

For example, increased water column stratification was observed during warm conditions like those following the major El Niño winters of 1983 and 1998, and during the extended warming of 2014–2015. Observations collected during these and other warm periods provide insights into the likely impacts that future increases in stratification due to anthropogenic climate change might have on LMRs. Off Oregon, vertical density gradients were so steep that upwelling winds (which in 2015 were among the strongest in at least the past 30 years) neither mixed the water column vertically, nor pushed surface waters very far offshore, resulting in the effects of coastal upwelling being limited to a very narrow band near the coast. Cold water was seen in outer shelf waters only in June 2015. Thus upwelling was not as biologically effective as one might expect.

More broadly, the CCLME is driven simultaneously by bottom-up, middle-out, and top-down processes that respond strongly to wind-driven upwelling variations. In spring and summer, intense coastal upwelling and weaker, but still important, open ocean upwelling over the continental shelf bring cold, nutrient-rich water to the surface, stimulating high phytoplankton productivity in a relatively narrow and cold mid-latitude to sub-tropical oceanic region. The negative side of upwelling is the transport of deep offshore low-oxygen and/or lower pH (undersaturated with respect to aragonite) waters into the productive upwelled surface waters. In extreme upwelling periods (e.g., in the summers of 2002 and 2006), shelf hypoxia was especially widespread in the northern California Current System (CCS), and the first record of anoxia in the northern CCS (over Heceta Bank) was documented. There is also evidence for longer-term declines in dissolved oxygen and aragonite saturation levels in the CCS.

Because of seasonal upwelling, there are sharp gradients in biochemical properties along the West Coast, representing the seasonal development of neighboring sub-tropical and subarctic water masses. Variable ocean conditions in the CCS often include rapid shifts in the boundaries of these water masses, or intermediate mixtures of different water masses. Rapid shifts in ocean conditions are often accompanied by rapid range shifts in highly mobile species and plankton, and these can include major reorganizations in ocean food webs. For instance, in warm periods in the CCS, tropical/subtropical species can move inshore and poleward by hundreds of kilometers within a single season.

Historical records for the CCS date back to the late 1800s, and they highlight many examples of seasonal and year-to-year variations in the state of the CCS, and a few examples of multi-year to multi-decadal changes. For instance, in the period since 1920, there have been many one- to multi-year periods with anomalously warm (cold) sea surface temperatures (SSTs) in the CCS, and many of these warm periods were associated with tropical El Niño (La Niña) events (Figure A1). Notable warm events are 1940–1941, 1957–1958, 1982–1983, 1986–1987, 1990–1994, 1997, 2003–2005, and 2014–2015. Extended cold periods include 1926–1929, 1931–1939, 1942–1950, 1954–1956, 1970–1971, 1973–1976, 1984–1985, 1988–1989, 1999–2002, 2007–2008, and 2010–2012. This variability reflects the combined influences of major basin scale climate modes (ENSO, PDO, and NPGO) and the influences of more regional atmospheric forcing.

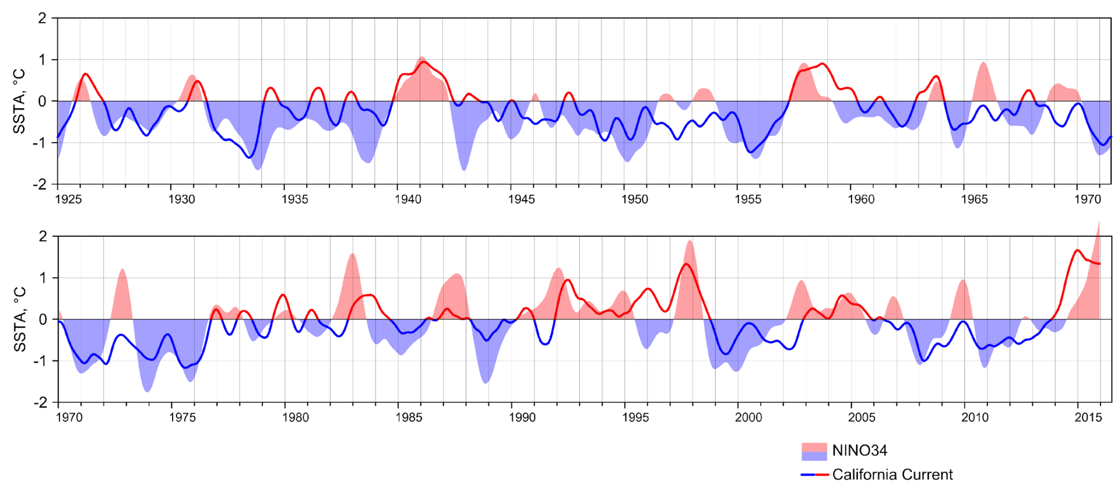

Figure A1. California Current System averaged (from the U.S.–Canada border to the U.S.–Mexico border, from the coast to 500 km offshore) sea surface temperature anomalies with the Nino3.4 index using a 12-month Lowess smoother on monthly data. Anomalies are calculated with respect to the 1981–2010 climatology using ERSST.v4 data. Figure provided by Paul Fiedler, NOAA/NMFS/SWFSC.

