Pacific Fishery Management Council – Fishery Ecosystem Plan
Climate and Communities Initiative

Scenarios for West Coast Fisheries 2040: Groundfish

Contents

Introduction

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

This document outlines four draft 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. We invite the Groundfish Advisory Subpanel and Management Team to review these scenarios in advance of a webinar scheduled for **Thursday, May 28, 2020, at 1:30 p.m**.

At this webinar we will discuss these scenarios, paying particular attention to how these possible future conditions might affect groundfish stocks, the fishing industry and fisheries management. In this document, we have highlighted how the conditions in each scenario might affect four representative species from the FMP: sablefish, Pacific whiting, black rockfish and canary rockfish. We chose these species to serve as representatives for the FMP, focusing on species that are more likely to be targeted than simply taken as bycatch. We also chose species with different management challenges and life history characteristics to provide some variety for this exercise.

As you review this document, please remember the following:

- Scenarios are not predictions about what *will* happen. They are stories about what *might* happen. They include fictional elements and are designed to stretch our thinking and open our eyes to new opportunities or hidden risks.
- As such, when you read these four scenarios, try not to focus on asking: "Will this happen?". Instead, focus on considering: "What if this situation does happen? What happens to stocks? What happens to the fishing industry? What does this mean for fisheries management?"

- These are imaginary stories. It doesn't matter whether every single detail is accurate, as long as the general thrust of each story is at least plausible.
- Use these stories as starting thoughts to generate more ideas about the conditions, challenges or opportunities that would arise for you if the world turned out as described in each scenario.

Looking to the Next 20 Years: What is prudent to assume?

Despite the obvious unpredictability of the future, when we look to the next 20 years, there are a number of trends and developments that we should 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 a series of 'predetermined elements,' relevant factors that we think it is prudent to assume will occur or continue in the timeframe of the next 20 years.

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 cycle to later in the year[1]. By 2040, annual average SSTs in the CCE will exceed even the warmest year during the 1976-2005 period almost two-thirds of the time.

The CCE will also 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 season 2013-2052[2]. Globally, the IPCC 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[3].

Levels of oxygen are projected to decline further. 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. **Hypoxia** is caused 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.

---

[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

Demographics

Global 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 populations in the Western US will continue to be concentrated in a few mostly urban areas and nearby cities, with 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 Fukushima or Deepwater Horizon that lead to the introduction to the ocean of nuclear waste and oil will occur, leading to major but transient seafood safety concerns. 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, which when consumed in seafood may threaten human health, it is expected that we will produce three times as much plastic in 2050 as we do today[5]. A growing human population will also lead to increased interest in the use of ocean waters for activities such as offshore energy and aquaculture.

Technology

Technology 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. 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.

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 puts strain on industry providers and government budgets. Societal values and behaviors will be in flux, driven partly by the evolving impacts of the pandemic. 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 and maintain stable fish populations will continue under a regulatory environment based around the Magnuson-Stevens Act. This will give stocks some degree of resilience to climate change and other factors shaping the future. The Magnuson-Stevens Act and other ocean policy laws will be periodically updated to respond to shifting national needs in ocean resource management and ocean zoning needs.

