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Scenarios for West Coast Fisheries

Climate and Communities Initiative

Pacific Fishery Management Council's Climate and Communities Core Team

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Contents

Scenarios for West Coast Fisheries 2040

Introduction

As climate variability and change become more established features of our world, the Climate and Communities Initiative is undertaking a scenario planning process to explore potential fisheries management challenges, and identify the tools, information, and approaches the Council might need to address those challenges.

This document outlines four scenarios that describe possible conditions facing West Coast fisheries and communities from 2020-2040. These scenarios have been created through a structured process involving dozens of stakeholders. For each scenario, we have highlighted how different potential future climate conditions might affect representative species from each of the Council's four FMPs. To choose the particular species and stocks discussed in this document, we focused mainly on species that are more likely to be targeted, that pose different management challenges, and come from different geographic locations.

Looking to the next 20 years: What is prudent to assume?

Despite the unpredictability of the future when we look to the next 20 years, there are a number of trends and developments that we can assume will happen. The path of these "predetermined elements" is mostly locked-in and known, no matter what else happens in the world. These conditions will hold across all of our scenarios. Below, we outline those "predetermined elements."

Environmental conditions

The California Current Ecosystem (CCE) will experience some level of **ocean warming**. Average sea surface temperature (SST) is predicted to increase by 0.36 degrees celsius (C) per decade in the 21st century across the CCE, with the greatest increase occurring in summer months and a slight shift in the seasonal warming cycle to later in the year.[1] By 2040, annual average SSTs in the CCE are predicted to exceed even the

warmest year during the 1976-2005 period almost two-thirds of the time.

The CCE is also predicted to experience increased **ocean acidification**. Evidence suggests that the CCE is acidifying more rapidly than the global average, with the nearshore and northern/central regions experiencing the most severe and persistent acidification. One model studying the CCE predicts a 0.2 unit drop in pH during the summer upwelling seasons from 2013 to 2063.[2] Globally, the Intergovernmental Panel on Climate Change states that it is virtually certain that sea surface pH will decline by the end of the century. The rate of decline varies according to which Representative Concentration Pathway (RCP, trajectory for greenhouse gas emissions) scenario is assumed.

Levels of oxygen are projected to decline further from current levels. Globally, the oxygen content of the ocean is very likely to decline by 1.6-2%, or by 3.2-3.7%, depending on which RCP scenario is assumed.[3] **Hypoxia** is a growing concern in parts of the CCE, and is made worse by ocean warming and compounded by increases in stratification, so it is prudent to assume that hypoxia will increase. There is also evidence that, due to seasonal upwelling, the CCE will continue to experience severe and persistent hypoxia.

Demographics

Global human population is projected to increase from 7.8 billion in 2020 to 9.2 billion by 2040,[4] creating greater demand for food, especially in fast growing regions in Africa and Southeast Asia. Closer to home, we can assume that while populations in the western U.S. will continue to be concentrated in a few mostly urban areas and nearby cities, increased teleworking will prompt some knowledge workers to move to smaller settlements in rural and coastal areas.

Ocean uses

Ocean conditions will continue to change because of human behavior. Pollutants will continue to affect marine systems over the next 20 years. Disasters like the Fukushima nuclear reactor meltdown or Deepwater Horizon oil spill will sporadically occur, leading to major but transient seafood safety concerns. A growing human population will also lead to increased interest in the use of ocean waters for activities such as offshore energy and aquaculture. Chronic sources of pollution, such as

nutrient runoff from agriculture and plastics production, will continue to affect marine fish stocks directly and seafood consumption patterns indirectly. While there is considerable movement underway to reduce single-use plastics, it is expected that we will produce three times as much plastic in 2050 as we do today.[5]

Technology

Technological advances, falling costs, and rising levels of concern will lead to greater use of sensors and other monitoring systems to assess a wide range of environmental conditions, species, and on-the-water human activities. Greater sensing capabilities, in combination with advances in fisheries and ecosystem science, will result in a data-intensive world that could facilitate more effective fisheries management through increasingly accurate assessments of stocks.

The early 2020s will be a time of difficult economic conditions due to COVID-19.

Economics and societal values

The early 2020s will be a time of harsh, difficult economic conditions as the impact of the global COVID-19 pandemic affects consumer demand and strains industry providers and government budgets. Societal values and behaviors will be in flux, driven partly by the evolving impacts of the pandemic. Fisheries will adapt their operations in response to shifting patterns of seafood demand and safety concerns raised by COVID-19. Over time, increasing evidence of climate change and the vulnerabilities that this creates, combined with a younger generation that prioritizes environmental concerns, will shift societal values (e.g. consumption, conservation) towards sustainability.

Policy environment

The efforts of the Pacific Fishery Management Council (PFMC) and western states and tribes to rebuild overfished stocks, maintain stable fish populations, and minimize bycatch under conditions that lead to shifting stock distribution and abundance will continue under a regulatory environment based around the Magnuson-Stevens Act. This will give stocks some degree of resilience in the face of climate change and other factors affecting the future environmental conditions. The Magnuson-Stevens Act and other ocean policy laws will be periodically updated in response to shifting national ocean resource management and ocean zoning needs.

Scenario framework

This interim scenario framework is constructed from a number of different variable factors that will affect fishing in the CCE over the next 20 years. At its heart are two fundamental uncertainties:

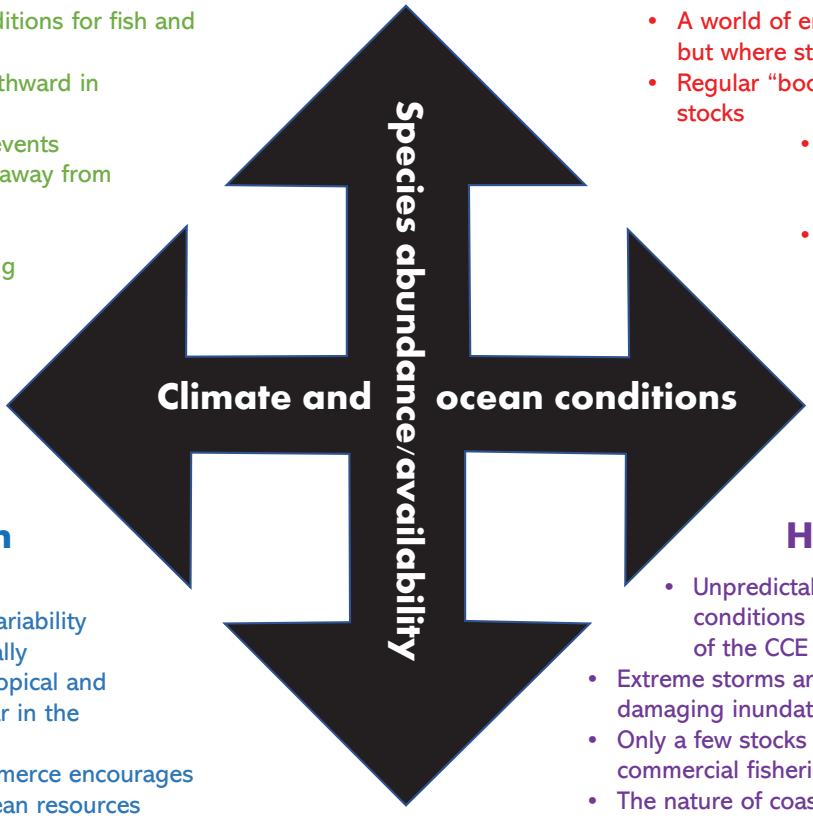
- How variable will climate and ocean conditions be? Over the next 20 years, will there be mostly gradual change (in temperatures, acidification, oxygenation), and relatively infrequent ecological surprises and weather events? Or will there be extreme variability in conditions from year to year along with frequent and major ecological surprises and weather events?
- What will happen to species abundance (productivity) and availability? Will the next 20 years see an increase in stock abundance or availability of important harvested species, or will stocks decrease or become otherwise less available?

Fortune and Favor

- Mostly favorable conditions for fish and fisheries
- Many stocks shift northward in predictable ways
- Few severe extreme events
- Societal values move away from globalization, instead
- encourage collective
- support of local fishing

Box of Chocolates

- A world of environmental surprises and extremes, but where stock levels increase on average
- Regular "boom and bust" cycles for some key stocks
- New technology is deployed to better monitor the unpredictable environment
- Seafood marketing becomes more difficult because of the high variability in availability



Blue Revolution

- Warmer climate/ocean
- conditions, but little variability
- Familiar stocks gradually
- decline but new subtropical and
- tropical species appear in the
- southern CCE
- Open, globalized commerce encourages alternative uses of ocean resources
- Aquaculture and offshore energy puts pressure on commercial fishing

Hollowed Out

- Unpredictable and extreme shifts in ocean conditions lead to a fundamental reorganization of the CCE food web
- Extreme storms and rising tides create regular and damaging inundations
- Only a few stocks remain at harvestable levels and most commercial fisheries suffer
- The nature of coastal activity changes as some places are neglected, others become fortified, commercial hubs

Alongside these critical uncertainties that frame the matrix, the scenarios also include consideration of a number of other unpredictable factors that are likely to shape the future of fishing and fishery management on the West Coast. These include:

- The availability and application of new technologies (e.g. monitoring equipment, gear, etc.)
- The growth in alternative ocean uses (e.g. aquaculture, offshore energy)
- Changes in consumer habits regarding their dietary preferences for animal and plant-based protein
- Social and political attitudes around globalization and localism

Future uncertainties:

- **Variability of climate & ocean conditions**
- **Species abundance**
- **New technologies**
- **Alternative ocean uses**
- **Consumer habits**
- **Social & political values**

The two scenarios on the left side of the matrix (Fortune and Favor, Blue Revolution) share a common set of physical drivers, as do the two scenarios on the right side (Box of Chocolates, Hollowed Out). The common set of physical drivers on the left side are premised on a smaller increase in ocean temperature and less variability in these drivers over time compared to the two scenarios on the right side. However, the way in which the ecosystem has responded to these drivers differs between the two scenarios on the left side, as they do for the two on the right side—greater biological productivity (Fortune and Favor and Box of Chocolates) or lesser biological productivity (Blue Revolution and Hollowed Out). Bearing this in mind, the scenario descriptions are organized into these four sections: summary; physical drivers; description of market, technology and ocean conditions; and ecosystem responses, including impacts to managed fish stocks.