There is evidence for increased variability in climate forcing important for the CCS: the PDO is no longer as strongly decadal; since the late 1990s, the PDO has changed sign about every five years. Over the past 40 years, we have had three "El Niño events of the Century" (1982–1983, 1997–1998, and 2015–2016). Similarly, there have been frequent environmental surprises in the CCS in recent years, including the Humboldt squid range expansion into the northeast Pacific (and CCS) from 2005–2009, the widespread ecological impacts in the CCLME of a delay in the onset of the upwelling season in 2005, the record northeast Pacific Ocean heat wave in 2014–2015, and the coastwide harmful algal bloom in 2015.

A synthesis of past CCS variations in relation to large-scale climate forcing supports a relatively simple conceptual model for a continuum of CCLME states moving between sub-arctic (cold) and sub-tropical (warm) extremes. The cold phases of the PDO and La Niña result in colder upper ocean temperatures, weaker stratification, increased nutrients, and northern copepod communities dominating the northern CCS. These copepod species are large in size and lipid-rich, and, when fed upon by mid-trophic level baitfish, provide a lipid-rich and bio-energetically enriched food chain that in turn sustains a host of upper-trophic level fishes (hake, sardines, and salmon), seabirds (shearwaters and albatross), and mammals (California sea lions, gray whales, and humpback whales) that migrate to the Northern California Current every spring to feed. The converse is true during a warm ocean, associated with a positive phase of the PDO, an El Niño, or warm extremes like the 2014–2015 "blob," giving rise to a stratified water column, reduced nutrients, and a prevalence of small, subtropical, lipid-poor copepods, and a less productive marine food-web that results in poor ocean growth and survival rates for salmon, and poor reproductive success years for sea birds. Warm periods in the CCLME have also brought changes in biogeography that include earlier seasonal migrations of whiting, sardines, and other highly migratory species (tuna, sharks, etc.) that extend farther north, even as far as Canadian waters. This was apparent in 2014 and 2015 in association with the warm conditions along the U.S. West Coast, and has been observed in many previous warm extremes in the CCS.

The negative and positive modes of the NPGO (weak and strong gyre circulation patterns) are associated with low and high nutrients and productivity levels in the southern portion of the CCS. The cold and warm modes of the PDO affect alongshore transport and affect a predominance of sub-arctic waters from the north, or sub-tropical waters from the south. Likewise, the intensity of certain harmful algal blooms is linked to warm phases of the PDO and El Niño cycles. These toxic algal blooms are the "canary in a coal mine," serving as indicators of ecosystem change.

While we have documented a large number of climate-induced changes over the past decades, there is a lack of understanding of the detailed mechanisms that couple physical forcing with biological responses. If we do not know the "rules" that govern ecosystem dynamics, we will not be able to bring climate variability in stock assessment models. There is a clear need for a better understanding of how the population structure and life history characteristics of LMR species will respond both to physical forcing and to within-community changes in predator–prey relationships and competitive interactions.

Appendix B

The 2012–2015 “climate change stress test” for the West Coast

2012–2015 drought impacts on West Coast salmon and salmon habitat

California has experienced well below average precipitation in each of the past four water years (2012, 2013, 2014, and 2015), record high surface air temperatures in the past two water years (2014 and 2015), and record low snowpack in 2015. Some paleoclimate reconstructions suggest that the 2012–2015 drought was California’s most extreme in the past 500–1000 years. Record high surface temperatures in 2014 and 2015 made this a “hot drought,” in which high surface temperatures substantially amplified annual water deficits above what would have happened as a consequence of precipitation deficits alone. While the multi-year drought was mostly focused on California, water year 2015 (October 2014–September 2015) was a record warm year for most of Western North America and brought exceptionally low springtime snow pack to most watersheds in Western North America (from Southeast Alaska to California).

In the PNW region, water year 2015 precipitation was near average, but a lack of spring precipitation and record-high surface temperatures led to record-low springtime snow packs. The combination of near-record-high surface air temperatures and low snow-fed runoff led to extremely low spring and early summer stream flows and extremely high stream temperature. Record-high stream temperatures in the lower Columbia Basin in 2015 contributed to high pre-spawn mortality for Willamette River and John Day River Spring Chinook salmon (June and July 2015, respectively), and upriver runs of sockeye salmon (July 2015). Approximately half the total 2015 Columbia River sockeye salmon run (250,000 adults) died from high water temperature related causes. On the other hand, returns of spring and fall Chinook came before and after the warming of river temperatures, so those runs were not affected adversely.

