Planning for the Future of Oregon's Dungeness Crab Fisheries

2040 Scenarios

December 2021 | Jonathan Star and Gway Kirchner

The Nature Conservancy

PREFACE

The Nature Conservancy (TNC) is a science-based, nonpartisan organization committed to conserving the lands and waters on which all life depends. In Oregon, TNC has over 80,000 supporters and members in every county. Based in communities around the state, we manage lands and waters in varied ecosystems and partner with ranchers, farmers, fishers, and timber and environmental interests on some of the most challenging conservation issues facing people and nature.

Around the world, TNC addresses the most pressing conservation threats at the largest scale and has built a record of success since our founding in 1951, which includes the following achievements:

- Protecting more than 125 million acres of land and thousands of miles of rivers worldwide and operating more than 100 marine conservation projects globally
- Advancing conservation in 72 countries spanning six continents and protecting habitats from grasslands to coral reefs, from Australia to Alaska to Zambia
- Conducting fisheries projects from the West Coast to Chile to Indonesia and bringing a collaborative, science-based approach to bear on the most critical fisheries issues facing our globe

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Requests for further information about the research in this report can be directed to Gway Kirchner, gway.kirchner@tnc.org.

Cover photo: Dungeness crab for sale on the Newport Docks (photo credits are provided at the end of this report; see Entry 1).

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Introduction

Oregon's Dungeness crab fisheries face a future of uncertainty. The impacts of climate change, economic conditions, consumer tastes, technology, and other developments will likely reshape many aspects of crab fishing in the decades ahead. To help prepare the industry for a different future, The Nature Conservancy (TNC) facilitated conversations among fishery stakeholders, managers, tribes, and others in a scenario planning exercise.

The purpose of *scenario planning* is not to predict the future—in uncertain times, that is an impossible task. Instead, the goal is to imagine different, alternative possibilities for what *might* happen over the decades ahead. Then the scenarios are evaluated to consider the consequent risks and opportunities and identify beneficial responses. As such, the purpose of this scenario planning project is to help coastal communities and Oregon's Dungeness crab fisheries—both commercial and sport fisheries—become better prepared for the uncertain future that lies ahead.

Four scenarios were created through a series of online workshops and webinars during fall 2020 and then developed further through conversations in summer 2021. In fall 2021, we used these narratives as the basis for a series of conversations about what actions stakeholders could take to prepare for future uncertainty and to secure a better future for their fisheries.

Constructing the Scenarios

To construct scenarios for Oregon's Dungeness crab fisheries and coastal communities, workshop participants used as their starting point an existing scenario framework first developed for the Pacific Fishery Management Council (PFMC). This exercise considered how climate change and other factors might affect stocks, and hence the industry's future health, for four fisheries with federal management plans: highly migratory species, coastal pelagic species, groundfish, and salmon.

The PFMC framework was tested in conversations with representatives from Oregon's crab fisheries. Several predictable trends were identified that are highly likely to shape the future of Dungeness crab: more ocean acidification, warmer ocean temperatures, more hypoxia, and over time, a rising sea level. In addition, higher inland temperatures are anticipated, which will impact coastal areas and juvenile crab rearing habitats in estuaries due to weather, water quality, and human population changes.

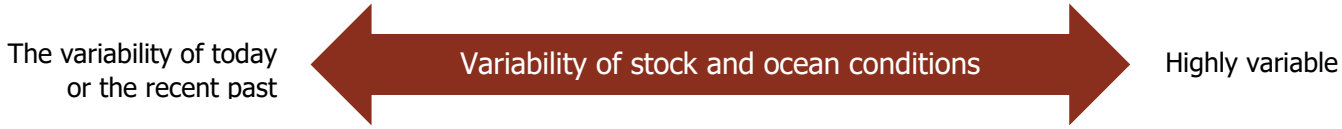
Critical Uncertainties Shaping the Future of Dungeness Crab

As noted above, the initial PFMC framework was modified to craft scenarios more relevant to Dungeness crab in Oregon by adapting the *critical uncertainties* used to create the framework. These critical uncertainties are contrasting factors with (a) a high probability of shaping the future of crab fishing and (b) a highly unpredictable direction of change.

The first critical uncertainty relates to how climate change will affect crab fishing. It is anticipated that areas affected by ocean acidification will expand, and ocean temperatures will increase along with associated domoic acid events. Domoic acid can build up in ocean environments during algal blooms, bioaccumulate in crab tissue, and cause neurotoxicity in humans. Over the longer term, sea levels will rise, threatening coastal infrastructure and important estuarine habitats. While these are all predictable developments, the critical uncertainty relates to the degree to which these conditions will vary compared to today. The following question and Figure 1 illustrate this climate-change-driven critical uncertainty:

1. Over the next 20 years, will variability in ocean conditions, and hence in crab and other fish stocks, remain broadly similar to today and the recent past, or will variability increase in significant ways?

Figure 1
Critical Uncertainty 1: Variability of Stock and Ocean Conditions



The second critical uncertainty relates to the health and viability of crab fishing in Oregon. Viability will mostly be driven by economic factors, such as short-term supply and demand, but also by longer-term structural changes, such as consumer tastes and technology developments. Viability will also be partly influenced by environmental conditions that shape the availability of crab and other fish stocks.

The following question and Figure 2 define the second uncertainty:

2. Over the next 20 years, will the industry be broadly attractive in terms of viability, or will it be mostly unattractive for fishers? (*Attractive* means there is interest in harvesting crab recreationally and commercially AND there are viable domestic and/or international markets.)