Full descriptions of each scenario follow.

A Scenario for 2040: Fortune and Favor

Low climate/ocean variability, stock availability increases

The natural environment in this scenario is not radically different from today. By 2040, conditions seem pretty favorable for fish and fisheries. The frequency of extreme events (such as marine heatwaves) is little changed from the 20 year-period up to 2020, although high-end temperatures depart from a higher long-term average. Many economically important stocks are about as abundant as they were in 2020 and in some cases they have increased. Although the effects of climate change have been gradual and relatively benign, ocean conditions—and fish stocks—have been far from static. Societal values have turned decisively to favor reducing greenhouse gas emissions, and there is broad support for new collective action through a variety of policies and government interventions.

This is a world of gradual ocean warming, with fish stocks responding favorably.

Physical drivers

In Fortune and Favor, warming has been gradual and at the low end of current global warming projections. Inter-annual variability in ocean temperature is relatively low compared to the Hollowed Out and Box of Chocolates scenarios. Likewise, marine heatwaves and swings between El Niño and La Niña conditions are also less intense and frequent, compared to the Hollowed Out and Box of Chocolates scenarios. However, ocean temperature variations diverge from a higher mean than today.

Compared to 2020, already modest upwelling in the southern CCE further relaxes while strengthening in northern CCE, resulting in persistent seasonal hypoxic (low oxygen) conditions in nearshore benthic areas in the northern CCE. Changes in upwelling strength are mostly noticeable from decade to decade, but less obvious from year to year.

Terrestrial climate impacts have not been as dire as predicted back in 2020. While West Coast droughts have occurred, their severity and

duration has been limited. On average, precipitation levels in the Sierras have remained consistent over time, although a greater percent of that precipitation is falling as rain. Annual snow accumulation levels are not significantly lower in 2040 than they were in 2020. Occasional cooler and wetter years (La Niña years) improve river flow and conditions for salmon.

Extreme winter storms, and rough weather generally, are much less frequent as winds weaken overall.

Policy, market, and technological conditions

While the effects of climate change have been relatively mild, the U.S. economy experienced major shocks during the 2020s. The impact of the Covid-19 pandemic was followed by worldwide cyber conflicts that further disrupted finance and supply chains. International relationships became more fractured, resulting in hostility, mistrust, and further declines in economic confidence. To dig out of such a difficult situation, all industries needed to challenge their conventions. By the mid 2030s, the fishing industry became less international and came to rely more on demand from U.S. consumers. This is aided by broad-scale efforts to promote domestically-produced seafood, driven by entrepreneurs, communities, and governments. By 2040, there is a renewed emphasis on buying local, supporting American seafood, and exploring alternative, community-based approaches to fishery management.

American culture in the 2040s shifts to emphasize nature-based solu-

tions to address long-term climate and pollution concerns. Despite the shocks that set back the economy and fishing industry in the 2020s, there is a growing realization that the 2020-2040 period granted the fishing industry a "temporary reprieve" from the long-term effects of ocean warming and acidification. A younger generation is now taking a longer-term, more ecosystem-based perspective to ensure long-term sustainability of the industry and the environment. This includes removing dams in some areas, restoring natural wetlands, and renewed efforts to recover depleted and endangered species. National and global policy commitments to ramp up greenhouse reduction efforts began in the early 2030s. By the 2040s, the U.S. economy is firmly on the road to decarbonization.

As the fishing industry resurged in the 2030s, national policy promoted communal, cooperative approaches.

By 2040, especially on the West Coast, fish is seen as a healthy, sustainable, local source of protein. As the fishing industry resurged in the 2030s, national policy promoted communal and cooperative approaches. This encouraged the growth of community-focused fishing, processing, and marketing, informed by investments in new monitoring technologies. A new generation is inspired to participate in fisheries. After "losing their way" in the 2020s, coastal communities re-embrace fishing as central to their identity and adopt new social arrangements (e.g., regional co-management). The economic shocks of the 2020s also accelerated a decline in recreational fisheries. But changing attitudes and new technologies (e.g., carbon neutral vessel propulsion) led to growing participation in the 2030s.

The gradually warming ocean has created an interesting balance of challenges and opportunities for fishermen and fisheries management. There is a greater diversity of fish species available in the CCE, but evidence suggests that, on average, fish are smaller-bodied than 20 years ago. Greater abundance and diversity have led to increased catch of weak stocks in fisheries using less selective gear. Fishermen are frustrated by resulting limits on the catch of target species. But while an ecosystem-based perspective in fisheries management constrains catch in individual fisheries, catches across all fisheries increase. There is growing pressure for technological innovations and institutional changes to address these issues and seek solutions.

Ecosystem response

Continued ocean acidification has not led to threshold effects that reorganize trophic structure. Populations of most shell-forming plankton at

For many important species, 2020 to 2040 was a time of range expansion or shift.

the base of the food chain have adapted to lower pH (more acid) conditions, although shellfish aquaculture operations continue to struggle. Harmful algal blooms occur but are not as extensive or damaging as in the other scenarios. Overall, conditions have stayed within the physiological tolerance range for most species, while ocean warming over these two decades produces more forage.

With some exceptions, most marine mammal populations are near or at what scientists estimate are pre-exploitation levels. The loggerhead sea turtle population in the West Coast EEZ has recovered and is de-listed under the Endangered Species Act; the leatherback sea turtle population, while not extinct, remains severely depleted, due to impacts far outside the CCE at nesting beaches.

For many important target species, 2020 to 2040 was a time of range expansion and/or range shifts. Important species are often available for longer, creating opportunities for discussions about extending fishing seasons. These changes seldom take fishermen and fisheries managers by surprise—fish movements are broadly predictable using enhanced data and modeling, and fleets have been able to reach the changing locations of stocks. Large purse seine vessels targeting CPS have been able to move with the stocks, and port infrastructure has been able to develop in northern areas to continue to support the industry. Place-based tribal fisheries see winners and losers.

Coastal pelagic species

Under the Fortune and Favor scenario, CPS overall harvest amounts will be somewhat higher than today, including higher Pacific sardine availability. While all CPS fishing vessels will have to adapt to fishing and landing in more northerly waters, the low trophic level species that CPS prey upon will be abundant under the Fortune and Favor scenario.

In a scenario of slowly warming temperatures, steady or increasing primary productivity, and fewer anomalous climate events, the Pacific sardine stock will thrive and grow as it expands northward and experiences less dramatic interannual climate variability. We might expect to see the southern stock that is thought to be centered off central Baja increasing its presence in the U.S. EEZ. The purse seine fleet can capitalize on flexibility to operate in more northerly waters and may experience more frequent years of higher catches.

Market squid *will become less available off Southern California, but populations will remain relatively steady north of Point Conception. La Niña years will see modest expansions in available harvest, although without the larger booms available under scenarios with greater climate variability. Squid markets will expand as consumers become more educated about the sustainability of squid fisheries, creating higher demand and higher prices.*

The ***northern anchovy*** *stock will also migrate north with the changing water temperatures and will stabilize at a relatively low but sustainable biomass under the Fortune and Favor scenario. The northern subpopulation will benefit particularly from increased upwelling in the northern CCE. Anchovy will be taken in small amounts as incidental catch in fisheries targeting other species, but will not command much fishery or market attention.*

Highly migratory species

For highly migratory species, the Fortune and Favor scenario will be most similar to our current environmental conditions, although technological improvements will allow fishermen improved harvest of highly migratory species with lower protected species bycatch. The CCE will continue to provide attractive forage for HMS, and without significant increases in worldwide marine pollution, HMS will remain attractive to consumers.

In a Fortune and Favor scenario, North Pacific ***albacore*** *populations would slowly increase as forage for juvenile albacore increases. With the increased forage under a Fortune and Favor scenario, albacore may spend more time in the CCE even if their basin-wide range contracts in response to large-scale changes in sea surface temperature. Albacore will continue to be a desirable food fish and difficult to replace with farmed fish or engineered protein. Recreational fisheries will continue to target albacore and recreational fishing opportunities for albacore will increase in more northerly ports.*

Under a Fortune and Favor scenario, the Eastern Pacific ***sword-***

fish *stock will stabilize and may increase, spurring innovation in gear and methods for harvesting swordfish with low protected species bycatch. Swordfish harvest in the CCE may increase as the species expands its range northward. Recreational fishing opportunities for swordfish will increase, but swordfish will continue to be mainly attractive as a species targeted in offshore adventure angling trips.*

Attention to habitat restoration will allow estuarine and marine habitats to thrive.

