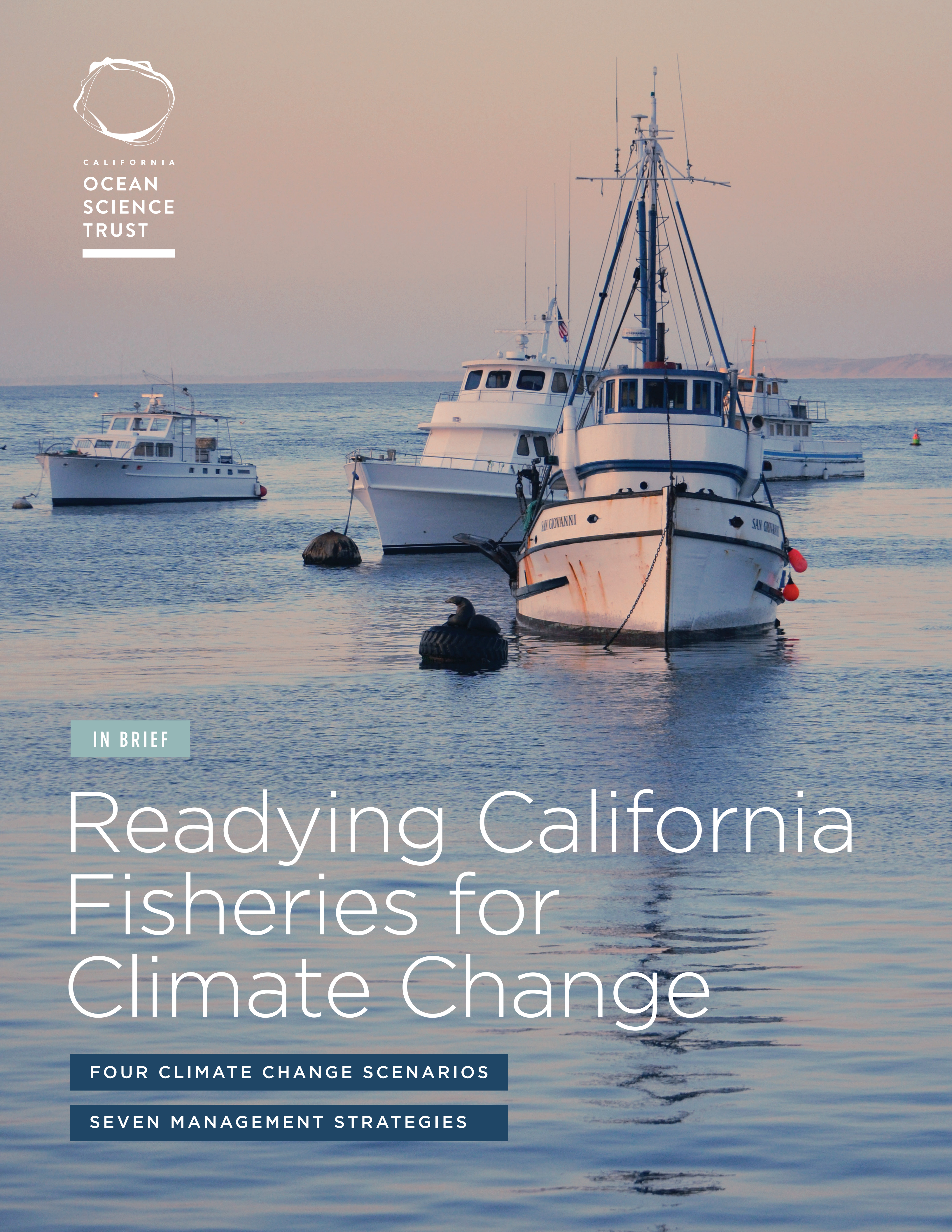


CALIFORNIA OCEAN SCIENCE TRUST

IN BRIEF

Readying California Fisheries for Climate Change

FOUR CLIMATE CHANGE SCENARIOS

SEVEN MANAGEMENT STRATEGIES

MITIGATE AND MINIMIZE CHANGING CONDITIONS. LEVERAGE NEW OPPORTUNITIES.