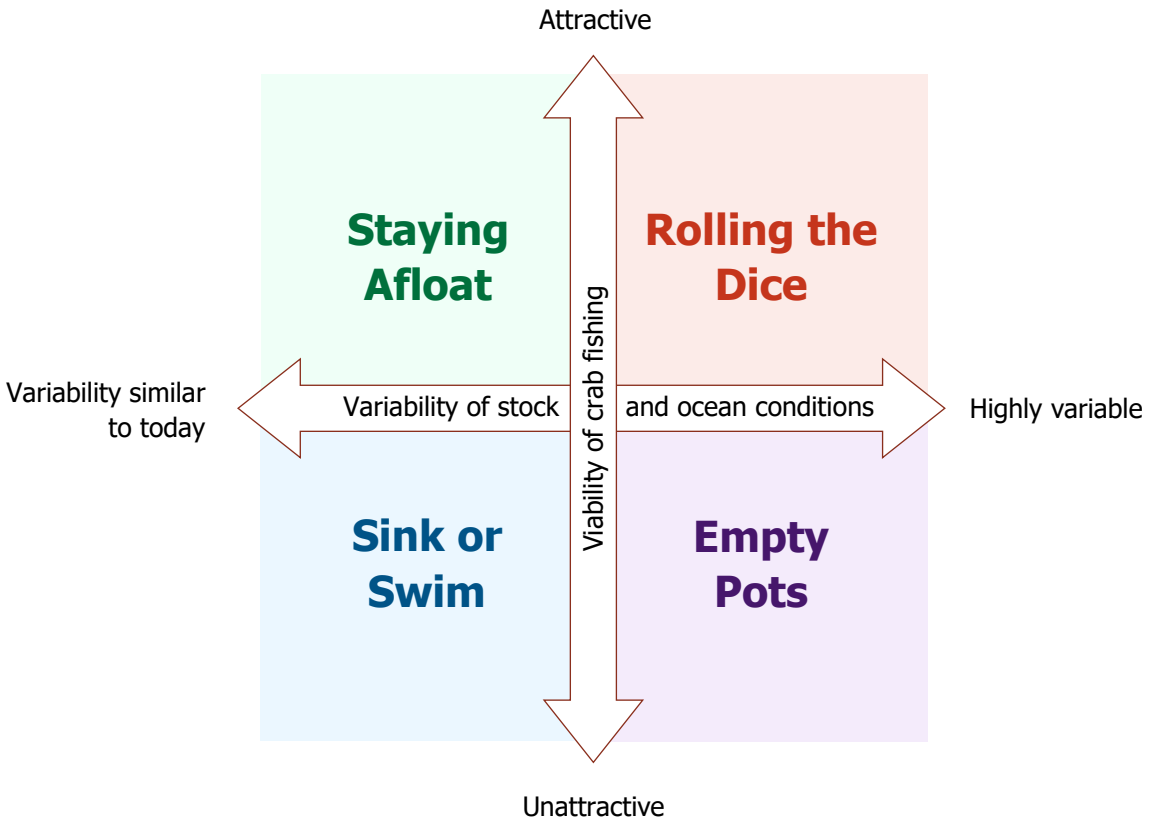
Figure 2
Critical Uncertainty 2: Viability of Crab Fishing in Oregon

These two critical uncertainties were combined into a two-by-two framework (Figure 3), creating four quadrants describing four different kinds of futures (scenarios) that Oregon's Dungeness crab fisheries may face in the next 20 years.

Scenarios for the Future of Dungeness Crab Fishing in Oregon

Figure 3 is a visual representation of the four 2040 scenarios discussed in this report. The upper left quadrant is a scenario where the variability of both the crab stock and ocean conditions is manageable, and economic viability is maintained: **Staying Afloat**. The lower left quadrant is a scenario where stock/condition variability is manageable, but more structural/long-term factors lead to a lack of viability: **Sink or Swim**. The lower right quadrant is a scenario where major stock/condition fluctuations combine with other factors to create severe threats to crab fishing: **Empty Pots**. Finally, the upper right quadrant is a scenario where crab fishing remains appealing despite the increased variability of conditions and available catch: **Rolling the Dice**.

Figure 3
An Illustration of Four 2040 Scenarios Defined by Variability and Viability



The next section of this report describes the Indigenous communities in Oregon, how they might be affected by changing Dungeness crab fisheries, and how they contribute to the fisheries' sustainability. The document's subsequent sections describe each scenario in more detail, including any nuances concerning tribes. The scenarios describe the physical and ocean conditions and the commercial and sport conditions, and they paint pictures of what life might be like in Oregon's larger and smaller ports. Scenarios are narratives about what might happen in the future; they are not predictions. Good scenarios should be plausible, challenging, relevant, memorable, and different from each other. They are designed to make us think about a range of future possibilities and encourage us to generate ideas about how to succeed under any or all of these conditions.

Indigenous Communities in Oregon

Oral histories and written accounts show that Northwestern Tribes traditionally used Dungeness crab for community and ceremonial events, as well as an everyday food source. For example, the Namgis First Nation at the northern end of Vancouver Island still uses Dungeness crab as a ceremonial food (Satterfield et al., 2017). Another researcher (Duncan, 2000) interviewed members of the Washington-based Suquamish Tribe and found at least half of the 92 participants reported regular consumption of Dungeness crab, and 47% reported consuming crab in ceremonial or community settings.

In Oregon, however, historical physical evidence of tribes using Dungeness crab is sparse and often found only in excavated tribal middens. One study

conducted by Losey et al. (2004) examined shell fragments in tribal community middens along Nehalem Bay, one of the few Oregon sites with large volumes of crab remains in archeological sites. This study found that Nehalem tribal members harvested adult crab using a pole to stab through the carapace and mass-harvested juvenile crab and other shellfish in shallow subtidal areas. Once collected, the tribe steamed crab and other shellfish on a bed of rock, coal, and seaweeds.

Tribal representatives participated in developing this report's scenarios and provided important insights on future climate change impacts on tribal communities.

Overall, tribes are focused on the health of the whole ecosystem. Climate change means tribes will face tough choices to prioritize which resources to save. Tribal governments may employ mitigation measures to change some trends and protect important habitats, such as eelgrass. This work will require a collaborative approach toward watershed co-management.

It is critically important to ensure that tribes are still able to access crab—not just for food but also for the continuation of cultural practices and a way of life. Domoic acid is a considerable concern because tribes often consume crab viscera before new outbreaks are detected. This early consumption creates a significant human health risk that could be lessened by the development of evisceration technology. Tribes may be able to employ tools as a buffer for acidification, such as grinding clam and other shells and adding them to ocean and estuary areas.

More specific input is included throughout the document.

Dungeness crab being transported in a storage bin (2).

STAYING AFLOAT

This scenario imagines a future world in which the variability of both ocean conditions and stock is manageable. Crab fishing remains an attractive and viable business for many.

PHYSICAL AND OCEAN CONDITIONS

By 2040, waters off the Oregon coast experience increases in harmful algal blooms (HABs), ocean acidification, increases in average temperatures, persistent seasonal hypoxia, and strengthened seasonal upwelling. Though these conditions have developed—largely due to climate change—their year-to-year variability remains manageable. Severe weather events are infrequent in the Pacific Northwest, as are rough winds in Oregon waters as winds weaken overall. Global oceans experience relatively low interannual variability, with less intense swings between El Niño and La Niña years.

Climate and ocean variability do not significantly deviate from today, but warmer waters produce more forage for crab. Acidity conditions have changed over the past two decades, but levels remain within the range of crabs' physiological tolerance. HAB events, some of which produce domoic acid, have increased over time, but evisceration advances reduce the risks of related closures.