Bluefin tuna *are likely more vulnerable to the effects of climate change than albacore or swordfish, but are also distributed across the Pacific basin. They are more likely to be affected by shifts in temperatures in their spawning areas in the pelagic Pacific west of the CCE. Under a Fortune and Favor scenario, bluefin are likely to persist within the CCE, possibly expanding their range northward. Bluefin allocation between commercial and recreational fisheries may become more challenging as this species expands its range within the CCE.*

Groundfish

For groundfish species and fisheries, the Fortune and Favor scenario will be most similar to our current environmental conditions. Technological advances will most aid the groundfish industry in marketing and distribution, supporting growing public interest in eating healthy wild-caught seafood. More attention to habitat restoration will allow estuarine and marine habitats to thrive, improving conditions for groundfish species that use nearshore areas for nurseries.

In a Fortune and Favor scenario with higher primary productivity and relatively less climate variability, ***sablefish*** *recruitment may stabilize in response to greater prey availability for juveniles, allowing the stock to remain relatively stable despite unusual shifts in the current patterns that drive their distribution. By 2040, adult sablefish may begin shifting to deeper habitats under this scenario. Body size of adult sablefish may also decrease over time, requiring us to re-think our assumptions about annual harvest levels in pounds of fish in relation to population numbers. Sablefish aquaculture will likely continue to create market competition for wild fisheries, although less so under this scenario than others.*

Pacific whiting *abundance in a Fortune and Favor scenario*

may fluctuate as much as it has in recent decades, a familiar situation for fisheries managers and participants. As the ocean slowly warms, however, the center of the Pacific whiting stock's distribution may shift northward. Depending on how far northward the stock moves, the U.S. and Canada may need to renegotiate the whiting annual catch allocation between the two countries.

The recent decline of kelp forests may prove a useful stress test for nearshore rockfish populations to assess how those populations might fare under climate scenarios that deplete kelp forests. In a Fortune and Favor scenario, kelp forests may rebound to the benefit of a host of nearshore fish species, including ***black rockfish****.*

Canary rockfish *may be more vulnerable to the potential effects of climate change at their juvenile life stages, but will benefit from the higher primary productivity of a Fortune and Favor scenario. Like many rockfish species, the canary rockfish stock's productivity varies wildly from year to year, with different combinations of ocean temperature, upwelling timing, and primary productivity thought to affect rockfish productivity. The relatively low climate variability in a Fortune and Favor world may negatively affect rockfish productivity if dramatic interannual climate shifts are needed to spur highly productive rockfish years. Canary rockfish fisheries will stabilize over time as fisheries become increasingly able to access mid-water rockfish stocks, and West Coast rockfish becomes better known on seafood menus.*

Salmon

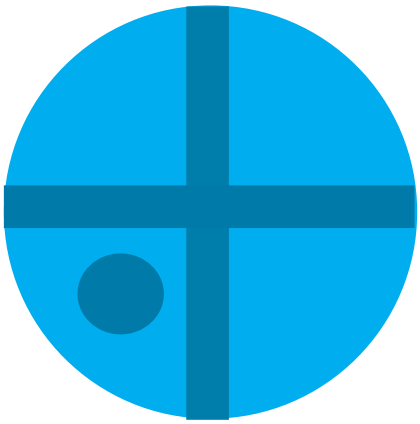
For salmon stocks, the Fortune and Favor scenario will be most similar to our current conditions, although with more consistently and reliably favorable ocean productivity. The CCE will continue to provide attractive forage for salmon and other higher-order predators, and reduced worldwide marine pollution will improve both freshwater and ocean habitat.

The ***Central Valley Fall Chinook Stock Complex*** *consists of primarily hatchery-based populations with vulnerable wild components. Humans have heavily engineered the Central Valley River system, but there are steady improvements in fish passage in the Central Valley under a Fortune and Favor scenario. Fishery and river management in a Fortune and Favor scenario includes managing river flow as much as possible to keep rivers cool, although the estuaries and ocean will experience some warming. Improved hatchery infrastructure and broodstock availability will also benefit this stock complex under this scenario.*

Southern Oregon/Northern California Coastal Coho *are more affected by stream and estuarine conditions than by ocean conditions. This stock is already near the southern end of coho's geographic range, thus will be vulnerable to warming river and ocean temperatures; however, the emphasis of river management on maintaining stream temperatures to support salmonids under the Fortune and Favor scenario will also benefit this stock during the freshwater life stage. A Fortune and Favor scenario includes precipitation levels similar to those experienced in 2020, which will also support this stock during its freshwater life stages. The 2021 removal of Klamath River dams will improve terrestrial and riverine habitat enough that this stock is able to survive at roughly similar to or modestly improved levels from 2020 under a Fortune and Favor scenario.*

Lower Columbia River Fall Chinook *are ocean-maturing and are most vulnerable to rising stream temperatures, particularly*

during their fall spawning return periods. Under a Fortune and Favor scenario, improved management focus on maintaining stream temperatures to support salmonids will be vital for this stock. Relatively stable precipitation patterns, with more snowpack in this scenario than in others, will help keep stream temperatures cooler for this stock, but rising ocean temperatures and intermittent years of unreliable upwelling will be challenging for this stock. However, the years with stronger upwelling will trigger more abundant forage for this stock and its more ocean-oriented life history will help it survive ecosystem fluctuations. By 2030, however, West Coast salmonid management will be made even more complex by efforts to supplement Southern Resident killer whale diets with more hatchery Chinook from the Columbia and other northern rivers.



A Scenario for 2040: Blue Revolution

Low climate/ocean variability, stock availability decreases

Similar to the Fortune and Favor scenario, in Blue Revolution the climate warms but is less variable year to year. Many familiar stocks decline but new subtropical and tropical species appear in the southern CCE. Although new fishing opportunities arise, the growth in alternative ocean uses puts pressure on many commercial fisheries. An open and globalized economy is looking for inexpensive ways to supply protein, and wild-caught fish struggle to meet those needs. Industry players don't suddenly go bankrupt, but interest in commercial fisheries gradually falls away as stocks decline and ocean use competition intensifies. Fish are still valued in this scenario, but in different ways.

Like Fortune and Favor, this is a world of gradual ocean warming. The climate warms, but is less variable year to year. familiar stocks decline, but new subtropical stocks appear. Fish are valued in different ways.

Physical drivers

In Blue Revolution the same set of physical drivers are affecting the CCE as those described above for Fortune and Favor, although the way in which the ecosystem has responded is different.

Warming has been gradual and at the low end of current global warming projections. Inter-annual variability in ocean temperature is relatively low compared to the Hollowed Out and Box of Chocolates scenarios. Likewise, marine heatwaves and swings between El Niño and La Niña conditions are also less intense and frequent, compared to the Hollowed Out and Box of Chocolates scenarios. But ocean temperature variations diverge from a higher mean than today.

Compared to 2020, already modest upwelling in the southern CCE fur-

With strong public support and policies focused on reducing carbon emissions, extensive offshore energy facilities are installed. Technological and regulatory innovations encourage the rapid development of inshore and offshore aquaculture.

ther relaxes while strengthening in the northern CCE, resulting in persistent seasonal hypoxic (low oxygen) conditions in nearshore benthic areas in the northern CCE but are less widespread in the southern CCE. Changes in upwelling strength are mostly noticeable from decade to decade, but less obvious from year to year.

Terrestrial climate impacts have not been as dire as predicted back in 2020. While West Coast droughts have occurred, their severity and duration has been limited. On average, precipitation levels in the Sierras have remained consistent over time, although a greater percent of that precipitation is falling as rain. Annual snow accumulation levels are not significantly lower in 2040 than they were in 2020. Occasional cooler and wetter years (La Niña years) improve river flow and conditions for salmon.

Extreme winter storms, and rough weather generally, are much less frequent as winds weaken overall.

Policy, market, and technological conditions

The deep economic difficulties of the early 2020s prompted a coordinated response from the G-20—the governments of the world's largest economies. The challenge was to revive prosperity while also dealing with growing climate concerns and the threat of international hostilities. The result was a significant investment in various technologies (e.g. biotech, alternative energy, data science) and commitment to a more open, market-based global trading regime. There is support for multilateral institutions (including bilateral and regional fishery management arrangements) to solve global environmental problems.

Throughout the 2030s, public sentiment (and public policy) became focused on reducing carbon emissions as climate crises became more apparent around the world. This led to a number of developments with direct and indirect consequences for the fishing industry.

First, national and regional policies provided incentives for the extensive deployment of offshore energy platforms using wind, currents, and the thermal properties of ocean waters. Large installations were built as far as 20 miles offshore, capitalizing on new technologies and less stormy conditions. Second, technological and regulatory innovations encouraged the rapid development of inshore and offshore aquaculture. Driven by environmental concerns, public tastes and values have moved away

from the consumption of animal-based protein. By 2040, seafood and plant-based proteins are the main beneficiaries of this shift in demand.