Climate change is already affecting California fisheries, with wide-ranging implications for all California fish stocks and fishing communities. Scientists have studied climate change impacts on fish populations and fishing communities at the national level, and have developed broad recommendations for reducing impacts. However, a paucity of scientific information that is directly applicable to California fisheries management is hampering action by state fisheries managers. This report addresses that gap.

As California works to update the primary policy guidance on fisheries management, a timely opportunity exists to provide scientific information and guidance on responding and adapting to a changing climate. A Working Group of the California Ocean Protection Council Science Advisory Team (OPC-SAT) tackled this issue with leadership from the Ocean Science Trust, the working group co-chairs, and a diverse membership including academic researchers, the National Marine Fisheries Service (NMFS), and the California Department of Fish and Wildlife (CDFW). This document has been prepared by Ocean Science Trust to distill the themes of a longer technical report that identifies the science and climate-ready options for managers and policy makers in California. The effort by the OPC-SAT Climate Change and Fisheries Working Group was convened at the request of CDFW and funded by the California Ocean Protection Council.

California's ocean supports a vast diversity of marine organisms and a vibrant fishing economy. However, increased greenhouse gases in the atmosphere are leading to a warmer ocean and more extreme climate variations. Increased frequency and severity of harmful algal blooms, loss of kelp beds in Northern California, and compromised shellfish populations are just a few of the unprecedented climate-driven changes we have already seen in California's oceans.

While no one can perfectly predict future effects of a changing climate, we do know that climate change will result in more variability and unpredictability that harm both fish stocks and fishing communities.

We Know:

- The California Current's natural variability means that fisheries managers have needed to be responsive to changing conditions. This provides managers with an important orientation to any accelerating changes wrought by a changing climate.
- The effects of climate change are wide-ranging and have linked ecological, social, and economic consequences for all California fisheries.
- Approaches exist for fisheries management that can help fishing communities and fish and invertebrate stocks prepare for, adapt to, and respond to climate variability.
- Some fisheries are now adopting flexible, adaptable management strategies as they experience the effects of a changing climate. What they're doing can be leveraged and/or applied to other fisheries to improve management throughout the state.

Fisheries are complex social-ecological systems, involving the physical environment, marine organisms, and the people who harvest, utilize, and make rules about managing these resources. This includes not only commercial, recreational, and subsistence fishermen, but also buyers, processors, wholesalers, retailers, and consumers; support industries such as equipment, fuel and ice suppliers; families and community networks; and scientists, managers, administrators, and legislators. As our climate continues to change, the entire fishery system will experience its impacts.

To provide useful guidance to all who are engaged today in building resilient fish stocks and fishing communities, the Working Group identified four possible future scenarios and the challenges they are likely to pose. Seven adaptable management strategies are offered to prepare for impacts and opportunities as our climate changes.