COMMERCIAL AND SPORT CRABBING CONDITIONS

These environmental conditions create a more predictable supply of crab from year to year, boosting demand as consumers can reliably get crab at the times of year that suit them. Dungeness crab is regularly available during the winter holidays. Crab marketing becomes more straightforward with increased predictability. Demand stays high due, in part, to the development of technologies that minimize the consumption risk from rising levels of domoic acid. These evisceration technologies are able to eliminate dangerous acid from much of the crab flesh.

Internationally, this scenario describes a favorable trading and demand environment. China's economic growth causes large increases in demand. Following many years of trade tensions in the 2020s, a more robust trading relationship now exists that favors U.S. crab exports. Variability is not eliminated, but thanks to strong overall demand, low supply years remain fairly lucrative as prices stay high during those times.

Live crab makes up a greater proportion of total crab sales, as canned crab loses its relative appeal. An accelerated push for sustainability boosts demand for live crab. Across the world, consumers grow more concerned about the environmental impact of fishing and farming, and quality guarantees and sustainability certificates help generate more business.

Calmer oceans also boost the appeal of crab fishing. These conditions reduce the danger to boats, allowing smaller vessels to stay viable and operational. Over time, these mostly benign conditions give rise to tensions as more operators seek to start fishing in what is becoming a stable and lucrative market.

Warmer inland temperatures bring more people to the Oregon coast to escape the summer heat. Coastal activities become more popular, and local real estate prices rise as people search for second homes. Those who cannot afford to stay close endure a long drive for a day trip. Crabbing charter trips are busier as good weather conditions and crab numbers ensure that customers return year after year. Sport crabbing is more popular than ever.

The biggest downside for both commercial and sport crabbers is that ports are insanely busy for much of the year, especially in the summer and shoulder seasons. Existing infrastructure must absorb the pressure of more visitors and residents, and miles-long traffic jams are common to reach ports. Commercial vessels find it difficult to maintain crews, partly because competition for labor is

fierce with so much activity and because many crew members are priced out of living close to a port. However, the general buoyancy of the markets for crab and other fish keeps interest high, and operators find ways to cope in busy, prosperous times.

Impacts on Other State and Federal Fisheries in Oregon

As ocean temperatures rise modestly, many stocks shift northward in predictable ways, and new, marketable stocks arrive from southern waters. Despite range shifts and smaller average body sizes, West Coast fishery stocks are considered healthy, sustainable protein sources, offering a greater diversity of species than in 2020.

Fishers using less selective gear cause higher bycatch. Consequently, fishing businesses are challenged somewhat by the more stringent restrictions put into place. Still, lucrative opportunities remain. Fisheries for coastal pelagic species see higher overall harvest amounts and move northward. Northern anchovy stocks lose fishery and market attention, but Pacific sardine and market squid populations increase in Oregon waters, particularly during La Niña years. Similarly, stocks of highly migratory species increase somewhat, including northern albacore stocks that benefit from increased juvenile forage availability. Groundfish fisheries do well thanks to higher primary production and less climate variability. Some stocks like sablefish and Pacific whiting move northward or toward deeper waters. Rockfish species do not move and benefit from higher productivity. Salmon stocks stabilize thanks to major dam removals in Oregon, fewer pollutants, and attractive forage. This situation allows crabbers to fish off-season and diversify when needed.

▪ ▪ ▪ Staying Afloat in 2040: Life in Oregon's Fishing Ports

Larger Ports

Oregon's larger fishing ports have grown, diversified, and become busier over the last 20 years. Fishing is still a dominant part of the economy, but new waterfront developments focus on retail and leisure sectors, as new breweries, restaurants, and outdoor spaces occupy prime positions. Shoreside support facilities and infrastructure have been relocated away from the main waterfront areas, including new plants with evisceration technologies to minimize domoic acid dangers. There is a regular struggle to build low-income housing in the ports and surrounding communities. Most properties are snapped up by buyers from larger cities in Oregon and California who have been able to work remotely since the COVID-19 pandemic of the early 2020s.

Smaller Ports

Crab fishing has flourished in Oregon's smaller ports over the last 20 years. Ocean conditions create a more productive habitat for crabs. Domoic acid dangers are not as severe as feared, and new evisceration technologies help remove the acid from crabs. The main difficulty for smaller ports is dealing with growth challenges. Larger catches have led to more traffic, as the catches get transported to processing plants elsewhere on the coast. Remote workers find smaller ports attractive for vacation homes or even permanent homes because broadband upgrades enable people to work anywhere. Good fishing conditions mostly keep small ports prosperous, but any downturn or closure means that low-income workers suffer the most.

SINK OR SWIM

This scenario describes a future world in which the variability of fish stocks and ocean conditions is manageable. However, more structural and long-term factors escalate cost pressures and eliminate the viability of all but the largest crab fishery operators.

PHYSICAL AND OCEAN CONDITIONS

In 2040, multiple climate change impacts negatively affect the offshore ecosystem and species across all trophic levels. Although variability and unpredictability remain relatively constant compared to 2020, marked increases in ocean acidification lead to declining stocks, especially in species in lower trophic levels like shelled invertebrates and plankton. Higher sea surface temperatures and larger, persistent HABs create obstacles for marine species and their habitats. Despite this, crab stock levels mostly remain consistent.

Oceanographic conditions experience comparatively low interannual variability and less intense swings between El Niño and La Niña years. The strength of nearshore upwelling has weakened but not drastically. Changes are only noticeable on a decadal scale.

COMMERCIAL AND SPORT CRABBING CONDITIONS

Commercial conditions put pressure on most crab fisheries as they struggle to remain viable. Ongoing trade tensions, especially between the U.S. and China, dampen international demand for crab. Although climate conditions are more challenging, a predictable crab supply encourages continued moderate domestic demand.

Conditions on the ocean and in coastal communities change markedly in this scenario. Public and private sectors invest heavily in new technologies, such as alternative energy and biotechnology. For crabbers and other fishers in Oregon, this means dealing with the construction and operation of ocean wind farms and a series of large-scale aquaculture operations—although seaweed farms appear to offer some benefits as a growing habitat for crab.

These new investments in coastal commerce change the nature of many coastal communities. Competition for commercial and residential real estate raises the cost of living for many people. New residents bring economic vitality to coastal communities, but growing evidence indicates that commercial captains and their crews are priced out of property markets.

The changing ocean conditions also lead to more frequent whale entanglements, prompting greater regulations on nets and pots and further reducing access to the resource. Required gear changes lead to higher costs for many in the industry—only larger players remain profitable under conditions of moderate demand, increased competition for ocean space, and more stringent regulations.

Smaller operators trend toward retirement, while larger concerns survive with the help of technologies to reduce bycatch and more effectively track stock locations. Fishers moving away from crab put more pressure on highly migratory species, especially if they can acquire necessary equipment and technologies. Otherwise, the fishers transition to the northward-shifting whiting fishery. Aquaculture's success in Oregon waters offers a viable career alternative for some commercial fishers looking for financial stability.