While aquaculture has put more competitive pressure on large scale commercial fisheries, in 2040 small, boutique operations are still appealing in an "ocean to market" setting. Fishing communities retain some of their character, helped by investments in and maintenance of coastal infrastructure, supported by Federal spending and the needs of new ocean industries. Experience in the 2020s conclusively demonstrates that knowledge work is no longer tethered to the office, so many well-compensated workers move out of urban areas, including to rural coastal communities. This is facilitated by large public and private investments in rural broadband access. While lifestyles in coastal communities don't collapse, commercial fisheries have shifted fundamentally towards a more symbolic role (such as offering demonstration tours). The few remaining large-scale fisheries have shifted to offshore processing and/or consolidated inland operations, because of competition for shorefront property.

Commercially important species become less abundant.

After declining throughout the 2020s, fishing as a form of recreation regained popularity, contributing to growth coastwide. While actual recreational catch is much lower in 2040, the experience is highly valued. Recreational fishermen also see more benefit when fish congregate around new energy installations.

The growing influence of aquaculture led to efforts to amend the Magnuson-Stevens Act to make fishery management councils responsible for regulating aquaculture activities in Federal waters. Additionally, relations between new ocean users and remaining commercial fishermen became fraught because of conflicts over space. The increasing competition for ocean space creates increasing administrative burden for the Council as it is drawn into regional ocean management projects and processes.

Ecosystem response

In the Blue Revolution scenario, by 2040 harmful algal blooms are more frequent compared to the early 2020s. Although the evidence is not definitive, many believe that harmful algal blooms have gotten worse due to waste generated by intensive inshore aquaculture operations combined with warmer ocean temperatures. In this scenario the ecosystem has become less productive over time, which may be a result of the effects of more acidic ocean water affecting lower trophic levels (plankton, forage) in the CCE food web.

Marine mammal populations mostly decline. Due to successful international efforts (nesting beach protections, fishery bycatch mitigation), sea turtle populations stabilize and sea turtles are frequently seen in the central CCE.

Commercially important species like sablefish become much less abundant; others like hake and sardine establish very different, more northward distributions, making them less available in the West Coast EEZ. Formerly infrequently-seen species, like skipjack tuna, regularly occur as far north as San Francisco, but not in quantities that can support large-scale commercial fisheries. Fishery managers are forced to address increased range compression of some targeted species and co-occurring protected species, especially around offshore facilities.

Coastal pelagic species

Under the Blue Revolution scenario, CPS stocks will move northward and fishing operations will adapt to fishing and landing in more northerly waters. Forage for CPS will decline under this scenario, reducing CPS population sizes in turn.

Some CPS harvest under the Blue Revolution scenario may shift from marketing for human consumption to marketing to provide feed for West Coast aquaculture operations for higher-order predators, although it faces stiff competition from plant-based feeds.

Successful bluefin tuna ranching competes with boutique fisheries for this high value fish.

Under the Blue Revolution scenario of warming temperatures, declining primary productivity and fewer anomalous climate events, the ***Pacific sardine*** *stock will decline in association with decreased prey availability. Sardine stocks will move northward, but their onshore/offshore distribution will be less variable from year to year. The purse seine fleet may need flexibility to operate in more northerly waters and may experience lower catch-per-unit-of-effort (CPUE) as sardine become relatively less aggregated.*

Market squid *will become less available off Southern California, with populations moving north of Point Conception. Under the Blue Revolution scenario, market squid populations will contract and the lower climate variability combined with low productivity will mean that the squid population will benefit less from La Niña years than in the past.*

The ***Northern anchovy*** *stock's central subpopulation will migrate north with the changing water temperatures, and the northern subpopulation will expand as the sardine stock contracts. Fishing for anchovy will become more profitable as the industry focuses on providing feed for West Coast aquaculture operations.*

Highly migratory species

For HMS, environmental conditions under the Blue Revolution scenario are more challenging than today, but are not significant enough to frustrate flexible fishermen. However, the greater success of the offshore aquaculture industry in the Blue Revolution scenario means more competition for HMS fishing operations and more opportunities for vessels that target species HMS prey upon.

In the Blue Revolution scenario, the North Pacific ***albacore*** *population slowly declines as forage for juvenile albacore declines. Their ocean-wide range contracts in response to*

large-scale changes in sea surface temperature. Predicting the location of albacore available within the CCE becomes a more difficult challenge. Aquaculture has only a partial impact on albacore, as it remains a desirable food fish and proves difficult to replace with farmed fish. Albacore becomes less attractive to recreational anglers as they move further offshore than usual, and thus less subject to allocation challenges between commercial and recreational fisheries.

The Eastern Pacific ***swordfish*** *stock declines under the Blue Revolution scenario, but new technology may offer opportunities to harvest with low bycatch rates. Swordfish harvest in the CCE remains steady as the species expands its range northward. As with albacore, swordfish allocation between commercial and recreational fisheries may be less of an issue than more nearshore species.*

Under the Blue Revolution scenario, ***bluefin tuna*** *are affected by shifts in temperatures in their spawning areas in the pelagic Pacific west of the CCE. Bluefin will likely persist within the CCE, possibly expanding their range northward. Off Southern California, bluefin tuna ranches compete with fishing boats for space and with the fishing industry for markets. As with alba-*

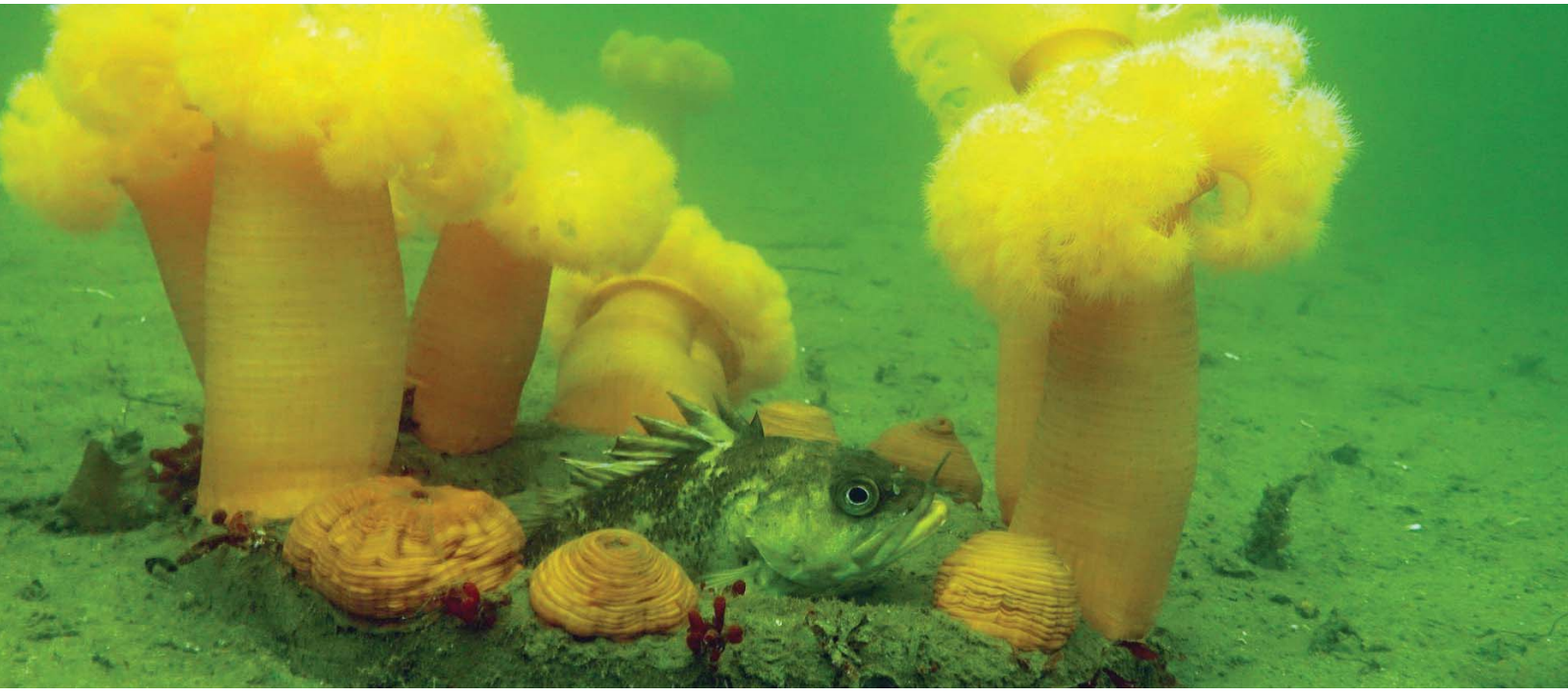
core, bluefin tuna allocation between commercial and recreational fisheries may be less of an issue than more nearshore species.

Groundfish

For groundfish species and fisheries, environmental conditions under the Blue Revolution scenario are more challenging than today. The greater success of the offshore aquaculture industry in the Blue Revolution scenario means more competition for groundfish fishing operations and more frustrating competition for ocean space, particularly for vessels that operate closer to shore.