For California, the combination of low precipitation, depleted reservoir storage, and record-high temperatures in both 2014 and 2015 caused exceptionally high stream temperatures in some watersheds. The lack of cold water stored behind Shasta Dam, in combination with water release decisions, led to a loss of stream temperature control below Shasta Dam in September 2014. Stream temperatures that exceeded the 56°F (13.3°C) target in Sacramento River Chinook salmon spawning areas are thought to have contributed to 95% mortality rates for eggs and fry produced by spawning Winter Run and Fall Run Chinook salmon in 2014. Concerns over a high potential for fish kills in the Klamath Basin were also raised in the summers of 2014 and 2015 because of high stream temperatures and elevated presence of pathogens detected in salmon; these concerns prompted emergency reservoir releases that were aimed at lowering downstream temperatures to alleviate those risks. In 2015, the lack of available cold water in Lake Shasta led regulators to slightly raise the target water temperature for Winter Run Chinook salmon spawning and incubation period flows, and exceptionally low egg-to-fry survivals (~3–5%) happened again in 2015.

High stream temperatures and low stream flows in summer 2015 also had widespread adverse impacts on salmon hatcheries in Washington, Oregon, and California, causing increased mortality for rearing juveniles and forcing hatchery managers to release hundreds of thousands of juvenile salmon earlier than desired.

Record-high mainstem temperatures, frequently in the low 70s°F (>21°C), in the Columbia River during mid-June through mid-July in 2015 contributed to extremely high pre-spawn mortality for upriver runs of sockeye salmon. For Snake River sockeye, only an estimated 280 adults survived the migration to the last dam encountered on the Snake River, which is less than 10% (over 4,000 ESA-listed adult Snake River sockeye) of the fish crossing the first dam encountered on the Columbia. Because of the low survival, Idaho Fish and Game trapped and transported 35 migrating adults to their hatchery, and 587 mature Snake River sockeye salmon adults from NOAA's captive broodstock program were released into Redfish and Pettit Lakes in Idaho's Sawtooth Valley to aid in offsetting the very low survival.

2014–2015 exceptionally warm ocean conditions in the Northeast Pacific
Much of the northeast Pacific Ocean experienced an "ocean heat wave" that featured record-high sea surface temperature anomalies from Alaska to Mexico in both 2014 and 2015. The record warming developed in several stages. First, unusually placid and persistent 2013–2014 fall/winter weather over the Gulf of Alaska caused a "warm blob" in the upper ocean in the Gulf of Alaska region and offshore of Oregon. Then in spring 2014, upper ocean temperatures became anomalously warm off the coast of Southern and Baja California, and this warming spread to the Central California coast in July 2014. In fall 2014, a shift in wind and ocean current patterns caused the offshore warming to spread onshore, and the entire northeast Pacific domain experienced exceptionally warm upper ocean temperatures in the nearshore zone to several hundred kilometers offshore (see Figure B1). While the broader northeast Pacific Ocean experienced warm SST anomalies though most of 2014 and 2015, nearshore waters from Vancouver Island south to San Francisco mostly experienced strong and at times above-average coastal upwelling that created a relatively narrow band (~20–100 km wide) of near-normal upper ocean temperatures during spring and summer in both 2014 and 2015, essentially holding the warm blobs at bay as long as upwelling winds and related currents were strong.