Despite worsening crab volumes, sport fishing survives largely intact. Fairly calm conditions ensure that the crabbing experience is still positive even if the catch volume is down from previous years. For commercial crabbers, a 10% to 20% drop in volume is a much bigger problem, which results in smaller operators exiting the industry. This dynamic boosts sport crabbing, as uncrowded waters prove to be a better experience for sport fishers and recreational charters. Rising concerns about domoic acid and whale entanglements cause

occasional closures, but most sport crabbers take them in stride.

The changing nature of vessels—fewer small commercial boats replaced by more large commercial vessels—poses challenges for many ports. Existing infrastructure is insufficient to cope with the change, and ports invest in larger slips to accommodate bigger commercial boats. Such investments are difficult and risky for ports, especially when the trends clearly show a gradual decline in volumes of crab and other species over time.

Predictable declines in crab numbers prompt tribes to take action to maintain the habitat, such as adding shells to eelgrass beds to encourage juvenile success. As stocks decline, a far greater emphasis is placed on better preserving whole ecosystems that protect crab. Over time, agencies on the coast and in watershed areas collaborate more.

State and Federal Fisheries Pursued in Oregon

Many familiar stocks decline gradually, and new species enter the California Current Ecosystem (CCE). Stocks of coastal pelagic species gradually move northward and decline somewhat as less forage is available. Fleets pursuing highly migratory species are challenged by declining stocks, but some can survive, especially with new technologies that reduce bycatch. Groundfish fisheries are a mixed bag. Whiting populations fluctuate and move northward across U.S. and Canadian borders. Nearshore groundfish are challenged by changing conditions and space competition, and some rockfish species like black rockfish become locally depleted. Salmon stocks struggle with changing environmental conditions, but new technologies and hatcheries ensure fisheries remain viable despite more competition from aquaculture.

▪ ▪ ▪ Sink or Swim in 2040: Life in Oregon's Fishing Ports

Larger Ports

Commercial activity appears to be doing reasonably well in Oregon's larger ports in 2040. New facilities have been built, new fishing vessels travel in and out of the harbors, and a constant stream of tourists visit museums, galleries, and retail malls. But the composition of these ports has changed in the last 20 years. Tougher conditions—lower crab volumes, more regulations, and stiffer competition—mean that far fewer small commercial boats are in operation. These days, large vessels dominate the harbors, accompanied by an abundance of much smaller recreational boats. New investments have reshaped many cities, as aquaculture and wind farms provide additional economic activity to complement or sometimes replace fishing. Local businesses supporting smaller commercial crab fishing have all but disappeared. A growing number of research institutes closely study all these changes, paying close attention to shifting habitat conditions, new gear regulations, and an ever-changing socioeconomic environment in the largest ports.

Smaller Ports

Commercial fishing has all but disappeared from Oregon's smaller ports by 2040. Domoic acid concerns cause frequent seasonal closures, and warmer temperatures affect the size and availability of crab. Fishing activity remains, but it is now dominated by recreational boats, content to catch lower numbers when conditions dictate. The loss of smaller commercial vessels has changed the character of many ports—they are quieter communities with more facilities catering to an older, retiree population looking for an escape from the bustle and inland heat of central Oregon, Washington, and California cities. There are attempts to increase investments in local facilities to keep some commercial activity alive, but it proves difficult to get local communities to sign on.

Empty Pots

This scenario presents a future world in which Oregon waters are characterized by extreme shifts in ocean conditions, reorganizing the marine food web both locally and across the CCE. These shifts create severe challenges for Dungeness crab fisheries, as well as other major state and federally managed fisheries pursued in Oregon waters.

Physical and Ocean Conditions

Ocean warming has reached the high end of projected levels, the impacts of which are particularly apparent in nearshore areas. The North Pacific Gyre has moved northward, and the West Coast experiences more dramatic and frequent swings between El Niño and La Niña, as well as increased marine heatwaves that sometimes coincide with El Niño years. On the other hand, the Pacific Decadal Oscillation has weakened, causing fewer cool years. Seasonal upwelling that previously occurred off the Oregon coast has weakened and no longer follows seasonal trends.

There are widespread increases in ocean acidification, and HABs appear regularly and significantly impact stocks throughout the seasons. Eelgrass and nurseries for juvenile crab suffer significant losses. Weather events have shifted as well. Fishers struggle with strong winds and heavy storms throughout the winter months, when the crab fishery is most active.

Crab stock abundance fluctuates and is difficult to predict from year to year. Changes in physical environments are responsible for stock fluctuations, but specific relationships are not well understood. Contributing factors likely include changes in preferred habitat, the loss of eelgrass and coastal habitats where juvenile crab mature, hypoxic and anoxic conditions that lead to adult mass mortality events, the abundance of competitors, and weather and temperature changes that shift stock concentrations.

Commercial and Sport Crabbing Conditions

Demand suffers in this scenario. Regular HABs affect global markets. Chinese authorities severely curtail Oregon's exports because they wish to limit Dungeness crab imports affected by HABs and marine pollution like effluence and poor water quality.

Domestically, U.S. demand falls largely because of the unpredictability of supply. Marketers find it difficult to make crab attractive regularly as seasons and availability keep shifting in the eyes of consumers. Finding no crabs available for the holidays, most consumers switch to alternatives, and few return in years of good supply. Furthermore, warming ocean temperatures in Oregon waters are likely associated with increased whale entanglements, which have prompted strict fishing regulations and eroded public perception of the fishery.

In addition to market pressures, crabbers suffer from increasingly extreme weather events. Coastal storms and inundation make living close to the ocean a riskier proposition. Houses and commercial properties are often flooded. Fishing operators find it difficult to staff boats, as many crew members have moved inland out of harm's way. More storms on the ocean mean business pressures, such as more boat maintenance and expensive and rising personal injury insurance premiums.

Highly variable Dungeness crab stocks and ocean conditions make the viability of the fishery unattractive. With the pressure on crab, operators look to other fisheries for opportunities. However, the general conditions also create damaging impacts on salmon and other fisheries. All salmon stocks have been significantly reduced or decimated, and most groundfish stocks have shrunk considerably, moved northward, or both, making it even tougher for crabbers to survive difficult periods and off-seasons.

The Dungeness crab fishery loses its role as a reliable "connector fishery" during the winter months.

Most other commercial fisheries pursued across the state also decline or are no longer accessible. Salmon and groundfish—two major fisheries long integrated into crab portfolios—are no longer viable. It is a real challenge to make a living from commercial fishing in Oregon. Many commercial fishers partially or fully leave the industry to pursue economic stability elsewhere.