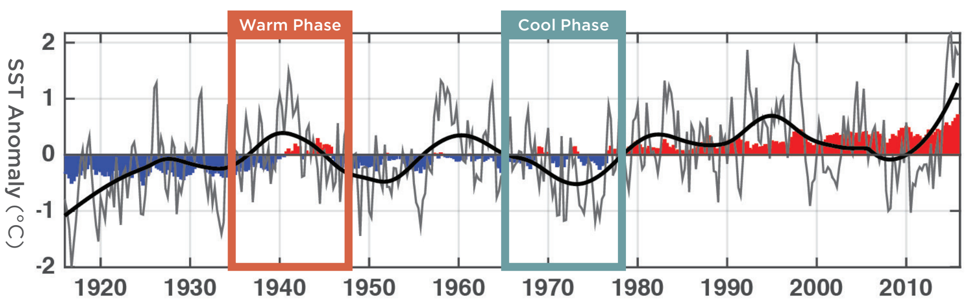
THE CALIFORNIA CURRENT

A Naturally Variable System

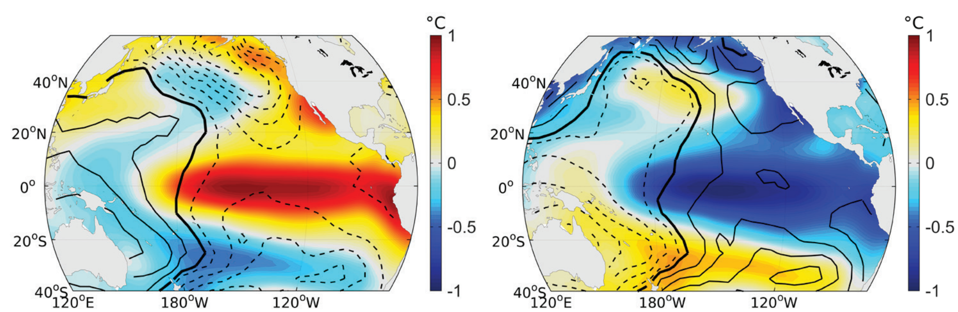
Due to climate events like the El Niño Southern Oscillation, the Pacific Decadal Oscillation, and the North Pacific Gyre Oscillation, the California Current is one of the most variable marine ecosystems in existence with climate and ocean temperature changes occurring on seasonal, yearly, and decadal timescales.

Simply put, the system regularly fluctuates between cool and warm conditions. In general, cool conditions tend to be more productive than warm conditions, as more nutrients are available in cool waters for phytoplankton and ecosystem production. These variable conditions drive population replenishment, species composition and distribution, and overall production, all affecting fishermen and their communities.

The California Current fluctuates between warm and cool phases. Many fish and invertebrate stocks favor either warm or cool environmental phases.



Global (color, red & blue), **California** (annual, black line; seasonal, grey line)



Sea Surface Temperature (SST) **Anomaly** (°C)

Warm Phase Favoring Stocks

- Basses (Kelp Bass, Barred Sand Bass, Spotted Sand Bass)
- California Halibut
- California Sheephead
- California Spiny Lobster
- Kellet's Whelk
- Pacific (Chub) Mackerel
- Pacific Bonito
- Pacific Sardine
- White Seabass

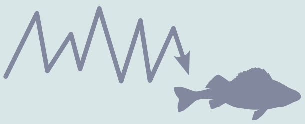
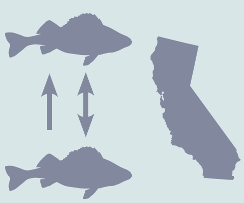
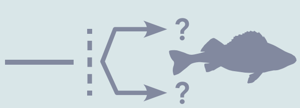
Cool Phase Favoring Stocks

- California market squid
- Chinook salmon
- Dungeness crab
- Geoduck clam
- Most groundfish
- Northern anchovy
- Ocean (pink) shrimp
- Pacific halibut
- Red abalone

THE IMPACT OF CLIMATE CHANGE

Four Potential Scenarios

Climate change is affecting all fisheries, but limitations of global and regional climate models make it difficult to predict specific changes. However, present knowledge exists to identify four climate-related scenarios for the California Current. In order to make recommendations that are relevant to fisheries management, the scenarios focus on a suite of potential impacts to fish stocks. They also consider impacts to the wider ecosystem and the fishing communities that depend on these stocks. These four scenarios are based on a comprehensive literature review and are not mutually exclusive. Elements from each may occur if climate trends continue.