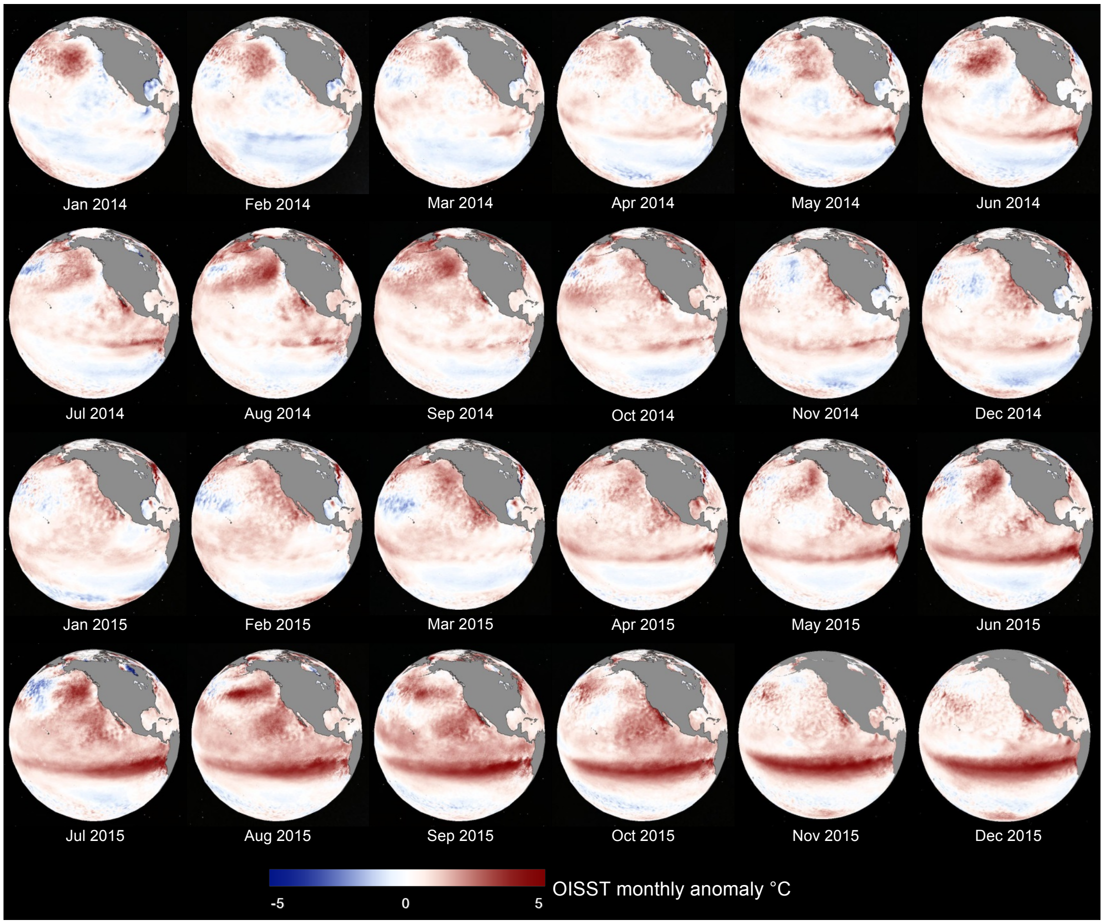

Figure B1. Observed monthly SST anomalies during the 2014–2015 northeast Pacific Ocean heat wave from OISST.v2 data using the 1981–2010 climatology. Image produced by P. Fiedler (NOAA/NMFS/SWFSC).

Ecological impacts of the 2014–2015 ocean heat wave on many elements of the CCLME have been widespread and included:

- The largest and most intense HAB ever recorded off the West Coast in summer 2015, stretching from Santa Barbara (CA) to Southeast Alaska.
- The first recorded sighting of over 15 southern and offshore (tropical and subtropical) zooplankton species on the Newport, Oregon, hydrographic sampling line.
- An Unusual Mortality Event (UME) for California Sea Lions from 2013–2015, with three consecutive years of exceptionally high California sea lion strandings and reproductive failures.
- A UME for Guadalupe Fur Seals in 2015.
- An unusually high number of whale entanglements in crab fishing gear in the nearshore zone along the California coast.

- A northward and inshore range shift for many tropical/sub-tropical species into the coastal waters of the CCLME and Gulf of Alaska. This included unusually large numbers of bluefin tuna, yellowfin tuna, yellowtail, dorado, opah, and marlin in the waters of the Southern California Bight in 2014–2015, as well as sunfish, pomfret, pompano, and mackerels in the Gulf of Alaska.
- Northward shifts in California's market squid fishery in 2014 and 2015.
- A massive Cassin's auklet die-off in fall/winter 2014–2015 on the PNW coast.
- Very poor Chinook salmon commercial troll fishery in CA in summer 2015.
- Prolonged shellfish fishery closures (for razor clams and Dungeness and rock crabs) in Washington, Oregon, and California as a consequence of the HAB that caused the toxin domoic acid to accumulate above regulatory limits.

While there were negative effects related to the warm conditions in the CCLME, some parts of the California Current in fact experienced positive signals:

- Juvenile rockfish numbers were extraordinarily high in 2014 and 2015 (2015 being the highest of a 33-year time series off Central California).
- Unprecedented numbers of loggerhead turtles in high densities in the Southern California Bight and seaward.
- Increased sightings of previously rare cetaceans (or first-ever records) throughout the California Current.
- An indication of the return of the short-finned pilot whale, *Globicephala macrorhynchus* (absent since the 1982–83 El Niño), to the Southern California Bight.
- Increased sightings of tropical seabirds throughout the California Current (and northward), as well as high bird productivity for the Farallon Islands' cormorants and auklets.