Only a few sport crabbers keep fishing, mostly bay crabbers, due to legacy and habit. There is little interest in recreational charters. Hot inland temperatures that bring in sea breezes and high winds, coupled with low volumes in crab stocks, severely dampen business. Charter vessels find it difficult to retain crews, as many have left the business for more regular, secure work.

Local community and political leaders strive to protect the most vulnerable communities. Only a few ports survive, mostly due to large-scale investments in infrastructure, such as waste treatment facilities. Closures encourage processors to relocate to newer facilities in the remaining ports. But most ports suffer. They struggle with regular episodes of flooding and coastal inundation, and they must deal with the growing problem of abandoned boats left to decay by owners who have no interest in or means of maintaining their vessels.

This scenario represents a set of dire conditions for tribes. As conditions are inhospitable for many species, tribes "triage" their fishing activity, making decisions about the most important species to save for economic and cultural reasons. As in other scenarios, the focus is on protecting the ecosystem as a whole and involves collaborative efforts with other watershed managers.

State and Federal Fisheries Pursued in Oregon

State and federal fisheries pursued off the coast of Oregon decline significantly; only a few stocks remain at harvestable levels. Increased stratification across the CCE has reduced nutrient availability and productive habitats for targeted species. Increasing and persistent marine heatwaves have further compressed nearshore habitats. Ecosystem and habitat changes have reordered the entire marine food web into a top-down structure, although few top predators remain.

Overall, recruitment and productivity are low in most managed stocks. Still, occasional population spikes occur in some stocks. The average body size of some fished species has declined, which translates to lower profits for fishing businesses. Species' unexpected range shifts have caused high bycatch rates and resource competition as southern stocks move northward. The numbers of coastal pelagic stocks, including Pacific sardine and northern anchovy, are at record lows, and the stocks have moved northward, though squid populations experience occasional spikes in La Niña years. Highly migratory species are no longer in demand by consumers, so some stocks grow modestly, despite less available forage. The groundfish fishery is challenged overall, especially longer-lived species like rockfish. Whiting stocks are less vulnerable to climate change impacts. Still, high salmon bycatch rates make this a risky fishery, particularly since salmon stocks have been devastated coast-wide, and some stocks have gone extinct.

A crab boat out of Florence, which took a researcher across to the Port of Newport to inspect results of a gear retrieval project funded by the National Oceanic and Atmospheric Administration (3).

▪ ▪ ▪ EMPTY POTS IN 2040: LIFE IN OREGON'S FISHING PORTS

LARGER PORTS

The waterfronts are reasonably busy on a summer weekend in 2040. But bustling activity is now the exception rather than the rule. People visit Newport and other ports for the cooler coastal air—a welcome relief from the intense inland summer heat. Despite the more moderate temperatures, Oregon's ports are not a particularly appealing prospect. Only a few businesses have survived the difficult decades, and most commercial activity now focuses on the removal and renovation of warehouses, processing facilities, and decaying commercial buildings. Boats have lain rusting in harbors for many years, with processing facilities closed up and derelict. Ports suffer because fishing, especially for crab, is a far more dangerous and less rewarding business. Only the hardiest of operations now survive. On the bright side, housing is more affordable, and there are plans for new investments in waste treatment and remediation technologies. Crab fishing goes through cycles, and the larger ports hope they can recover in the decade ahead.

SMALLER PORTS

Smaller ports have endured a difficult couple of decades. Ocean conditions, particularly frequent HABs, have led to dwindling fish stocks and a severe drop in commercial and recreational activity. But climate change impacts have caused additional damage: more intense storms and frequent coastal flooding because of atmospheric rivers. Only the hardiest residents are willing to stay in the ports or surrounding communities, resulting in a series of economically deprived areas within coastal communities. Political and community leaders look for ways to maintain and bolster the places faced with such decline and dangers. A few ports are hardened against flooding, and the defenses have held. But others are not as lucky, and more people simply retreat inland. For some, this means relocating and rebuilding a mile or two from the coast, but others looking for jobs move to larger central Oregon cities.

Rolling the Dice

This scenario imagines a world in which the Dungeness crab remains appealing despite the increased variability of ocean conditions and stocks.

Physical and Ocean Environment

Environmental surprises and extremes characterize the marine ecosystems off the coast of Oregon. Strong stratification has compressed nearshore upwelling, and chronic HABs occur in southern Oregon, northern California, and sometimes coastwide. Ocean warming has reached the high end of projected levels, the impacts of which are particularly apparent in nearshore areas. The North Pacific Gyre has moved northward, and the West Coast experiences more dramatic and frequent swings between El Niño and La Niña, as well as increased heatwaves that sometimes coincide with El Niño years. On the other hand, the Pacific Decadal Oscillation has weakened, causing fewer cool years. Marine mammal stocks have mostly recovered across the CCE, and some fish stocks maintain healthy, albeit variable, levels.

Weather events have shifted as well. Stronger winds create more upwelling, cold water, and a more productive ocean. But fishing conditions are more difficult. Fishers struggle with winds and heavy storms throughout the winter months, when the crab fishery is most active. Less predictable winter wind directions and more frequent extreme weather events increase the danger at sea, which increases fishing businesses' personal injury insurance costs. Coastal communities and ports are damaged by these weather events, along with rising tides and sea levels.

Commercial and Sport Crabbing Conditions

Despite the unpredictable nature of crab stocks, live crab remains in high demand, both internationally and domestically. Consumers recognize the variability and are willing to change their habits and buy when available. Live crab is seen as a high-end, high-priced delicacy. New developments in freezing crab have also boosted the market. While it does not fetch the premiums of live crab, it offers a more consistent product throughout the year and helps both domestic and international markets.

The Dungeness crab fishery remains lucrative during some years, but widespread mortality events and increased HABs make landings less reliable. Intense and frequent winter storms and unexpected weather events put a great deal of pressure on the industry. The uncertainty demands a great deal of flexibility and innovation. Crabbers survive lean seasons by switching to other fisheries. These changeovers also require flexibility in fleet and gear, and investments in such flexibility favor larger fishing fleets and deeper pockets.

Crabbers see the need to invest more in technology in this scenario. Investments in data monitoring and tracking pay off, partly to help predict stock locations and avoid bycatch but also to ensure that consumers understand the provenance of crab through a sustainable supply chain. Unpredictable weather is a major concern, so more effort is placed on precisely forecasting conditions. Just as larger, wealthier fleets can more easily switch from crab to other fisheries, they can more easily find the resources to invest in technology.

In later years, technology investments move increasingly toward more automation on vessels and in processing. As coastal storms hit fishing communities and people leave the area, captains find it more difficult to operate crews. The result is a less labor-intensive, more capital-intensive operation using fewer crew members and workers. The challenge for the industry is to maintain authenticity in a world where more technology becomes essential. Ports work with crabbers by setting up live tanks to sell crab directly to consumers on the shore—summer demand from tourists and locals is high.