	SCENARIO	RESPONSES & IMPACTS	VULNERABILITY
NO IMPACT OF CLIMATE CHANGE	**1 Historical Variability**  Historical climate variability is characterized by fluctuations between warm and cool phases. Cool phases are generally more productive for some fisheries, while warm phases are more productive for others.	**Ecological Impacts** Productivity of stocks fluctuates with warm (less productive) and cool (more productive) conditions. Species shift their range to 'follow' favorable environmental conditions. **Potential Human Responses** No change, increase effort, shift or diversify target species, follow the fish, increase non-fishing activity. **Potential Social & Economic Implications** Patterns of activity and associated costs and benefits shift as fishery participants adapt to opportunities or cope with loss; participants modify or expand social networks.	**Fish & Invertebrate Stocks** Species that favor warm conditions include sardines, highly migratory species, and California spiny lobster. Those that favor cool conditions include Northern anchovy, Dungeness crab, Pacific halibut, and spot prawn. **Fishing Communities** Highly specialized and localized fisheries, those without the ability to adapt to new fishing opportunities, and/or those without integrated and diversified socioeconomic systems are more vulnerable.
DIRECTIONAL CLIMATE CHANGE	**2 Increased Variability**  Increased climate and oceanographic variability causes extreme and sometimes unpredictable environmental conditions (e.g., warming, ocean acidification, hypoxia, more extreme/frequent storms, erosion, and flooding of coastal areas).	**Ecological Impacts** Contraction and expansion of species' spatial distributions and variable or possibly reduced fish production. **Potential Human Responses** All responses listed in historical variability plus leave fishing. **Potential Social & Economic Implications** Variable economic returns; higher costs (fuel, learning, shifting); disruption in fishery support and seafood distribution links; safety concerns due to volatile weather; social, cultural and economic stress; modified or expanded social networks; increased production may lead to economic gains in some sectors; enhanced fishery and community well-being.	**Fish & Invertebrate Stocks** Highly specialized or localized species and calcifying organisms are more vulnerable. Long-lived species with built-in buffer to high variability are less vulnerable. **Fishing Communities** Highly specialized and localized fisheries, small-scale fishing operations, those with specialized gear, and communities dependent on a small number or narrow range of species are more vulnerable.
	3 Range Shifts  Long-term warming trends, more frequent warm phases, and fewer cool phases can lead to changes in acidity, temperature, and ocean circulation.	**Ecological Impacts** Changes in quality and/or quantity of prey; range contraction and/or reduced production of species that favor cool-more productive conditions; range expansion of species that favor warm-less productive conditions; changes in species life histories due to warming (tropicalization). **Potential Human Responses** No change, shift or diversify target species, follow the fish. **Potential Social & Economic Implications** Higher costs (fuel, learning, shifting); disruption in fishery support and seafood distribution links; displacement of existing fishery participants; modified or expanded social networks; increases in fishing opportunity result in economic benefits.	**Fish & Invertebrate Stocks** Populations near the poleward edge of their distribution and species that favor cool conditions are more vulnerable. **Fishing Commuities** Small-scale fishing operations, those without access to permits, and those not in risk-sharing networks are more vulnerable.
	4 Crossing Thresholds  Slow and steady changes in ecosystem properties can result in dramatic, rapid, and step-wise shifts in species composition and food web productivity when a threshold in one or several of these properties is crossed. The properties may be either biotic or abiotic.	**Ecological Impacts** A step-wise change in the CCLME may result in an extreme case of tropical- or subarctic-dominated systems or to a fundamentally different ecological state. These shifts are difficult to predict in terms of their timing, magnitude, and ecological state. **Potential Human Responses** No change, shift or diversify target species, increase nonfishing activity, leave fishing. **Potential Social & Economic Implications** Risk of economic disaster for fishing communities; potential for emerging fisheries; participants modify or expand social networks.	**Fish & Invertebrate Stocks** Highly specialized or localized species are more vulnerable. Generalist species are better able to adapt to changes. **Fishing Communities** Communities with less livelihood diversity, smaller-scale fishing operations, or those that rely on a smaller range of fisheries are more vulnerable.

MANAGING FOR A CHANGING CLIMATE

Increasing responsiveness and adaptability will prepare fisheries management for more variability and unpredictability.

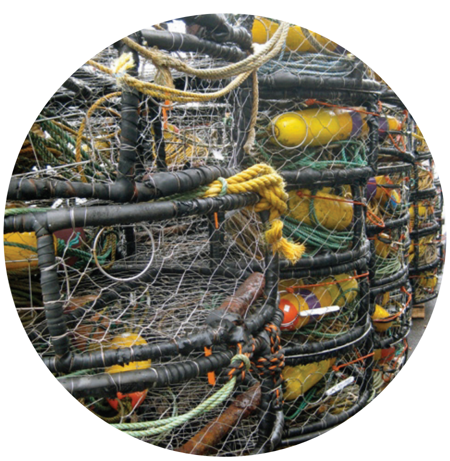
The California Sardine Fishery: Management Accounting for Environmental Variability

With variability in climate comes variability in fish stocks. Accordingly, the California sardine fishery has a climate indicator explicitly written into its harvest control rule in support of a healthy fish stock. With increasingly variable cycles expected, managers should consider adding this type of indicator into other fisheries.