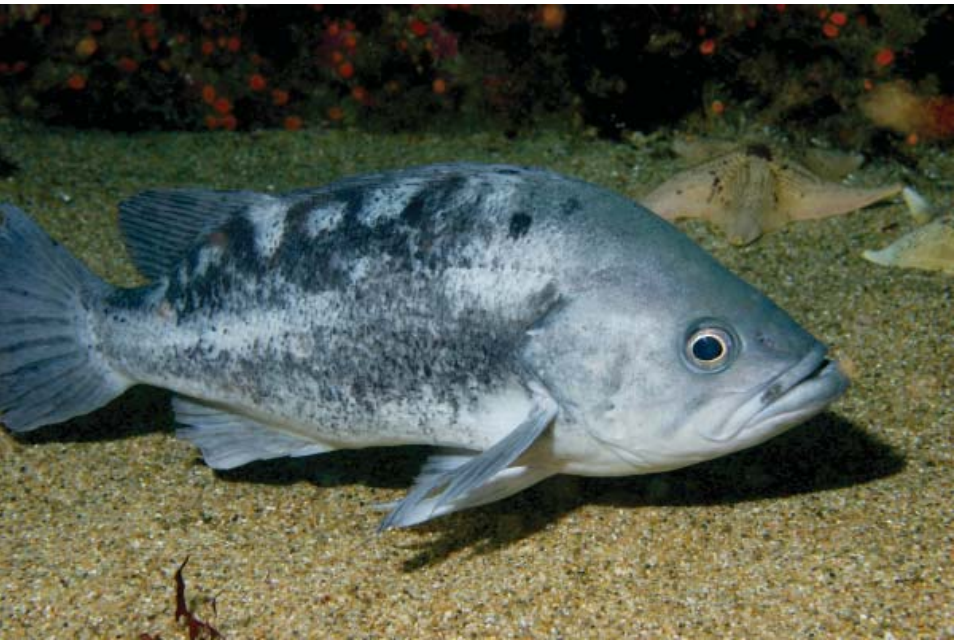
In a Blue Revolution scenario with lower primary productivity and relatively less climate variability, ***sablefish*** *recruitment declines in response to lowered prey availability for juveniles. Sablefish fisheries are particularly affected by the Blue Revolution scenario's increasing aquaculture efforts. Sablefish are subject to aquaculture research and production in 2020, and their high market value ensures that cultured fish seized ever greater market shares by 2040. Wild fisheries will see increasing market competition, including from countries with lower labor costs, and may need more management and technological flexibility to time landings and sales.*

Pacific whiting *abundance under a Blue Revolution scenario fluctuates as much as it has in recent decades, a familiar situation for fisheries managers and participants. As the ocean*



slowly warms, however, the center of the Pacific whiting stock's distribution shifts northward, leading to pressures for the U.S. and Canada to renegotiate the whiting annual catch allocation. Pacific whiting processors become increasingly interested in marketing whiting products as aquaculture feed.

In a Blue Revolution scenario, ***black rockfish*** *may become locally depleted, and may be subject to increasing fishing pressure from recreational fisheries. Fisheries managers will need to continually seek out new and more accurate catch data collection methods to prevent localized populations of black rockfish from crashing. As commercially-caught wild fish sees increasing competition from cultured fish products, black rockfish becomes a less popular commercial fisheries target.*



Canary rockfish *may be more vulnerable to the potential effects of climate change at their juvenile life stages, and the stock will be challenged by the lower primary productivity of the Blue Revolution scenario. Like many rockfish species, the canary rockfish stock's productivity varies wildly from year to year, with different combinations of ocean temperature, upwelling timing, and primary productivity thought to affect rockfish productivity. The relatively low climate variability in a Blue Revolution scenario may also negatively affect rockfish productivity if dramatic interannual climate shifts are needed to spur highly productive rockfish years. The canary rockfish stock may stay low but stable and allocations between commercial and recreational fisheries may become challenging as recreational and niche commercial fisheries grow.*

Salmon

For salmon stocks, the Blue Revolution scenario will offer more challenging conditions for wild salmonids, but improved hatchery practices and technology will benefit hatchery stocks. The

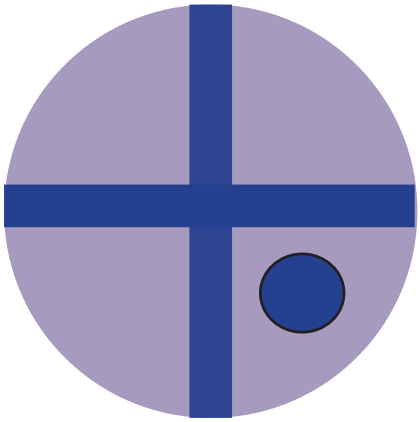
Blue Revolution scenario will challenge commercial salmon fishermen with even more competition from cultured salmon in seafood marketing channels. Ocean productivity is lower under this scenario, although more consistent from year to year. The general decline in marine mammal stocks, including pinnipeds, will modestly reduce ocean predation on salmonids.

The ***Central Valley Fall Chinook Stock Complex*** *consists of primarily hatchery-based populations with vulnerable wild components. The heavily engineered Central Valley River system sees some fish passage restoration in a Blue Revolution scenario, but large-scale habitat improvements in the Central Valley are unlikely. This stock complex's resilience is threatened by warmer estuarine and ocean temperatures, but will be strengthened in a Blue Revolution scenario with improved hatchery infrastructure and broodstock availability. This stock complex will benefit somewhat from years with greater snowpack, but by 2030 will face slowly worsening ocean productivity and increasing sea surface temperatures.*

Southern Oregon/ Northern California Coastal Coho *are more affected by stream and estuarine conditions than by ocean conditions. This stock is already near the southern end of coho's geographic range, thus will be vulnerable to warming river and ocean temperatures, and to the relatively low ocean productivity in this scenario. A Blue Revolution scenario includes precipitation levels similar to those we experience in 2020, but more of that precipitation is falling as rain rather than snow, which is challenging for this stock during its freshwater life stages. Depressed Federal and state budgets delay the 2021 removal of Klamath River dams until 2027, further challenging this stock's resilience over the near term.*

Lower Columbia River Fall Chinook *are ocean-maturing and*

are most vulnerable to rising stream temperatures, particularly during their fall spawning return periods. A Blue Revolution scenario will be challenging for this stock. Warmer fall stream temperatures may delay their arrival to spawning grounds and the later-fall spawning variant, brights, may make up ever greater percentages of the stock. Slowly warming sea surface temperatures and lower ocean productivity will mean less abundant forage for this stock. Terrestrial habitat restoration under a Blue Revolution scenario will be most helpful to this stock if that work focuses on improving estuary habitat and on near-coastal barriers to fish passage.



A Scenario for 2040: Hollowed Out

High climate/ocean variability, stock availability decreases

This scenario creates extreme and sometimes insurmountable challenges for the fishing industry. Ocean acidification, deoxygenation, and shifts in decadal oceanographic processes lead to a fundamental reorganization of the CCE food web. Only a few stocks remain at harvestable levels and commercial fisheries suffer—a few firms opportunistically engage in commodity fisheries while small, part-time operations deliver local, boutique products. Extreme storms and rising tides create regular and damaging inundations. Interest in recreational fishing continues on a long-term decline.

Physical drivers

Warming is at the high end of current global warming projections. Ocean temperature records are set across the entire CCE and nearshore waters are particularly affected. There is lots of variability from year to year, driven by the intensification of periodic and cyclical climate phenomena. Marine heatwaves, sometimes coinciding with large magnitude El Niño events, are persistent. The magnitude and frequency of swings between El Niño and La Niña conditions are much greater than at present. The North Pacific Gyre current system shifts northward. The Pacific Decadal Oscillation signal is weaker, with very few cool periods and deviations from higher mean temperatures compared to present.

An unstable world produces unprecedented conditions and many fish stocks crash.

Upwelling strength and regional hypoxia events vary substantially year to year in both frequency and magnitude. Upwelling is weaker and less seasonally persistent throughout the CCE compared to current average conditions. Nutrient availability is often limited,

due to strong stratification from increasing temperatures, reducing the development of productive habitat. In many years, strong offshore winds disperse nutrient-rich water, reducing the development of productive habitat. Furthermore, during marine heatwaves upwelling habitat is compressed into the nearshore area.

Harmful algal blooms in coastal waters are chronic in Northern California and Southern Oregon, driving periodic fishery closures. Coastwide harmful algal blooms occur in some years.

More precipitation falls as rain except at very high elevations. In a few years, maximum snowpack depth comes within 90% of the present day historical average, but melts off more rapidly in most years and rarely lasts beyond midsummer. In the 2030s, California enters a period of prolonged drought with low to no snowpack. Coastwide, the intermittent relatively cooler and wetter years become ever more important to snowpack buildup and river flow volumes.

In some years strong winds and heavy seas are a constant in the winter and large storms regularly roll through. Freak weather events such as intense summer wind/rain squalls occur in the Southern CCE. Seasonal wind direction is less predictable.

Policy, market, and technological conditions

By 2040, the effects of economic downturns, climate change and marine pollution have become more and more apparent across the world. In many ways, the market for fishery products never really recovered from the economic shocks of the early 2020s. More generally, people worry about species extinction and basic ecosystem services, and they put wmore emphasis on protected species and alternative protein sources like algae, hemp, and laboratory-grown "meat." Commercial fishing is seen as an unsustainable way of obtaining protein. As fisheries decline, a smaller portion of government budgets is devoted to science and management.

There is strong public support for broad protections of ocean space and most commercial fishermen cannot see the benefits of staying in the game.

With supply lacking, wild caught fish has become a high-priced delicacy that only a few rich people can take advantage of. In a world of polluted oceans, wild caught fish need rigorous quality control, or catches from pristine, less-polluted locations.