Access to most commercial fisheries is variable. Ocean conditions, space competition, and management restrictions make it challenging to count on reliable landings in historically lucrative fisheries

like groundfish and crab. Fishers with access to new technologies hold onto crab permits to take advantage of boom years but shift their efforts to albacore fisheries or the emerging squid fishery in intervening years. Without steady winter fisheries (groundfish and crab), fishers diversify their work and participate in tuna ranching or dulse aquaculture operations as these become more popular in Oregon waters.

As with commercial fisheries, recreational operators survive and thrive by becoming more flexible. More algal blooms lead to occasional seasonal delays or closures, so charter operators put boats on insurance layups. Charters also look for ways to change how they do business, adjusting schedules to run charters every other day or lengthening trips to include other experiences like whale watching. Overall, recreational crabbing survives fairly well in this scenario—given the uncertain conditions, crabbing remains a mostly safe experience for sport and recreation.

State and Federal Fisheries Pursued in Oregon

Stock sizes across the CCE increase on average, with regular boom-and-bust cycles for key stocks. Although many species move northward, innovation allows the exposure of previously unexploited stocks, and fishers increase portfolio and gear diversification to remain competitive in the industry.

The abundance and distribution of coastal pelagic species fluctuate, and traditional fishing grounds shift as most species move northward. Years of high productivity are intermittent and unpredictable. Squid stocks thrive under this scenario, particularly in La Niña years, as do northern stocks of anchovy. Highly migratory species vary by year, leading to inconsistencies in fisheries. Despite some competition from offshore tuna ranching, northern albacore stocks, popular among Oregon's fishers, increase modestly and remain sought after by consumers. The groundfish fishery becomes more unpredictable as unexpected climate-change-related losses and benefits arise. Managers, researchers, and fishers respond to stock fluctuations with more flexible practices, and the fishery remains somewhat viable. Salmon stocks are challenged by climate variability but benefit from boom-and-bust cycles of ocean productivity. Fishing is inconsistent from year to year because of changes in abundance, shifting fishing grounds, altered seasonal behavior, and migratory patterns.

The Evolution is loaded with crab pots in Newport, Oregon (4).

ROLLING THE DICE IN 2040: LIFE IN OREGON'S FISHING PORTS

LARGER PORTS

The key to success for larger ports in 2040 is being prepared for the unexpected. Many areas have been revitalized but not via big investments in retail malls or major infrastructure facilities. Too much uncertainty exists for anyone to feel comfortable taking on that risk. Instead, the revitalization has come from new approaches and practices. Ports have changed their regulations and built storage facilities so that small-scale crabbers can sell direct to consumers on the waterfront. Recreational charters now combine crabbing trips with whale watching. Downtowns host regular festivals, which bring in visitors even when conditions are unsuitable for crab fishing. At a time when climate conditions have affected agriculture in the Western U.S., local seafood has become more popular, with farmers markets as one of the main channels. Research institutes in Newport have experienced a funding infusion, as there is greater interest in understanding habitat conditions, stock locations, and weather conditions.

SMALLER PORTS

Life is precarious in many of Oregon's smaller fishing ports in 2040. In good seasons, enough crab and other stocks support a decent living. But long-term viability is constantly threatened by a couple of back-to-back bad seasons when stocks are low or the constant danger of rough weather keeps people onshore. Occasional coastal flooding makes waterfront property particularly vulnerable. The number of permanent residents has fallen in the past 20 years, but people move in on a seasonal basis, especially when conditions are likely to provide for a decent season. Ports have adjusted their infrastructure and facilities. They have built temporary housing and small-scale processing facilities. Crews live in camper vans. There have been no big investments in roads to improve access, but shuttle buses now serve visitors on busy summer days during good conditions.

Ideas and Actions

In November 2021, the scenarios just described were used as a platform to spark conversations among workshop participants about potential actions. It is not possible to know which of these scenarios best represents the future. Still, by imagining each of them, we can identify possible actions that could or should be taken to help the fisheries succeed. As such, generating ideas and actions helps fishers, ports, communities, and others better prepare for any future eventuality.

Participants were asked to review the four scenarios, imagine the challenges and opportunities of each, and then identify the ideas and actions that would be needed to ensure success in such a situation. TNC prompted these conversations by organizing discussions around the following questions:

- What actions should stakeholders take now to prepare for a future like Staying Afloat, Sink or Swim, Empty Pots, or Rolling the Dice?
- What actions should stakeholders pursue to avoid difficult scenarios or ensure that preferred ones happen?
- What actions make sense in all or most of the scenarios?
- What are the short-term experiments that should be tried, given we do not know which scenario will play out?
- What are the longer-term commitments that should be made to prepare for the next 20 years—and beyond?

Suggested Ideas and Actions by Scenario

In the **Staying Afloat** scenario, one of the main concerns voiced by workshop participants was the challenge of dealing with the growth of crab fisheries. In this future scenario, it will be important to expand the infrastructure needed for all aspects of crabbing: docks and boat launches, facilities to hold live crabs, and infrastructure to ensure that visitors can buy directly from fishing vessels. Ports must also be prepared to deal with regular conflicts between users in crowded fishing waters. This scenario's growth challenges also raise the question of support for broader community needs, such as affordable housing for crews.

Staying Afloat also revealed the importance of business diversification at a time of uncertainty. It will be essential for fishing businesses to be diversified in other fisheries. Ideally, operators will have funds set aside to cope with instability. In relatively good times, this scenario might provide an opportunity to develop forms of risk pooling and insurance.

International and domestic supply chains are critical in Staying Afloat. Investments will be needed to improve distribution and transportation, such as enhancing cold storage throughout the supply chain. It will also be important to ensure that supply chains can serve domestic markets, such as adequately supplying Oregon restaurants.

Finally, the changing nature of ocean conditions and stocks will require better and more timely data to inform a more responsive fishery and fleet.

Sink or Swim represents a scenario where the viability of Oregon's crab fisheries is challenged. Domoic acid concerns come to the fore, so it is vital to ensure that testing becomes more responsive and timelier. These enhancements might require a decentralized and collaborative approach to domoic-acid hot-spot detection. To head off this scenario's worst effects, tribes and other groups might pursue eelgrass restoration to improve habitat and deliberately create ocean acidification refugia for crabs. Larger commercial operators will see returns from investing in evisceration technologies.

Another major challenge is managing the transition to larger vessels. Investments in infrastructure will need to accommodate larger boats, especially in Oregon's larger ports. This adjustment will also mean more dredging activity, especially in small ports. As with Staying Afloat, it will be critical that the fleet in any given port maintains diversification

in the Sink or Swim scenario, so flexible infrastructure is an important priority.