Sardines favor warm phases of the California Current; reproduction is generally less successful during cool conditions. The fishery's harvest control rule -- a higher harvest under warmer temperatures and lower harvest under cooler temperatures -- is designed to reduce fishing pressure when the population is particularly vulnerable. Simulations suggest that the probability and duration of the drastic sardine collapse in the early 1950s could have been substantially reduced if harvest rates had been lower during that cold period.

Prevent Missed Opportunities in Expanded Fisheries

In 2014, squid became abundant north of the fishery's typical range and a small number of permittees and associated buyers briefly shifted their efforts, with squid trucked south to processing facilities. Fishermen's ability to access opportunities depends on the adaptive capacity of fishing communities and flexible and timely permitting approaches that respond to range shifts.



Prepare for Harmful Algal Blooms

In 2015 and 2016, California's Dungeness and rock crab fisheries experienced unprecedented impacts when a harmful algal bloom prompted closures to protect public health. The closures delayed the season statewide and caused financial and social impacts on fishing communities. Climate change may increase the frequency of harmful algal blooms, highlighting the need to better understand these events and prepare for their impacts.

SEVEN MANAGEMENT STRATEGIES

Based on a review of recent literature from around the nation, the team identified seven management strategies that managers and decision-makers should consider in preparing fisheries for the ecological scenarios outlined above. These approaches were selected because they have sound scientific grounding, make sense given the variability of the California Current itself, and are practical from an implementation perspective. Many can be adopted now; some are already in use. Others need prior monitoring, financial investment, and/or coordination between agencies, which will also require time, planning, and potentially support by other agencies and/or entities. Effectively addressing both existing variability and the effects of future climate change will require a thoughtful portfolio of proactive and reactive approaches and actions.

LESSONS FROM THE EAST COAST

Management Flexibility

The East Coast of the United States is experiencing a number of climate-related fisheries impacts that convey lessons for the West Coast. Management flexibility could have helped to avoid the economic collapse of the Atlantic cod fishery. Shellfish and crustaceans were increasing due to absence of predation from cod. Fisherman were not able to switch between these species due to rigid regulation of fishing permits. This led to unemployment for families that harvested cod. Flexible management strategies that allow for switching species may also put less pressure on cod stocks and may also be more resilient to changes in abundance or species composition of marine ecosystems.

As climate change continues, scientists anticipate more variability and less predictability for California fisheries. While existing management approaches have allowed managers to adapt, to some extent, to the high degree of inherent variability in the California Current, it is crucial that managers now adopt flexible, responsive, and adaptable management tools and strategies to increase ecological and social resilience to changes that may occur under any scenario.

MANAGEMENT STRATEGIES

1. MANAGE FOR ECOLOGICAL RESILIENCE

A resilient ecological system is able to withstand or recover from impacts related to climate and ocean changes.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
1.1 Reduce compounding stressors Reduce compounding non-climatic stressors (e.g., pollution) that interact with climate change impacts and have negative effects on fish	MLMA MLPA	$$$	Yes
1.2 Apply the precautionary principle in stock management Apply the precautionary principle in stock management for those stocks that are expected to be negatively impacted by climate change	MLMA	$	No
1.3 Manage for population structure Protect age-structure diversity in fish stocks	MLMA MLPA	$	No
1.4 Evaluate vulnerability of fish stocks A ranked vulnerability index of fish stocks would assist in the prioritization of investment and management action	MLMA	$$	Yes
1.5 Expand climate and fisheries research Increase understanding of how fisheries respond to climate change	MLMA	$$	No
1.6 Protect nursery grounds and/or essential fish habitat Work with agencies and partners to protect fish habitat	MLMA MLPA	$$	Yes

* cost refers to the relative cost incurred by CDFW and does not include existing investments.