A large segment of the population now opposes killing animals for food, and public awareness campaigns periodically dampen broad demand for seafood in the U.S. while related trade barriers choke off exports. In 2040, there is strong public support for broad protections of ocean space in reaction to visible degradation of the terrestrial environment.

Most commercial fishermen could not see the benefits of staying in the game given public attitudes, bad fishing conditions, and limited opportunity to catch financially viable amounts of fish. Few are willing to replace those retiring from fisheries. In response, public support of long-term subsidy programs to sustain fisheries and fishing communities grows. With international trade restricted, domestic food security is an underlying rationale voiced by proponents. Only those with the deepest pockets and the deepest convictions survived. By 2040, a few large firms involved in commodity production remain, along with artisanal operations supplying local markets. But these small, fragmented artisanal operations are ill-equipped to influence the policy debate about public support. Recreational fishing still exists, although participation continues its long-term, declining trend.

Coastal infrastructure suffered, thanks to sea level rise, coastal inundation, and storms, further limiting public exposure and access to seafood and the ocean. Funding for public infrastructure maintenance and adaptation has been limited and directed to essential facilities and urban areas. Rural fishing and coastal areas were not considered national priorities and declined economically and socially in fits and starts. Some

rural fishing communities were thus abandoned; others adapted and refocused to cater to a public that now sees the coast and ocean as a last wild space for nature appreciation. Remaining fishing firms consolidated and located in a few ports that were maintained primarily for other purposes such as shipping, tourism, or urban waterfront. These locations invest heavily in fortifications against damaging storms.

Streams and rivers dry up or are subject to such high fluctation that salmon runs are permanently lost.

Even aquaculture has suffered in such difficult conditions. Coastal areas that might have hosted fish farming were seen as too polluted to support the production of healthy foods. Existing facilities were further hurt by storms. Policies generally discourage or block the development of marine aquaculture. Some land-based, closed-cycle aquaculture of marine species survives to supply the remaining high-end seafood market.

Ecosystem response

The CCE has been rocked by a series of "ecological surprises" including the unexpected effects of ocean acidification on primary productivity. Other surprises resulted from unexpected shifts in the occurrence and availability of previously unexploited species like shortbelly rockfish, pyrosomes, and pelagic red crabs, sometimes resulting in large bycatch events. A very warm ocean marked by extreme swings in physical drivers results in an overall decline in productivity. Productive areas become extremely compressed and spawning habitat is lost. Traditional fishing grounds move, some are lost, and patchiness grows.

Harmful algal blooms in coastal waters are chronic in Northern California and Southern Oregon, driving periodic fishery closures. Coastwide harmful algal blooms occur in some years.

Marine mammal populations decline, with some species disappearing from the CCE entirely. The population of leatherback sea turtles foraging in the CCE has gone extinct while the rebound in the loggerhead sea turtle population has been checked.

For the majority of managed stocks, recruitment and productivity is low compared to current averages, with only occasional spikes. Overall, all or most key stocks become less abundant; some remain intractably depleted while others seem to disappear for a time and then reappear for a year or two in harvestable quantities, but overall there is less to catch in the water. Some species suffer population changes such as smaller maximum body size, making them less profitable to catch.

Streams and rivers dry up or are subject to such high fluctuation that

salmon runs are permanently lost, especially in California and Oregon, and 2020s ESA-listed species are now extinct.

Some of the few newly-seen species outcompete previously valued target species. The food web becomes more top down, with a few dominant predators. Some of these new species provide windows of opportunity as markets and consumer attitudes change; for example, at the other end of the food chain, harvesting periodic jellyfish blooms becomes modestly profitable, and environmentally-conscious consumers choose to eat "low on the food chain," paradoxically increasing demand for lower trophic level species at the same time that predation pressures have increased.

Coastal pelagic species

Under the Hollowed Out scenario, CPS products will become gourmet products for foodies interested in eating lower on the food chain. CPS stocks will move even farther northward than under other scenarios, and small pelagic species formerly taken off the Baja Peninsula will enter southern U.S. waters. Forage for CPS will decline under the Hollowed Out scenario, reducing CPS population sizes to record low levels.

In a scenario of warming temperatures, variable and decreasing primary productivity, and more frequent and dramatic anomalous climate events, the ***Pacific sardine*** *stock will diminish and expand northward. The combined effects of climate warming, increased climate variability, and decreased primary productivity will reduce available harvest for the stock and will*

make fishing more challenging. The purse seine fleet may capitalize on their flexibility to operate in more northerly waters, and will see dramatic shifts in the sardine stock location from year to year.

A Hollowed Out scenario would see occasional spikes in ***squid*** *population during La Niña years, although ocean acidification will diminish the populations of small crustaceans that serve as their prey base. Squid in a Hollowed Out scenario will need to find new sandy habitat in cooler water for their population to remain viable over the long term. By 2040, market squid will primarily flourish in waters off British Columbia.*

As forage declines, coastal pelagic species populations fall to record low levels. Sardine and anchovy are no longer used as bait; they become gourmet products for foodies.

The central subpopulation of the ***northern anchovy*** *stock will also migrate north with the changing water temperatures, but ocean productivity is so low that anchovy's northern subpopulation will not expand. Overall, northern anchovy will be less available to fisheries and predators under a Hollowed Out scenario.*

Highly migratory species

For highly migratory species, the Hollowed Out scenario will be challenging in a variety of ways. Consumer demand for HMS products will drop significantly, allowing many stocks to grow despite declining forage. Fishing vessels operating in the CCE will have difficulty tracking HMS migration patterns from year to year, and the fishing industry will suffer from persistent market indifference to HMS products.

North Pacific albacore *populations would slowly decline as forage for juvenile albacore declines and as their range contracts in response to large-scale changes in sea surface temperature. With decreased forage, albacore will still spend time in the CCE as its range expands, although the center of albacore landings will shift north and overall catch will decline. Although there will be calls from fishermen to revisit the U.S.-Canada Albacore Treaty, the persistence of the stock within the CCE will be low enough that incentives to renegotiate will be low. With increased worldwide pollution, public fears over mercury in HMS flesh will drive down demand for albacore. For both commercial and recreational fisheries, albacore harvest will go to those vessels that are best able to make longer-range*

trips offshore.

The Eastern Pacific ***swordfish*** *stock under a Hollowed Out scenario would stabilize, and may increase due to lower demand for HMS products. Although swordfish may become more abundant within the CCE as the stock moves northward along the West Coast of North America, swordfish distribution will be less consistent and predictable from year to year, lowering CPUE. As with albacore, public demand for swordfish products will decline as fears of mercury in HMS products grow.*

Under a Hollowed Out scenario, ***bluefin tuna*** *are likely to persist within the CCE and expand their range northward. Worldwide declining interest in seafood, combined with public aversion to HMS products, has particularly reduced public demand for bluefin tuna as sushi. Worldwide populations of bluefin tuna begin to rise in response to declining human consumption, although adult tuna body size decreases as tunas spend more time and energy searching for prey.*

Groundfish

For groundfish species and fisheries, the environmental conditions of the Hollowed Out scenario are extraordinarily challenging, particularly to the status of stocks of longer-lived species. Species with nearshore habitat are particularly stressed by the many harmful effects of land-based activities on

estuarine and marine habitat. Groundfish fisheries that operate farther offshore are one of the few bright spots in West Coast fisheries management, particularly those that can produce more upscale products like fillets, rather than meal and oil. Groundfish stock complex assessments become more desirable for managing multi-species groups of groundfish.

Black rockfish will be thought of as a delicacy harvested from the less polluted ocean areas

In a Hollowed Out scenario, with lower primary productivity and greater climate variability, ***sablefish*** *recruitment may decline in response to lowered prey availability for juveniles and may be negatively affected by unusual shifts in the current patterns that drive their distribution. Adult sablefish may shift to deeper habitats by 2030, with a portion of the stock becoming less available to the trawl fisheries. Available harvest levels will vary more dramatically under increased climate variability, and total population abundance will depend heavily on a few "good" year classes. Although competition from sablefish aquaculture is less likely in a Hollowed Out scenario, culturists who are able to grow sablefish to market size without using ocean net pens will have significant competitive advantage over fishermen.*

Pacific whiting *have a low vulnerability to climate change, but the stock is highly mobile. In a Hollowed Out scenario, Pacific whiting abundance may fluctuate as much as it has in recent decades, a familiar situation for fisheries managers and participants. As coastwide salmon stocks plummet, Chinook bycatch in the whiting fisheries becomes more controversial and more challenging to address. The center of the Pacific whiting stock's distribution will shift farthest northward under this scenario and will fluctuate dramatically from year to year. The stock's summer migrations to northern and cooler waters will regularly take the stock into waters off Southeast Alaska. Exploratory whiting fisheries off Alaska will force the renegotiation of the U.S.-Canada Whiting Treaty, ultimately flipping the distribution of the stock's Total Allowable Catch to Canada's benefit, while also making Alaska-based stakeholders permanent participants in annual catch setting processes.*

Black rockfish *associate with nearshore kelp forests and rocky reefs, making them vulnerable to shifts in the health of kelp forests. In a Hollowed Out scenario, fishing for black rockfish will remain popular for anglers interested in safari-type trips to*

less populated parts of the coast. For people who are still eating meat in the Hollowed Out scenario, rockfish will be thought of as a delicacy harvested from the less polluted areas of the ocean. As with other scenarios, black rockfish will be subject to localized depletion, particularly in areas where primary productivity has most strongly declined in response to increasing temperatures, ocean acidification, and marine pollution.