---

[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/

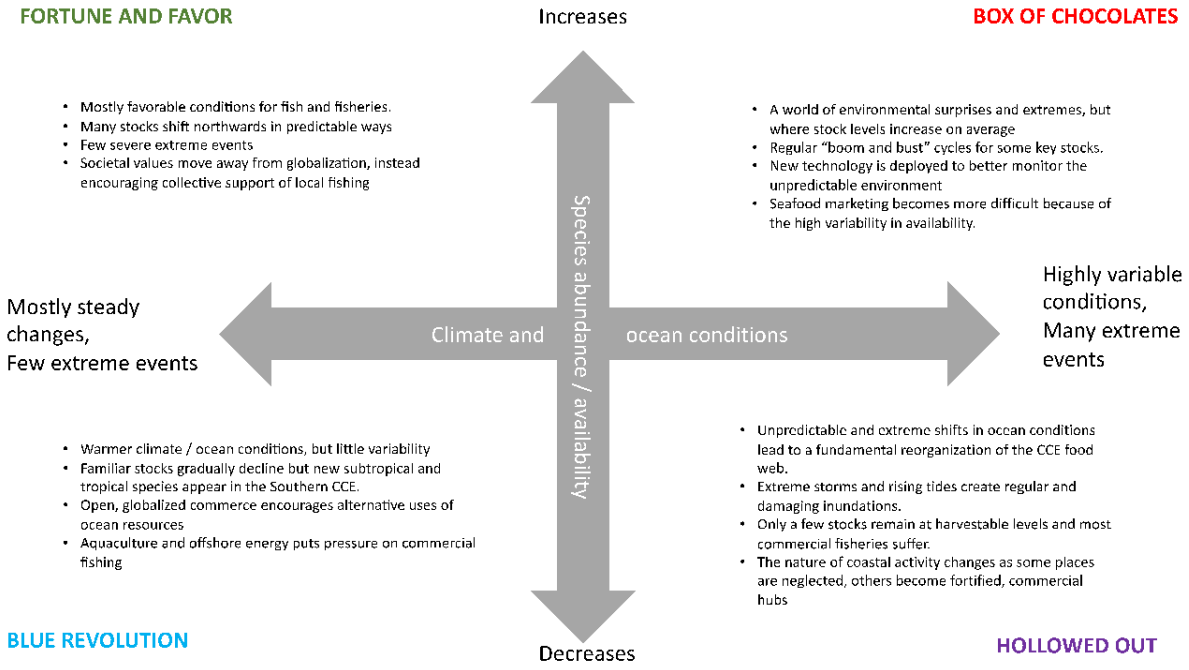
Scenario Framework

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:

1. 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?
2. What happens to species abundance and availability? Will the next 20 years see an increase in the stock of important species available to harvest, or will stocks decrease?

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 preference for protein
- Social and political attitudes around globalization and localism

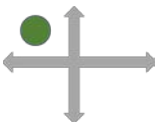


Following are more complete descriptions of each scenario. There are 4 sections:

- Summary
- Description of environmental conditions (climate, ocean, stocks)
- Description of market, technology and ocean conditions
- Impacts on groundfish

A Scenario for 2040: Fortune and Favor

Low climate/ocean variability, stock availability increases



Summary

The natural environment in this scenario is not radically different from today. By 2040, conditions seem pretty favorable for fish and fisheries. The severity or frequency of extreme events (such as marine heatwaves) is little changed, 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. Societal values have turned decisively to reduce greenhouse gas emissions and there is broad support for new collective action through a variety of policies and government interventions.

Environmental Conditions

Warming has been gradual and at the low end of current global warming projections. Inter-annual variability in physical conditions (SST, upwelling strength) is relatively low. 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.

Continued ocean acidification has not led to threshold effects that reorganize trophic structure. Populations of most shell-forming plankton at the base of the food chain have adapted to lower pH (more acid) conditions, although shellfish aquaculture operations continue to struggle. Overall, conditions have stayed within the physiological tolerance range for most species, while ocean warming over these two decades produces more forage. This is helped by sustained upwelling in the Central and Northern CCE without any major harmful algal blooms.

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 improve river flow and conditions for salmon.

Relaxed upwelling in the southern CCE results in fewer periods when protected species are concentrated in inshore fishing areas due to habitat compression. One result is whale entanglements are far reduced from the 2010-2020 decade.

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

Although the effects of climate change have been gradual and relatively benign, ocean conditions – and fish stocks – have been far from static. Many stocks show detectable northern and offshore (to deeper water) range shifts. These changes seldom take fishermen and fisheries managers by surprise – fish movements are broadly predictable using enhanced data and modeling. Fleets have been able to reach the changing locations of stocks, whether moving further north (for HMS) or deeper (for groundfish). 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.

For many important target species, the last 20 years has been a time of range expansion. Important species are often available for longer, creating opportunities for discussions about extending fishing seasons.

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 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. There is growing pressure for technological innovations and institutional changes to address these issues and seek solutions.

Policy, market, and technological conditions

While the effects of climate change have been relatively mild, the US 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 US consumers. By 2040, there is a renewed emphasis on buying local, supporting American seafood, and exploring alternative, community-based approaches to fishery management.

Millennials reaching positions of power in the 2040s emphasize nature-based solutions 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, 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.

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. The economic shocks of the 2020s also accelerated a decline in recreational fisheries. But changing attitudes, new technologies (e.g., carbon neutral electric vessel propulsion), and new social arrangements (e.g., co-ops) led to growing participation in the 2030s.

Impacts on 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. Reduced marine pollution 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 US 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, sea otter ranges will expand, and as those otters prey on urchin populations, 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 interannaual 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.

A Scenario for 2040: Blue Revolution

Low climate/ocean variability, stock availability decreases

Summary

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 is still valued in this scenario, but in different ways.

Environmental Conditions

Ocean waters have warmed modestly relative to the 2020 average, while climatic conditions exhibit limited variability. Marine heatwaves become less intense and frequent, while El Niños and La Niñas pack less of a punch than in the early decades of the 2000s.

The CCE exhibits weaker upwelling, especially off central and southern California. This contributes to a gradual decline in productivity and forage. Changes in upwelling strength are mostly noticeable from decade to decade, but less obvious from year to year. This weakened upwelling also leads to less widespread hypoxic conditions in the southern CCE. However, harmful algal blooms break out regularly in the northern CCE. Although ocean waters continue to acidify, it doesn't inhibit the growth of offshore finfish aquaculture.

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 and annual snow accumulation levels are lower by 2040 than they were in 2020. In La Niña years, increased spring flow allows more opportunity for passage for salmon.

As the ecosystem becomes less productive over time, 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. Winter storms, and rough weather generally, are much less frequent as winds weaken overall.

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 targeted species and co-occurring protected species.

Policy, market, and technological conditions

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. 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.