The China market weakens in this scenario, so developing alternative international and domestic markets will be necessary. Local consumer education is vital so that consumers are more willing to accept variability in supply.

Sink or Swim also requires preparation for future collaboration with other ocean users. Offshore wind developments might affect crab populations, so it will be important for representatives to join collaborative discussions about siting.

In terms of technology, those with deep pockets have an advantage in this scenario. Over the next 20 years, there is a case for retrofitting crab boats with hydrogen fuel, a more sustainable fuel source. Large commercial operations survive better than smaller crabbing concerns, using technologies to reduce bycatch, more effectively track stock, and build a more responsive operation that takes advantage of highly migratory species.

Empty Pots is a scenario that few will want to see. Preparing for this future—or avoiding the worst of it—will require a number of actions. In such difficult circumstances, the fleet will need to be reduced, which will most likely require a buy-out or other rationalization programs. It is uncertain what a revised fleet might look like, but it will probably focus on a few large commercial boats with smaller boats for the sports fishery.

What remains of the crab stock is under threat, so it will require a high level of care. This stewardship might mean shortening the season or ensuring zero handling mortality during the summer months.

In a world where the market is limited to live crab only, infrastructure will need to adapt to fewer products. Poor crabbing conditions will lead to a lack of investment in infrastructure for crab and other species. Local and state politicians will need to support facilities requiring maintenance and refits in the future, or even retrofits for alternative uses. Similarly, funds will be needed to ensure that estuaries' water and habitat quality are not degraded further.

Difficult situations in this scenario also raise the possibility of more ambitious plans to save or transform Dungeness crab fisheries in Oregon. We might need to consider and develop crab hatcheries. Given the likelihood of extreme weather conditions, a floating structure might need to be developed to allow vessels to continue crabbing when bars are impassable.

Workshop participants described the **Rolling the Dice** scenario as a continuation of the present-day situation, so ideas emerging from this scenario could apply right now. Success in this scenario will be all about flexibility. This adaptability might mean crabbers gaining or retaining the ability to access new fisheries and develop the markets for other species, such as market squid. Some ports already have alternate fisheries (e.g., nearshore rockfish in Port Orford), but not all small ports do.

Better information will be important in all scenarios, but it will be most critical here. It will be essential to invest in expanding and improving the weather buoy system. Any research that enables better tracking for a given year's crab populations will also be vital.

Workshop participants mentioned a whole range of infrastructure needs: maintenance and rehabilitation of jetty structures and enhancement of egress and ingress roads, boat ramps, moorage for sports boats, and ice-houses for cold storage. Also, tapping the domestic market will bring benefits, but it will require better freezing and shipping techniques. Some new innovations are emerging in the market, such as nitrogen freezing.

Themes to Ensure Future Success

In reviewing the ideas across all scenarios, a number of important themes emerged that reflect the likely paths to future success.

Flexibility

In any situation of uncertainty, nimbleness and agility is a smart bet. Crabbers have known this for

generations, but it appears even more important given climate change and the broad variability that the fishery might face in the future. In terms of business and commercial viability, operators need the ability and means to switch between fisheries to survive difficult periods, which might require new forms of access to funding or risk pooling.

Nimbleness is also required in approaches to managing the fishery. This flexibility might involve looking anew at the parameters of the current 3-S framework (i.e., size, sex, season), such as shortening seasons, adjusting the recreational size limit to equate to the commercial size limit, and many other possible ways to adjust fishery management's basic elements. Another possibility is introducing a quota-share fishery (which might work well in difficult scenarios and could be done without a stock assessment). This approach would allow the market to consolidate the fishery; however, it would also make it difficult for new market entrants.

In any scenario, it will be important for operators, fishery managers, and others to ensure that they can experiment and operate with as much flexibility as possible.

Research

Better information is critical to the future success of Dungeness crab in Oregon. It helps ensure that operators can be more effective in preparing for and reacting to conditions and that fishery managers can anticipate needs and create better plans.

There is a wide range of information needs, including a more accurate and timely assessment of domoic acid. At a fundamental level, effective research helps the industry and all stakeholders better understand the basic life history of crab. At the moment, many pieces of the puzzle are missing, such as natural mortality. The current methodology for stock assessments does not lend itself to an assessment of the Dungeness crab stock—new surveillance methods are needed to track crabs. Other information needs include salinity monitoring, or predicting instances of hypoxia or ocean acidification. Investing in weather buoys can give valuable advance information about likely crabbing conditions.

It is also important to consider the source of information and how research is conducted. In the years ahead, more decentralized data gathering is likely. Instead of relying on conventional approaches to research, it will be valuable to engage the fleet in research activity. This collective effort might involve placing sensors on crab pots and vessels to check for salinity, hypoxia, and a range of variables.

Collaboration

A more successful Dungeness crab fishery means more collaboration between different parts of the system. Effective collaboration is the result of continuing to talk, share ideas, and build trust. It needs time to develop. Initiatives such as this scenario planning project exemplify platforms that allow dialogue and collaboration.

In practical terms, it is easy to see how collaboration between scientists and operators is essential to achieve better research. Fixing supply chain problems involves fishers, port operators, and distribution and infrastructure providers. Ensuring better access to domestic markets requires connecting crabbers with local food movements.

There is also the need for collaboration across jurisdictions. For example, Oregon would struggle to produce a stock assessment for crab without support from California and Washington.

It is also worth mentioning the very real challenges of ensuring effective collaboration. Historic suspicions about forming alliances create obstacles. But suspicions will diminish and relationships will improve only by repeated interactions and dialogue over time.

Dockside sales of crab and other seafood are becoming an important part of Oregon's fishing economy. In Newport, Oregon Sea Grant's summer Shop on the Dock Program provides guided tours that teach consumers how to choose, buy, and transport fresh seafood (5).

Infrastructure

Infrastructure investment and maintenance are essential to the future success of Oregon's Dungeness crab fisheries. This theme connects strongly to the other themes—for example, the need for flexible infrastructure and how infrastructure requires a collaborative approach.

But it is also worth calling out infrastructure as its own theme. Success involves maintaining dredging requirements and some existing facilities, like jetty structures. It also requires investment in broadening accessibility to cold-storage transportation across the U.S. or to dockside tanks for live crabs.

In the future, the whole concept of infrastructure support might need to be expanded. If the biggest challenge is finding workers, then providing affordable accommodation close to ports is worth investing in.

The requirements for infrastructure investment and maintenance raise essential questions. Who pays for it? What are the sources of funding? The benefits of shared infrastructure go beyond any one organization, so collaborations between local, state, federal, and commercial organizations are likely.