While the greater climate variability of a Hollowed Out scenario may spur occasional large ***canary rockfish*** *year classes, warmer temperatures and a reduced prey base may either force canary rockfish to migrate to cooler waters and may result in slower growth rates as they spend more energy foraging. Juvenile rockfish will continue to serve as forage for higher order predators and the stability of the canary rockfish stock in a warmer and lower productivity scenario may be threatened by that heavy predation. While rockfish will become a delicacy for fish eaters, finding and catching canary rockfish will be more challenging in a Hollowed Out scenario.*

Salmon

The Hollowed Out scenario is devastating for salmonids coastwide. Although declines in populations of higher order predators, such as pinnipeds and birds, have significantly reduced predation on salmonids at all life stages, the combined poor freshwater and poor ocean productivity cause many stocks to wink out and remaining stocks are at low abundance.

*The **Central Valley Fall Chinook Stock Complex** is composed of primarily hatchery-based populations with vulnerable wild components. Under a Hollowed Out scenario, the wild components of this stock complex have gone extinct and the hatchery populations support a small and exclusive recreational fishery. Ocean productivity is so poor under this scenario that this stock complex has no resilience to withstand the lack of improvements to its freshwater habitat. Just maintaining hatchery stocks will become challenging by 2040 under the Hollowed Out scenario, as rivers become ever drier in the summer and as questions about whether to provide water to farms or rivers become moot.*

***Southern Oregon /Northern California Coastal Coho** are more affected by stream and estuarine conditions than by ocean conditions, but ocean temperatures and productivity under the Hollowed Out scenario are dire enough to negatively affect this stock. By 2030, this stock will have declined under this scenario to the point where it is listed as endangered, rather than threatened, under the Endangered Species Act. Under the Hollowed Out scenario, this stock will become extirpated from most of its historic range, with a few remaining fish regularly returning to the Elk River in Oregon.*

***Lower Columbia River Fall Chinook** are ocean-maturing and are most vulnerable to rising stream temperatures, particularly during their fall spawning return periods. The warming ocean and stream temperatures under a Hollowed Out scenario will be challenging for this stock. Shifts in precipitation patterns to rain over snow will decrease winter snowpack, ultimately leaving spring rivers warmer and drier. The overall abundance of salmonids in this river system will depend more and more on fall returning stocks like this stock; however, warmer spring temperatures will challenge the survival of this stock's younger life stages. Slowly warming sea surface temperatures and lower ocean productivity will mean less abundant forage for this stock. Political will and funds to improve freshwater habitat remain weak under the Hollowed Out scenario, driving this stock to conditions experienced by more southern Chinook in 2020.*

A Scenario for 2040: Box of Chocolates

High climate / ocean variability, stock availability increases

This is a scenario of environmental surprises and extremes—but where, on average year to year, the abundance and availability of exploited species is at or near historical levels. Fishermen see "boom and bust" cycles for some key stocks. Species infrequently seen before on fishing grounds periodically appear in catchable amounts, while other species dwindle. New technology is deployed to better monitor the environment, predict environmental conditions, and exploit resources. Seafood marketing becomes more difficult because of the high variability in availability.

Physical drivers

In Box of Chocolates the same set of physical drivers are affecting the CCE as those described above for Hollowed Out, although the way in which the ecosystem has responded is different.

Warming is at the high end of current global warming projections. Ocean temperature records are set across the entire CCE and nearshore waters are particularly affected. There is lots of variability from year to year driven by the intensification of periodic and cyclical climate phenomena. Marine heatwaves, sometimes coinciding with large magnitude El Niño events, are persistent. The magnitude (and frequency) of swings between El Niño and La Niña conditions are much greater than at present. The North Pacific Gyre current system shifts northward. The Pacific Decadal Oscillation signal is weaker with very few cool periods and deviations from higher mean temperatures compared to present.

Like Hollowed Out, this is a world of environmental surprises and extremes, but fish population are more productive, presenting novel opportunities.

Upwelling strength and regional hypoxia events vary substantially year to year in both frequency and magnitude. Upwelling is weaker and less seasonally persistent throughout the CCE compared to current average conditions. Nutrient availability is often limited, due to strong stratification from increasing temperatures, reducing the development of productive habitat. In many years, strong offshore winds disperse nutrient-rich water, reducing the development of productive habitat. Furthermore, during marine heatwaves upwelling habitat is compressed into the nearshore area.

Harmful algal blooms in coastal waters are chronic in Northern California and Southern Oregon, driving periodic fishery closures. Coastwide harmful algal blooms occur in some years.

More precipitation falls as rain except at very high elevations. In a few years, maximum snowpack depth comes within 90% of the present day historical average but melts off more rapidly in most years and rarely lasts beyond midsummer. In the 2030s California enters a period of prolonged drought with low to no snowpack. Coastwide, the intermittent relatively cooler and wetter years become ever more important to snowpack buildup and river flow volumes.

In some years strong winds and heavy seas are a constant in the winter, and large storms regularly roll through. Freak weather events such as intense summer wind/rain squalls occur in the Southern CCE. Seasonal wind direction is less predictable.

Policy, market, and technological conditions

This is a highly turbulent, unpredictable world that tests fishing operators and managers to their limits. Technology offers valuable assistance. Precise monitoring of environmental conditions and human activities has allowed improved prediction of environmental conditions, although accurately predicting stock abundance remains challenging for shorter-lived species. For example, technologies like the mechanized reading of otoliths (ear bones in fish used to determine their age) allows more frequent and accurate stock assessments for a wider range of species. A revolution in fishing technology has occurred, with new remote sensing platforms and gear innovation allowing fishermen to better capitalize on

the shifting availability of stocks.

However, in 2040 fishing operations are more capital-intensive, and new kinds of technological expertise, both in the fishing and processing realms, is required to compete. The latter has given an advantage to younger fishermen who are, on average, more adept and willing to use new technology. But they had to raise the capital to buy out existing rights holders and invest in technology. This intensified long-term trends in consolidation and vertical integration in many places.

Consumers want predictability, but this is a world where nothing stays the same for long.

The functional extinction of many wild salmon stocks in California, combined with the evolution of techniques that improve hatchery production and ocean survival (including the use of wide scale genetic modification), drove policy changes in both the ESA and Magnuson-Stevens Act. Dams were breached on the Klamath and Snake Rivers, improving prospects for some wild stocks. Wide-scale deployment of other alternative energy sources continued to drive debate about dam removal on the main stem of the Columbia River, counteracted by the need for water storage in the face of increasing drought frequency.

While the 2020s is a period of great power competition that roils international trade, by the mid 2030s the U.S. has recommitted to multilateralism and global trade. However, the U.S. negotiates trade agreements designed to mitigate the environmental and employment effects of a more open economy.

Consumers have become much more receptive to wild-caught fish for health and emotional reasons. However, processing and marketing the variability in the mix of species landed from year to year became a difficult task. Consumers (and hence buyers) want a degree of predictability, and yet this is a world where nothing stays the same for long, stressing markets. This regulatory environment and mix of incentives allows the expansion of marine aquaculture, but not on the scale seen in Blue Revolution, because ocean conditions make wide scale deployment challenging.

Some fisheries (albacore, swordfish, sablefish, salmon) focused on moving up the value chain through boutique fresh products and connections between harvesters and consumers. Commodity fisheries (hake, Pacific sardine, market squid) developed more sophisticated prepared products to increase margins. Innovation and consumer appreciation for wild caught fish has allowed for more successful exposure of new and underexploited species. The opportunity to catch species not previously

encountered off the West Coast, especially in the Southern California Bight, proves a boon to recreational fisheries.

Coastal infrastructure is more often damaged in winter storms, especially on Northern California and Oregon coasts. Some smaller ports effectively cease to function except where new ways of landing and processing seafood are pioneered. Small vessel artisanal fisheries survive, but larger vessels concentrate in a few ports. It remains unclear whether the infrastructure will be able to catch up to highly unpredictable conditions.

Ecosystem response

In the Box of Chocolates scenario, primary production (of plankton and forage species) is comparable to Fortune and Favor conditions in some years, but much more variable from year to year. Due to harmful algal blooms, fishermen that depended on the Dungeness crab fishery for much of their income shift their efforts into other state and Council-managed fisheries.

Many marine mammal stocks have recovered to pre-exploitation levels, but their occurrence on fishing grounds tends to be variable. The leatherback sea turtle population migrating into the CCE from the Western Pacific has stabilized and forages extensively in the Columbia River plume.

The ranges of many stocks shift northward and deeper, affecting their availability to West Coast fisheries. This is compounded by big changes in local abundance from year to year, especially for short-lived species. These big swings in abundance increase pressure for fishermen to move fluidly between fisheries, especially those that rely on similar gear types. Range shifts result in previously absent subtropical and tropical species being periodically abundant (or taking up residence) in Southern California.

Coastal pelagic species

CPS stocks under the Box of Chocolates scenario will notably fluctuate in their abundance and distribution, making fishing and marketing challenging. However, the stocks will benefit from the CCE's primary productivity, and population fluctuations will occur as a response to the highly variable climate conditions under this scenario. As under other scenarios, CPS stocks will move northward and fishing operations will have to follow.