Near-term climate risks and impacts already in the pipeline for West Coast salmon

Adult West Coast coho salmon returns in the fall of 2015 were likely negatively impacted by poor stream and ocean conditions in 2014 and 2015; coho salmon returns to the Columbia River and Puget Sound in fall 2015 were well below recent run-size averages and pre-season forecasts. West Coast coho salmon that will return in fall/winter 2016–2017 have also likely been negatively impacted by poor stream and ocean conditions related to the 2015 "snow drought" and 2014–2015 northeast Pacific Ocean heat waves, and poor ocean conditions associated with the warm blob. Adult Chinook salmon (and steelhead) returns to California for the next three years (depending on ocean residence times for fish maturing in 2016, 2017, and 2018) have also likely been negatively impacted by poor stream and ocean conditions in the CCLME. For Oregon and Washington Chinook salmon and steelhead, brood years 2014 and 2015 were likely negatively impacted by poor freshwater conditions in spring/summer 2015. Ocean migrants in 2014 likely experienced a transition year from relatively good ocean conditions in spring/summer 2014 to poor ocean conditions in fall 2014 through winter 2016.

The expected effects of the 2015–2016 tropical El Niño in the CCLME are likely to favor a more coastally oriented warming in the winter, spring, and summer of 2016. If this expectation is realized, spring 2016 ocean migrants from West Coast streams will likely encounter an ocean strongly influenced by (if not dominated by) a subtropical food-web that favors poor early marine growth and survival for both coho salmon and Chinook salmon, which would tend to favor reduced abundance for these year classes. In contrast, mid-winter snow pack and precipitation in fall 2015 and early winter 2016 have been near to well-above normal from the Sierras to British Columbia, and air temperatures have been near normal. If the rest of the 2016 water year stays on track for abundant snow pack, stream flow, and stream temperatures, freshwater spawning and rearing conditions in 2016 will be much improved over those from 2015, and should favor increased freshwater productivity for West Coast salmon and steelhead (see Table B1). However, poor ocean conditions expected in 2016 may counteract the good freshwater conditions (providing another example of a "natural experiment").

A climate timeline for West Coast salmon

2012	2013	2014	2015	2016
Year 1 CA drought	Year 2 CA drought	Year 3 CA drought	West Coast "snow drought" and record high temperatures	Abundant snow pack and streamflow?
Cold productive NE Pacific	Cold productive NE Pacific	NE Pacific in transition from good to bad ocean conditions	Record warm temperatures in NE Pacific; many signs of stress on "subarctic" species off the West Coast	A still warm and unproductive NE Pacific?
BY 2012 fall chinook	Smolt migration	Ocean year 2	Ocean year 3, majority maturing	
	BY 2013 fall chinook	Smolt migration	Ocean year 2	Ocean year 3, majority maturing
	BY 2013 coho	Smolt migration	Adult returns	

Table B1. Characterization of freshwater and ocean conditions for U.S. West Coast salmon, 2012–2016.

Appendix C

Coastal-zone change is expected to come on many fronts

Significant changes to human communities beyond those driven by climate are likely. In the next 15–20 years, there will be secular trends in human demographics, technology, and markets that are likely to significantly change coastal communities and their dependence on ocean resources. For example: 1) the population of fishermen is skewed toward older ages with relatively few young people, and in the next 10–15 years they may move out of fishing, leaving a very different population of fishermen in terms of age distribution and culture; 2) once fossil fuel prices increase again, there may be a renewed push for wind and tidal energy; 3) high fuel costs may make many fisheries unviable; and 4) the decreasing relative cost of aquaculture fish may make it hard for wild fisheries to compete. Fisheries without farmed substitutes or very efficient fisheries may not survive. The highest value fisheries are managed by the states, not NMFS or the Council; with increased climate variability, these resources will shift and there will be a greater need to collaborate between federal and state regulatory entities. With each of these scenarios, there will be different impacts on communities. Small fishing communities, with fewer diversified resources, will probably be more impacted than larger communities that are less reliant on fishery income. These are just a few examples, some highly uncertain, of climate-induced pressures impacting humans.

Sea level rise will perhaps be among the most observable impacts of anthropogenic climate change in the CCLME, as it will visibly and structurally impact both coastal ecology and human communities. The loss of coastal pinniped haulout areas and other nursery grounds could force a number of marine mammal species to change their range. For humans, impacted harbor infrastructure, rapidly eroding coastal bluffs, and inundation of low-lying areas pose the most immediate risk from sea level rise. Less visible, but potentially equally disruptive to the coastal ecology, will be the contraction and landward migration of estuarine environments that in many places are now bordered by hardened shorelines (i.e., developed properties protected by dikes, levees, rip-rap, etc.). Changing productivity and distributions of various fish species will impact fishery-dependent coastal communities. The species landed and the relative dependence of communities on fishing will shift.

For human populations not involved in marine activities, the changing hydrologic patterns will impact hydropower generation, agricultural resources, and domestic resources. Each of these will create secondary and tertiary stresses, as well, that have to be identified and considered in the context of the continually increasing human population in the western states and larger regional areas. Another consequence linking population movements and fisheries is that the anticipated warming may increase the human population living along the coast, thus increasing the demand for high-quality seafood.