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Appendix A: Full List of Suggested Ideas by Scenario

The workshop participants shared many ideas of what the future would hold should each scenario play out. This appendix summarizes their ideas.

Staying Afloat

- Diversification into other fisheries
- Development of insurance markets (risk pooling)
- Technology to address rising levels of domoic acid
- Finer-scale information about domoic acid
- Enhanced supply chain distribution and transportation
- Enhanced access and connection to local markets
- Expansion of shore docks for crabbing
- Shoreside facilities for holding live crabs (e.g., pumping seawater ashore)
- Facilities to interact with visitors and direct them to consumer markets
- Preparation of ports to manage user conflicts
- Investments in available and affordable housing for crew members
- Enhanced information to inform a more responsive fishery and fleet

Sink or Swim

- Eelgrass restoration by tribes for ocean acidification refugia
- Need for rapid domoic acid testing
- Evisceration technologies
- Diversification into international markets beyond China
- Community-supported fisheries (fish boxes)
- Education of consumers to accept more variable supplies
- Infrastructure to accommodate larger vessels
- Dredging in smaller ports
- More decentralized procedures for detecting domoic acid hot-spots
- Retrofitted crab boats to use hydrogen fuel
- Collaborations concerning the sites for any offshore wind developments
- Crab boat diversification to supply wind farms
- More research on sea otter reintroduction
- Adaptive approaches for managing domoic acid, improving response times

Empty Pots

- Buy-outs or rationalization programs to reduce the fleet size
- Shorter seasons to maintain remaining crab stocks
- Zero handling mortality during summer months
- Involvement of local politicians to modify land use laws to maintain deteriorating facilities
- Steps to ensure that the estuary water habitat does not deteriorate
- Prevention efforts to avoid filling in mudflats and seagrass beds
- Crab hatchery exploration
- Infrastructure adaptation in response to fewer products (e.g., live only)
- Floating structure developed to allow vessels to crab when bars are impassable
- Law enforcement at boat ramps

- Closer work with researchers (e.g., Oregon Sea Grant, others) to learn more about ocean acidification, hypoxia, and other challenges

Rolling the Dice

- Rehabilitation and maintenance of existing jetty structures
- Development of markets for other species (e.g., market squid)
- Increased dredging
- Investment in infrastructure: ingress and egress roads, ramps, moorage for sports boats, icehouses, and cold storage
- Expansion and continued improvement of the weather buoy system
- Data investment to track populations (e.g., stock fluctuations, migration) from year to year
- Development of better freezing and shipping techniques for domestic markets

APPENDIX B: FULL LIST OF SUGGESTED IDEAS BY ACTION AREA

The workshop participants' ideas can be categorized by the applicable scenario, as in Appendix A. Alternatively, they can be grouped into broad action areas that encompass the actions necessary to better prepare for the future conditions of a scenario(s). This appendix defines the action areas.

REACHING MARKETS

- Think about developing new markets sooner rather than later—it takes a long time to develop new markets. Learn from Positively Groundfish, who does a good job of outreach to a range of consumers (individuals, restaurants, etc.).
- Explore how to improve the product's value (through logistics on shipping, receiving, processing).
- Pursue connections with the local food movement, which was boosted during COVID-19.
- Explore different direct sales models. Learn from Bellingham Dockside Market. Their approach to more direct sales could be an option for smaller markets. Other models link Alaska's fish buying to domestic farmers markets.
- Ensure diversification in all markets (international and domestic).
- Maintain the infrastructure to distribute crab to the rest of the world. Flying crab to China is constrained due to a lack of planes.
- Explore how to keep crabs alive at the dock for longer.
- Develop tools, such as salinity monitors.

FISHERY MANAGEMENT

- Improve weather and research buoys.
- Identify funding to monitor throughout the crab season, ensuring a better understanding of the resource throughout the season.
- Increase recreational and/or commercial size limits—or ensure that the recreational size limit is the same as commercial.
- Ensure better interagency, cross-agency, and cross-state communication and coordination.
- Share management resources to get work done.
- Ensure faster management response times, especially in relation to domoic acid.
- Close the fishery early in bad seasons.
- Reduce recreational bag limits during the soft shell crab time to reduce crab waste.
- Work at the regional or West Coast level to understand the leading edge of change.
- Explore and address questions, such as:
    - Does there need to be a quota?
    - Can fishers fish on a moving stock?
- Communicate with fishers so that they know what they can and cannot do.
- Promote actions that increase the diversity of a fishing crew.
- Explore the possibility of creating a quota-share fishery (especially in the Empty Pots scenario):
    - Review recent history for a moderate/low landing year.
    - Create a window period with participation qualifications.
    - Define quotas per permit.
    - Create a six- to eight-week season that starts on December 1.
    - Evaluate landings at the end of a pre-designated timeframe, likely after the first six to eight weeks of the season.

    - If additional harvests can be taken, consider (a) having a second competitive opener or (b) adding to quotas and continuing the quota.
- A quota-share system would improve safety and allow the market to consolidate the fishery, but it would also make it more difficult for new entrants.
- Gather necessary information to conduct a stock assessment (e.g., natural mortality).
- Conduct a Management Strategy Evaluation (common objectives, operating model).
- Explore if predictive modeling of short-term ocean conditions would be viable.

Preparing for Climate Effects / Maintaining Crab Stocks

- Require more information on the impacts of domoic acid.
- Work with the fleet to provide data to validate the domoic acid prediction models.
- Collaborate with the fleet to deploy environmental sensors.
- Promote a better model of collaborative science.
- Increase public awareness of ocean acidification on Dungeness crab.
- Learn from other fisheries that have been impacted by acidification.
- Restore eelgrass areas and promote ocean acidification refugia (e.g., shell grinding).
- Add chemicals to counter acidification.
- Explore how to pull 3-S levers (i.e., size, sex, season) in different ways.
- Extend decentralized data gathering.
- Situate crab nurseries in some estuaries to maintain acidity and decrease predation.
- Collaborate with Washington and California on a stock assessment.
- Rethink the methodology for a stock assessment—develop new methods.

Infrastructure / Technology / Fleet Investments

- Develop better ways to transport and/or process smaller volumes.
- Diversify markets for a higher-value product.
- Invest in infrastructure for some fisheries to sell off the dock and in better airport access for others.
- Explore sources of investment (e.g., a revolving loan fund) and increase awareness of the costs and expenses of building infrastructure.
- Improve cold storage and transportation (vessels and port facilities).
- Decentralize data collection to inform stock assessments.
- Focus on addressing domoic acid—it is the priority issue.
- Invest in affordable housing for crew members.
- Support rapid testing for domoic acid.
- Invest in salinity sensors.
- Investigate rope-less pots.
- Modify traps for different-sized crabs.