The ranges of many stocks shift northward and deeper, affecting their availability to West Coast fisheries. This is compounded by big changes in local abundance from year to year, especially for short-lived species.

In a scenario of slowly warming temperatures, variable and increasing primary productivity and more frequent and dramatic anomalous climate events, the ***Pacific sardine*** *stock expands northward. Fishing for CPS will become more difficult, however, since stock distribution will vary more from year to year, and years of unusually high available harvest will be intermittent and difficult to predict.*

A Box of Chocolates scenario will be good for ***market squid****, particularly during La Niña years, when they will be abundant even in their southern habitat. Northern populations of squid will still flourish, and El Niño years will continue to be challenging for the market squid populations and fishery.*

The central subpopulation of the ***northern anchovy*** *stock will migrate northward with the changing water temperatures, and the northern subpopulation will fare well under the CCE's higher primary productivity. Although anchovy will not take the place of Pacific sardine in the ecosystem, the population will stabilize by 2040 and will supplement the role of sardine in the ecosystem.*

Highly migratory species

For highly migratory species, environmental conditions under a Box of Chocolates scenario will be variable enough to make fishing inconsistent from year to year. However, the fishing industry will prove more flexible and adaptable, using new fish tracking models and technology to take advantage of HMS populations migrating through the CCE. While a Box of Chocolates scenario provides some competition from tuna ranching, wild HMS stocks will remain abundant enough for persistent year-to-year harvest and HMS products will continue to be popular

with consumers.

In a Box of Chocolates scenario, North Pacific ***albacore*** *populations would slowly increase as forage for juvenile albacore increases. With the increased forage of a Box of Chocolates world, albacore may spend more time in the CCE, although the center of albacore landings will shift north and the highest catch will occur later in the year. Discussions around the U.S.-Canada Albacore Treaty will become heated over the shift in distribution. For both commercial and recreational fisheries, albacore harvest will go to those vessels that are best able to take advantage of new tuna tracking technologies and make longer-range trips offshore.*

The Eastern Pacific ***swordfish*** *stock in a Box of Chocolates scenario would stabilize and may increase, spurring innovation in gear and methods for harvesting swordfish with low protected species bycatch. Although swordfish will become more abundant within the CCE, swordfish distribution will be less consistent and predictable from year to year, lowering CPUE. As with albacore, swordfish harvest will go to the vessels that invest in new tuna tracking technologies and that are able to make trips farther offshore.*

Bluefin tuna *are likely to persist within the CCE and expand their range northward. Net pen grow-out operations appear in the Southern California Bight to take advantage of the persistent warm year-round ocean temperatures in that area. As with albacore and swordfish, bluefin allocation between com-*

mercial and recreational fisheries may be less of an issue than more nearshore species.

Groundfish

For groundfish species and fisheries, the Box of Chocolates scenario will be the most unpredictable, with unexpected benefits and losses. Allowable harvest and landings of particular species and species groups will fluctuate dramatically from year to year, requiring more flexibility from the fishing industry, managers, and scientists.

The center of the Pacific whiting stock's distribution may shift northward, but will also fluctuate from year to year, making negotiations with Canada challenging.

In a Box of Chocolates scenario with higher primary productivity and greater climate variability, ***sablefish*** *recruitment fluctuates, but a few large year classes stabilize the long-term outlook for the stock. For larger year classes, the Box of Chocolates scenario shows greater prey availability for juvenile sablefish, although also greater competition from other species also experiencing boom and bust years. By 2040, adult sablefish will expand their distribution to encompass their current habitat and much deeper habitats. Sablefish aquaculture will likely continue to create market competition for wild fisheries, although less so under this scenario than others.*

Pacific whiting have a low vulnerability to climate change, but the stock is highly mobile. In a Box of Chocolates scenario, ***Pacific whiting*** *abundance fluctuates as much as it has in recent decades, a familiar situation for fisheries managers and participants. The center of the Pacific whiting stock's distribution may shift northward, but will also fluctuate dramatically from year to year, making negotiations with Canada challenging. Salmon bycatch will become extraordinarily challenging for this fishery in 2026-2040, as wild salmon stocks dwindle and as new policies develop to address bycatch of hatchery-only salmon stocks. Whiting processing practices and technology will evolve to allow more of the harvest to be prepared and sold as fillets and other higher-end products.*

Black rockfish *associate with nearshore kelp forests and rocky reefs, making them vulnerable to shifts in the health of kelp*

forests. In a Box of Chocolates scenario, where fishing effort concentrates in a few ports along the coast, the overall black rockfish population may stabilize, but there will be localized depletion in areas close to the remaining fishing ports and localized abundance in rocky areas near less popular and accessible coastal areas. Black rockfish will remain popular with all fishery sectors, but will not experience the same rise in harvest as mid-water rockfish.

Greater climate variability in a Box of Chocolates scenario will ensure that the ***canary rockfish*** *stock experiences the oceanographic shifts it needs to generate occasional highly productive year classes. These large year classes will help stabilize and increase the populations of canary and other more pelagic rockfish populations over the long-term, if the Council applies the lessons it learned from the rockfish rebuilding period to better manage populations of long-lived and slow-growing species without the boom-and-bust fisheries of the mid-20th century.*

Salmon

Salmon stocks under the Box of Chocolates scenario will be challenged by dramatic climate variability, but will benefit from greater ocean productivity. This scenario is characterized by boom-and-bust cycles for most species, including salmonids. Salmon fishing will also be inconsistent from year to year, both in the abundance of salmonids and in their distribution and migratory patterns. Even in years when salmon are abundant, they may be difficult to find in historic fishing locations at familiar times of year.

The ***Central Valley Fall Chinook Stock Complex*** *is composed of primarily hatchery-based populations with vulnerable wild*

components. While the Central Valley River system is heavily engineered and requires attention to habitat improvements, the hatchery portion of this stock complex will benefit from the improved ocean forage of the Box of Chocolates scenario. Under this scenario, wild salmon stocks would dwindle in California and acceptance of hatchery stocks and river engineering would increase. This particular stock complex would continue as a hatchery stocks, with a management emphasis on more predictable year-to-year run size and timing.

Southern Oregon /Northern California Coastal Coho *are more affected by stream and estuarine conditions than by ocean conditions. This stock is already near the southern end of coho's geographic range and under the Box of Chocolates will be vulnerable to warming river and ocean temperatures, but will benefit from higher ocean productivity. The 2021 removal of Klamath River dams will improve terrestrial and riverine habitat enough that this stock is able to survive at roughly similar to 2020 levels under a Box of Chocolates scenario.*

Lower Columbia River Fall Chinook *are ocean-maturing and are most vulnerable to rising stream temperatures, particularly during their fall spawning return periods. This stock will be challenged in its freshwater habitat by periodically unfavorable precipitation patterns and unpredictable snowpack. In years of warmer fall stream temperatures, the fall returning tule subpopulation may have challenges returning to spawning grounds, while the later-fall returning bright subpopulation will be more challenged in the spring outmigration of its juveniles. However, ocean productivity is higher under the Box of Chocolates scenario, which will be particularly beneficial to the Chinook that reach the ocean. Targeted habitat restoration efforts to remove barriers to fish passage under the Box of Chocolates scenario will be particularly beneficial for this northern salmonid stock.*

Cross-FMP Issues Across Scenarios

In the future, fisheries management will not only need to address the challenges within each FMP in isolation. There will also be the requirement to consider how interactions between species in different FMPs might play out. These scenarios also enable us to identify a number of instances where there are links and connections across more than one FMP.

Cross-fishery participation: there are numerous instances where fishermen fish a portfolio of species. Albacore vessels often participate in crab and salmon fisheries, while purse seine vessels switch between HMS and CPS. We can imagine situations where, for example, the Dungeness crab fishery declines, leading to fishermen losing a key portfolio component that affects their participation in other fisheries.

Bycatch issues: if a non-target species' stock declines, precautionary management to minimize bycatch will constrain fishing opportunities for target stocks. Salmon bycatch has been a big challenge within groundfish fisheries. Salmon trollers are constrained by overfished yelloweye rockfish. International issues around Pacific halibut bycatch will continue to challenge groundfish fisheries here and off Alaska.

Bait sources: regulatory issues in CPS management could affect other FMP fisheries that depend on those fisheries for bait, such as charter fleets that use sardine as bait.

Aquaculture and offshore energy: what are the possible connections between West Coast fisheries, particularly CPS harvest, and any future Council action on aquaculture and offshore energy related to anything from direct impacts on where fishing can occur to indirect impacts on ecosystem productivity or data available for assessments from surveys?

Range Shifts: shifts in species' ranges or migratory patterns may increase the chance of cross-FMP and transboundary interactions, and will certainly make scientific work to predict those changes more challenging.

Endnotes

1 Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans.

2 Marshall, K.N. et al. 2017. Risks of Ocean Acidification in the California Current Food Web and Fisheries: Ecosystem Model Projections. Global Change Biology, 23, 1525-1539, doi: 10.1111/gcb.13594.

3 Changing Ocean, Marine Ecosystems, and Dependent Communities

4 United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Volume I: Comprehensive Tables.

5 https://www.futureagenda.org/foresights/plastic-oceans/

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