Appendix D

Examples of successful integration of physics and ecology to support decision-makers

The Centers bring established strengths into this effort. We have a long history of collaborating with regional climate centers (e.g., the University of Washington's Climate Impact Group) on LMR–climate studies. Both California and the Pacific Northwest have a large cadre of climatologists who have worked actively to develop LMR-relevant climate products, including down-scaling, climate-informed hydrologic projections, and more. Moreover, we have a variety of local projects and case studies that are already working to incorporate climate change. These include a variety of water- and temperature-related projections and analyses for salmon in Idaho, coastal California, the Central Valley, and Puget Sound, as well as efforts aimed at seafood safety (harmful algal blooms), vulnerability analyses for managed fishery species, and changes in marine fishery (human) behavior. In addition, our CCIEA program is currently using downscaled climate model output to investigate potential ecosystem changes in the California Current. Our researchers are actively pursuing research into salmonid restoration efforts that will be most effective and lasting under climate change. Finally, both Centers have a good deal of expertise in ecological and population modeling that could be used to develop realistic models and evaluate the efficacy of alternative management scenarios under likely future conditions.

Scientists at both Centers recognize the importance of developing ecosystem based fishery management (EBFM) strategies, and have been addressing the issue in a variety of ways for decades. In 1951, the California Cooperative Oceanic Fisheries Investigation (CalCOFI; http://calcofi.org) was initiated as a federal/state/academic joint effort between the SWFSC, the California Department of Fish and Wildlife, and the Scripps Institution of Oceanography, to look for environmental triggers for sardine biomass fluctuations. The annual *CalCOFI State of the California Current* report is a valuable tool for expressing the impacts of short-term variability. Unfortunately, due to funding reductions at both the state and federal levels, the CalCOFI program now only covers the Southern California Bight. The NWFSC developed a single monitoring line extending out from Newport, OR that complements CalCOFI, Central California's Trinidad Head Line, as well as other long-term monitoring efforts providing broader coverage of the CCLME. Additional programs have developed cruises for assessing both groundfish and coastal pelagic species, and fishery scientists are improving the ability to compare data across the monitoring efforts. The two Centers collect large suites of environmental data, but often the biological data are very specific to the cruise objectives and not compatible between species-monitoring objectives. Data from these assessment cruises are made available through ERD web services (http://coastwatch.pfeg.noaa.gov/erddap/index.html).

The West Coast Region Climate Team (WCRCT)
Consisting of staff from the WCR and the two Centers, the WCRCT enhances the dissemination of climate information across the NMFS offices. Monthly meetings and a monthly internal newsletter provide a forum for exchanging climate observations and understanding management issues that need climate consideration. Members of this group also participate in a larger NOAA Western Climate Working Group led by the National Weather Service. NMFS scientists are making every effort to recognize climate variability, and are trying to monitor fishery stocks to evaluate the ways in which stock fluctuations are related to climate variability.

The California Current Integrated Ecosystem Assessment (CCIEA)
The NW and SW Fisheries Science Centers, the WCR, the sanctuary office (NOS), OAR, and the regional associations have jointly developed the CCIEA. The goal of the CCIEA is to assemble environmental and ecosystem data to allow EBFM to replace single-stock assessment management plans and provide integrated sanctuary management plans. The CCIEA has adopted protocols for assessing environmental, ecological, and human activities to develop a suite of indicators that can be monitored to assess climate variability impacts. For the past four years, the CCIEA has provided the PFMC with a State of the California Current Ecosystem report,[10] which includes a review of critical indicators and provides a summary ecosystem report. In an important step toward bringing ecosystem consideration into stock management, the CCIEA team has been asked to work with the PFMC's Ecosystem Working Group (EWG) to develop a standard protocol for including environmental and ecosystem indicators into the implementation of the PFMC's FEP.

The main successes to date have been: 1) the development of mechanisms to bring the strong environmental science from throughout the CCLME into a much more cohesive structure that forms the basis of the CCIEA; 2) the screening and ranking of hundreds of indicators of components, processes, and ecosystem attributes ranging from physical forces to human dimensions; and 3) the development of conceptual models, risk assessment methods, and MSE methods that are producing management-relevant products and publications, including many that relate to climate change and variability. Working with the PFMC EWG allows an extended evaluation of which indicators are most relevant for the fishery-management decisions that require environmental consideration.