** identifies approaches that may require either monitoring or research to plan or implement.

2. MANAGE FOR SOCIAL RESILIENCE

A resilient social system is able to respond and recover from impacts related to climate and ocean changes.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
2.1 Adopt flexible permitting mechanisms Processes that provide flexible permitting, both at the individual fisherman level as well as for groups (co-ops; fishing communities)	MLMA	$	Yes
2.2 Promote collaborative planning and research among fishermen, managers, and partners Fishing communities brainstorm with managers about adaptation approaches; collaborative research projects can improve fisheries and MPA management	MLMA MLPA	$	No
2.3 Work with fishing communities to plan for unexpected changes Collaborate to identify and implement strategies for coping with and adapting to challenges associated with climate change	N/A	$	No
2.4 Evaluate vulnerability of fishing communities Develop methods to rapidly assess vulnerability of fishing communities	MLMA	$$	Yes

3. INCREASE MANAGEMENT ADAPTABILITY

Given the substantial variability and uncertainty that is expected to be associated with climate change, it will be important to ensure that fisheries governance is prepared to anticipate and respond effectively and appropriately.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
3.1 Incorporate adaptable catch control rules Adopt rules to adjust fishing effort in accordance to historical and increased variability due to climate change	MLMA	$$	Yes
3.2 Account for climate change in stock assessments Incorporate environmental variability and uncertainty into stock assessments	MLMA	$$	Yes
3.3 Move single-species conservation area boundaries when needed Adjust conservation area boundaries if no longer effective in protecting the target fished species (e.g., rockfish conservation areas)	MLMA MLPA	$$	Yes
3.4 Change seasonal closures when needed Adjust season closures to reflect current stock phenology, if needed	MLMA	$$	Yes
3.5 Incorporate changes in indicators/ecological factors into management Link monitoring information to management approaches	MLMA MLPA	$$	Yes
***3.1**, **3.3**, **3.4**, and **3.5** are reactive approaches - where management is rapidly updated in response to a change after it has occurred.*			

* cost refers to the relative cost incurred by CDFW and does not include existing investments.

** identifies approaches that may require either monitoring or research to plan or implement.

4. SUPPORT FISHERIES TRANSITIONS

Support is needed not only to help fisheries participants negatively impacted by changing ocean conditions but also to access new fishing opportunities.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
4.1 Manage for human well-being Improve human well-being as an integral part of environmental sustainability	MLMA	$$	Yes
4.2 Prepare for emerging fisheries Create a management strategy that provides opportunities for fishermen to target new species while ensuring that any new fishery is sustainable	MLMA	$$	Yes
4.3 Establish a new permitting program/policy to change access to expanded or emerging fisheries Develop new program, legislation or policy utilizing indicators of stock range shifts and status to allow temporary changes to access expanded fisheries	MLMA	$	No
4.4 Plan for tipping points Prepare management for crossing thresholds	MLMA	$$	Yes

* cost refers to the relative cost incurred by CDFW and does not include existing investments.

** identifies approaches that may require either monitoring or research to plan or implement.

5. STRENGTHEN MONITORING AND FORECASTING

Improving targeted monitoring and forecasting will help managers better understand fluctuations in oceanographic conditions and ecosystem responses.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
5.1 Increase collection of effort information Improve data collection on fishing effort in addition to fisheries landings	MLMA	$$	No
5.2 Identify critical biophysical, social and ecological indicators to monitor Develop indicators for better detection and prediction of when species have begun to experience range shifts, decline in abundance, or cross thresholds	MLMA MLPA	$$	Yes
5.3 Expand monitoring to inform both MLMA and MLPA objectives Develop MPA monitoring metrics that will also benefit fisheries management	MLMA MLPA	$$	No
5.4 Streamline monitoring programs Coordinate efforts so that costs may be minimized or leveraged by streamlining monitoring and reducing duplicative or unneeded monitoring effort	MLMA MLPA	$	Yes
5.5 Inventory ecological hotspots Identify and map locations vulnerable to ocean acidification, hypoxia, and other climate change impacts	MLMA MLPA	$	No
5.6 Support regional climate change impact projection projects Downscale climate models to provide projections for specific locations and build long-term forecasting	MLMA MLPA	$$$	Yes
5.7 Implement co-monitoring Incorporate data collection by fishermen and citizen science groups into monitoring programs	MLMA MLPA	$	No

* cost refers to the relative cost incurred by CDFW and does not include existing investments.