With warmer temperatures leading to longer seasons, recreational fishing operations have ballooned in more northerly ports. 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 (especially CPS) 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; however, most or all of the new West Coast aquaculture installations occur within state waters (inshore of 3 nm). 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.

Impacts on 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 product will seize 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.

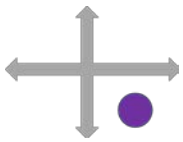
Pacific whiting abundance under a *Blue Revolution* scenario fluctuates as much as it has in recent decades, a familiar situation for fisheries managers and participants. As the ocean slowly warms, however, the center of the Pacific whiting stock's distribution shifts northward, leading to pressures for the US 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 interannaual 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.

A Scenario for 2040: Hollowed Out

High climate/ocean variability, stock availability decreases



Summary

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.

Environmental Conditions

By 2040, the ocean is warmer than in the *Fortune and Favor* and *Blue Revolution* scenarios, and much warmer than 2020 average conditions. Marine heatwaves are intense and frequent, exacerbated by large swings between El Niño, and La Niña conditions. The North Pacific Gyre current system shifts northward while the Pacific Decadal Oscillation becomes less evident, contributing to these regular periods of strong warming.

As a consequence of these swings in physical forcing mechanisms, upwelling strength is extremely episodic and variable in annual duration and intensity. In addition, the CCE has been rocked by a series of "ecological surprises" including the unexpected effects of ocean acidification on primary productivity.

In most years, precipitation comes in the form of rain, except at very high elevations. Snowpack rarely lasts beyond midsummer. In a few years, snowpack comes within 90% of the historical average, but that is mainly in the Pacific Northwest. Extreme weather conditions feature heavily. In some years strong winds and heavy seas are a constant in the winter and large storms regularly roll through.

A very warm ocean marked by extreme swings in physical drivers results in an overall decline in productivity and a reorganization of the CCE food web. Productive areas become extremely compressed and spawning habitat is lost. Traditional fishing grounds move, some are lost, and patchiness grows. A vulnerable Puget Sound suffers from continuing land-based pollution and especially warmed waters, making it nearly uninhabitable for most of the species that used to live there.

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.

Across the board in nearly every fishery, recruitment declines and remains low 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 that remain 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.

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 more 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.

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 precise, 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 economically viable amounts of fish. As those participating in fisheries retired, few had the appetite to replace them. 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. Recreational fishing still exists, although participation continued 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 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.

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.

Impacts on 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.

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.

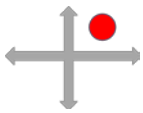
Pacific whiting have a low vulnerability to climate change, but the stock is highly mobile. In a *Hollowed Out* scenario, Pacific whiting abundance may fluctuate as much as it has in recent decades, a familiar situation for fisheries managers and participants. As coastwide salmon stocks plummet, Chinook bycatch in the whiting fisheries becomes more controversial and more restricted. 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 US-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.

A Scenario for 2040: Box of Chocolates

High climate / ocean variability, stock availability increases



Summary

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.

Environmental Conditions

Like the *Hollowed Out* scenario, this is a world with a much warmer ocean but with lots of variability from year to year. Greater environmental variability is driven by the intensification of periodic and cyclical climate phenomena. Marine heatwaves in the 2030s, sometimes coinciding with large magnitude El Niño events, persist for periods ranging from months to years. SST records are set across the entire CCE and nearshore waters are particularly affected. The Southern California Bight feels like a tropical sea in most years.

Upwelling strength, marine heat waves, regional hypoxia events, and widespread harmful algal blooms vary substantially year to year in both frequency and magnitude. In the Central and Southern CCE upwelling is extremely weak to nonexistent in more than half the years. In contrast, in the Northern CCE upwelling intensifies but, 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.

In the Pacific Northwest more precipitation falls as rain; snowpack fluctuates around the long-term average but melts off more rapidly in most years. 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.

Winter storms are more frequent and intense in the Northern CCE. Freak weather events such as intense summer wind/rain squalls occur in the Southern CCE. Seasonal wind direction is less predictable.

While many stocks' ranges shift northward and deeper, distribution of pelagic species is highly variable over time. Range shifts result in previously absent subtropical and tropical species being periodically abundant (or taking up residence) in Southern California.

Harmful algal blooms in coastal waters are chronic in Northern California and Southern Oregon, driving periodic fishery closures. Fishermen that depended on the Dungeness crab fishery for much of their income shifted their efforts into other state and Council managed fisheries.

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 and stock abundance. 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 operations are more capital intensive and new kinds of technological expertise is required to compete. The latter has given an advantage to younger fisherman 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.

The functional extinction of many wild salmon stocks in California combined with the evolution of hatchery production (including the use of wide scale genetic modification) drove policy changes in both the ESA and MSA. 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.

Consumers have become much more receptive to wild-caught fish for health and emotional reasons. However, 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.

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.

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 boutique / artisanal fisheries survive but larger vessels concentrate in a few ports.

Impacts on 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.

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 on addressing 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, largely because 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.