[10] http://www.pcouncil.org/wp-content/uploads/2016/02/D1a_NMFS1_2016_IEA_SoCC_FINAL_MAR2016BB.pdf

Appendix E

West Coast Region draft priorities for Regional Action Plan to implement NOAA Fisheries' Climate Science Strategy (December 2015)

NOAA Fisheries' West Coast Region (WCR) staff reviewed the August 2015 NOAA Fisheries Climate Science Strategy for potential links to our requirements for recovering species listed as threatened or endangered under the Endangered Species Act (ESA), for conserving and managing marine species under the Magnuson-Stevens Fishery Conservation and Management Act (MSA), and for protecting and recovering species managed under the Marine Mammal Protection Act (MMPA). The WCR has significant ESA responsibilities for anadromous species; therefore, our climate science and information needs to span freshwater and terrestrial areas as well as marine waters. Some of our initial ideas about high-level WCR priorities for climate science fall into four categories of science needs, below. We look forward to further engagement with the Science Centers on developing management programs that appropriately respond to emerging climate science.

1) Science-management liaison capacity

The WCR needs both Fisheries Science Centers (Northwest and Southwest) to continue to support at least one scientist each to serve on the WCR Climate Team. Activities would include informing WCR staff of new Center climate research and activities while staying informed of WCR climate-change activities and information needs. These Center Climate Team members would also facilitate WCR coordination with other Center scientists conducting research in marine and freshwater environments. The WCR and the Centers should also support liaison capacity to facilitate opportunities for a collaborative (i.e., regulatory and Center staff) approach to informing, developing, refining, and advocating for tools that are immediately useful for regulatory decision-making under conditions such as drought and changing climate. (Objective 7)

2) Periodic updates on the state of science about expected climate effects on protected and managed species and habitats

The WCR needs ongoing guidance on the state of climate science and its applicability to protected and managed species. The Centers are working on useful climate-change information relevant to most managed fish species, in the form of species narratives for fisheries vulnerability studies and 5-Year status reviews for listed salmonids. Presumably, when methods are completed, narratives for marine mammal and turtle vulnerability assessments relevant to the WCR will become available within the next few years. These products, along with other sources of available information, will be helpful for properly considering climate change in our ESA, MMPA, MSA, and international fisheries management activities. Our concern is that after these initial products are developed, there is no process or plan (except ESA 5-year status reviews) for updating the information. The WCR needs the Centers to periodically update products that describe potential effects of climate and climate change on managed species throughout their life cycles. (Objective 6)

For MSA-managed species, we appreciate receiving, and will continue to need, the annual updates envisioned in Objective 6 of the National Climate Science Strategy for Ecosystem Status Reports. The Pacific Fishery Management Council currently receives annual ecosystem updates as part of its California Current Ecosystem Status Report. We look forward to continuing to work with the Centers on developing that report, as envisioned in the Council's Fishery Ecosystem Plan.

Many bilaterally or multinationally managed species are tied in with domestic management programs under the MSA or ESA, or with species groups managed domestically. We see an ongoing need for information on the potential effects of climate variability and climate change on the distribution and abundance of internationally managed species.

3) Freshwater ecosystem information on climate effects

a. Continue to investigate the resiliency of restoration activities to climate change (e.g., Beechie et al.'s 2013 review of restoration activities that increase resilience to climate change, and Boughton and Pike's 2013 report on floodplain rehabilitation and climate uncertainty). (Objectives 2 and 7)

b. Help identify: 1) landscape areas or watersheds that are likely to continue to be hydrologically "snow driven," or transitional, and thus continue to provide cool water temperatures in a warming climate; 2) areas where hyporheic flows are important to maintaining surface flows and cold water, and impacts of climate change on such flows; and 3) watersheds where cool water releases could be maximized based on geomorphology, hydrology, and vegetation downstream under likely climate scenarios. (Objectives 1, 2, 3, 5, and 7)

c. Examine the link between geology/topography and sediment movement and the potential to reshape stream channels as a consequence of climate change-induced changes to hydrology (e.g., more extreme events). How would aquatic species, including salmonids, likely respond? Where might we expect most changes to occur? (Objectives 1, 3, 4, 5, 6, and 7)

d. Assist the WCR in developing the capacity to conduct ESA reviews of proposed actions that include time frames appropriate to the life span of the structure(s) being proposed. For example, WCR engineers need aid from Center scientists in assessing whether we are using the right tools and methods to analyze whether a culvert will pass fish in flows throughout the design life of the culvert. We also need help developing site-specific tools to project hydrologic and geomorphologic changes likely in watersheds, and to model potential impacts of new structures on species and habitats. (Objectives 2, 3, 4, and 7)

e. Range shifts. Do we expect, or can we realistically project, freshwater range shifts for any of our aquatic species that use freshwater ecosystems? If so, what might the timing be and what might future ranges look like? This information would be important for recovery planning and critical habitat designations, etc. (Objectives 2, 3, 4, and 7)

f. Unoccupied habitat, e.g., behind dams or otherwise not currently used: Can we identify which unoccupied freshwater habitats may become important for our listed species based on climate change projections and what we know about regional and local weather, climate, and habitat conditions? This information would be important for recovery planning, critical habitat designations, and in guiding management initiatives such as responding to insufficient cool water releases for downstream fish needs during particularly hot or low-flow years. (Objectives 2 and 4)

g. Ecological community changes, such as species invasions or losses: As climate changes and freshwater ecosystems respond, what may happen to freshwater ecological communities? What species may become prevalent? What species may dwindle or disappear? What should we be watching for? How might freshwater life stages of our listed species respond to changes in freshwater communities (e.g., density and occurrence of other species in the community). (Objectives 1–7)