** identifies approaches that may require either monitoring or research to plan or implement.

6. EXPAND CROSS-BOUNDARY COORDINATION

As fish shift northward and into new areas, there will be a need for more regional, national, and international coordination.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
6.1 Increase interagency coordination Facilitate coordination across agencies	MLMA MLPA	$	No
6.2 Expand transboundary fisheries management Facilitate coordination across political boundaries	MLMA PFMC NMFS	$	No
6.3 Expand meaningful engagement with Tribes and Native Communities Collaborate with California Tribes and Native Communities to determine potential climate change impact on traditionally harvested stocks	FGC and CDFW tribal policies	$	No

7. INCREASE RESEARCH AND MANAGEMENT CAPACITY

Partnerships can help bring capacity and support to implement climate-ready management approaches.

APPROACH	SUPPORTED BY	RELATIVE COST*	PRIOR MONITORING NEEDED?**
7.1 Identify and address personnel and funding needs Additional personnel and funding will be needed to address new research and management efforts	MLMA MLPA	$$	No
7.2 Expand training and other capacity-building opportunities for fisheries professionals Invest in training for fisheries professionals	MLMA MLPA	$$	No

* cost refers to the relative cost incurred by CDFW and does not include existing investments.
** identifies approaches that may require either monitoring or research to plan or implement.

Further Reading

Chavez, F. P., C. Costello, D. Aseltine-Neilson, H. Doremus, J. C. Field, S. D. Gaines, M. Hall-Arber, N. J. Mantua, B. McCovey, C. Pomeroy, L. Sievanen, W. J. Sydeman, and S. A. Wheeler. Readying California Fisheries for Climate Change (California Ocean Protection Council Science Advisory Team). California Ocean Science Trust, Oakland, California, USA.
The report linked to this In Brief. Guidance to California fisheries managers on potential impacts of climate change on fisheries (state-managed fish and invertebrate stocks and associated fishing communities) and management approaches to prepare for these changes. Full report available at www.oceansciencetrust.org/projects/climate-change-and-california-fisheries

Pinsky, M. L., and N. J. Mantua. 2014. Emerging adaptation approaches for climate-ready fisheries management. Oceanography 27:147-159.
Presents eight approaches that fisheries managers can use to potentially reduce the impact of climate change on people and ecosystems.

Sydeman, W. J., and S. A. Thompson. 2013. Potential impacts of climate change on California's fish and fisheries. Farallon Institute.
Report that synthesizes impacts of climate change on fish stocks and marine ecosystems in California.

Contacts

Leila Sievanen
Associate Scientist,
Ocean Science Trust
leila.sievanen@oceansciencetrust.org

Francisco P. Chavez
Sr. Scientist, Monterey Bay Aquarium Research Institute
chfr@mbari.org

Christopher Costello
Professor, University of California, Santa Barbara
costello@bren.ucsb.edu

Photo Credits

COVER: © D. Parks
PAGE 2: © S. Towes
PAGE 3: © S. Towes
PAGE 4: © S. Howzit
PAGE 5: © C. Pomeroy
PAGE 7: *(top to bottom)* © S. Webster, © K. Kurtis © V. Termini
PAGE 8: © O. Dodd
PAGE 10: © NOAA National Marine Sancutary
PAGE 12: © T. Wise
PAGE 15: © S. Johnson

Funding was provided by the California Ocean Protection Council.

CALIFORNIA OCEAN PROTECTION COUNCIL

California Ocean Protection Council OPC-SAT Science Advisory Team

CALIFORNIA OCEAN SCIENCE TRUST