4) Marine ecosystem information on climate effects

a. Are other agencies within and outside of NOAA assessing the vulnerability of coastal communities to the physical effects of climate change? Are NOAA Fisheries' analyses of the dependence of fishing communities on fisheries resources adequate to partner with other agencies to identify communities that could be negatively affected by *both* the physical effects of climate change (sea water rise, increased storms, flooding, etc.) *and* the economic effects of changes in availability of fishery resources? (Objectives 2, 3, 4, 5, and 7)

b. When mapping coastal areas with expected sea-level rise, as discussed in 4a, we need to also coordinate with mapping efforts for pinniped haulout areas? How do we expect sea-level rise to affect available haulout space given the high-relief coastal areas prevalent along much of the U.S. West Coast? (Objectives 2, 3, 4, and 5)

c. Marine species and shellfish managed with ESA recovery plans need updating with climate science so that we can assess whether changing climate conditions should trigger revisions to recovery plans and their implementation policies. Sea turtle recovery plans are particularly out of date; WCR is uncertain about the potential effects of shifting climate conditions on sea turtle populations, and needs climate-science support to update recovery plans. The potential long-term effects of climate change on protected shellfish recovery are also unknown, and may be compounded by changing ocean chemistry as discussed in 4i, below. (Objectives 2, 3, and 7)

d. Sardine and anchovy populations appear to be shifting northward. Do we know whether this is likely a long-term shift, or a short-term fluctuation in distribution? If sardines are moving northward beyond our CalCOFI survey area, should we revise our survey methodology and harvest-setting parameters to account for that shift in distribution? In 2–3 years, we might benefit from a workshop or forum to bring together scientists on adjusting stock assessments and harvest parameters in response to changing climate. (Objectives 1, 3, 4, 5, 6, and 7)

e. The Centers are already working within the Pacific Fishery Management Council process to review relationships between the sablefish stock and its ecosystem, which the WCR takes to include the potential effects of climate on sablefish abundance and distribution. We are interested in seeing similar work on Pacific whiting, but would defer to the Council's interests on which groundfish species should follow sablefish in characterizing the relationships of groundfish species to their environment within stock assessments. Beyond these commercially important species, is it possible to conduct a deeper assessment of the long-term effects of climate fluctuations and change on our longer-lived species, so that we can plan for healthy stock status for our rockfish and other long-lived species in the decades ahead? (Objectives 1, 2, 4, 5, 6, and 7).

f. Managing ocean salmon fisheries and setting allowable harvest levels by seasons has been made more difficult by recent shifting temperature conditions. Can we improve what we know about how shifting ocean temperatures are likely to affect salmon ocean migration patterns and survival likelihoods, so that we can in turn better predict fisheries returns? The effects of temperature on ocean salmon are a concern both for U.S.–Canada bilateral management processes, and for U.S. West Coast fisheries management. (Objectives 2, 3, 4, 5 and 7).

g. Do we know enough about the migratory patterns of highly migratory species, like tunas, billfishes, and sharks, to predict: a) how those patterns might be affected by near-term climate shift and long-term climate change, and b) how those patterns might affect the abundance of harvestable highly migratory species within the U.S. West Coast Exclusive Economic Zone? Further, if abundance of lower trophic level species is affected by climatological changes, what indirect effects can we expect on higher trophic level highly migratory species? (Objectives 3, 4, 5, and 7).

h. What annual, interannual, and longer-term changes do we expect to see in the ranges of the resident and migratory marine mammals of the U.S. West Coast EEZ? How might shifting marine mammal ranges be related to varying climatic and oceanic conditions, or to shifting ranges, abundance, and availability of prey species? WCR is specifically concerned with:

> i) large whale distribution and migration related to shipping lanes and to entanglement in pot and trap fishing gear;

ii) how shifting ocean distribution of Chinook salmon (see 4f) might affect Southern Resident Killer Whales;
iii) the availability of nearshore prey to pinnipeds, particularly those that use California's Channel Islands; and
iv) whether shifts in marine mammal ranges may affect between-population disease transmission. (Objectives 2 through 7)

i. Do we know enough about ocean acidification and hypoxia to identify the geographic areas most likely to be affected by changing ocean chemistry? What do we know about the effects of ocean acidification on ESA-managed shellfish and their population recovery? For those managed species that are not shell-forming organisms, have we identified potential trophic effects of ocean acidification? (Objectives 4, 5, 6, and 7)