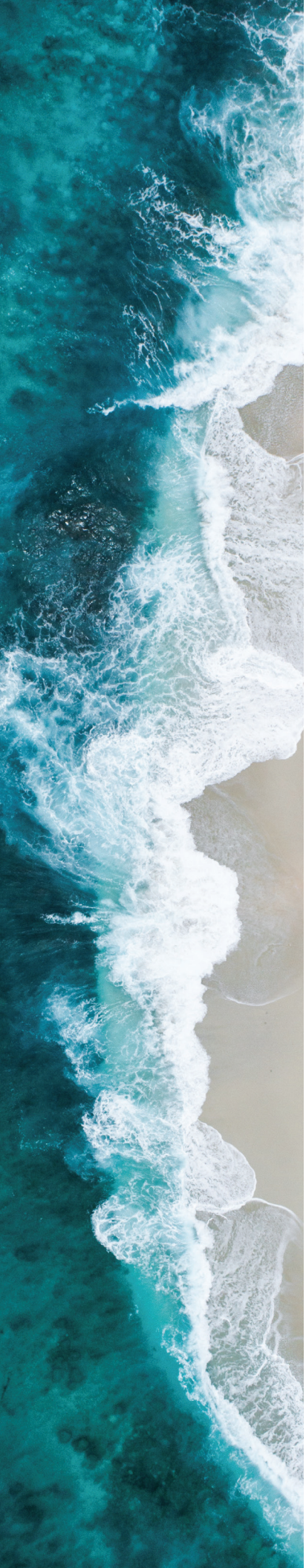
STATE OF CALIFORNIA

OCEAN ACIDIFICATION Action Plan

OCTOBER 2018



About this Document

This State of California Ocean Acidification Action Plan (Action Plan) was produced by the California Ocean Protection Council in cooperation with the California Ocean Science Trust. It articulates a 10-year vision for addressing ocean acidification and a series of pragmatic actions to work towards that vision. It is designed for integration into public agency operations and to inform decisions made by members of the private sector and scientific community. It was developed within the framework of the International Alliance to Combat Ocean Acidification (OA Alliance), a global partnership founded in 2016 to assist governments in taking meaningful action to anticipate, mitigate, and adapt to the significant changes to the chemistry of the world's oceans that are now occurring as a result of carbon dioxide (CO_2) emissions and other contributors. This Action Plan fulfills one of California's obligations to the OA Alliance, is consistent with the OA Alliance's goals and may serve as a model for other jurisdictions seeking to undertake concrete actions to better understand, mitigate, and adapt to ocean acidification.

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Acknowledgments

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Executive Summary

GLOBAL CARBON EMISSIONS are driving changes not only to the Earth's climate, but also to the chemistry of the world's oceans. The oceans are acidifying because they are absorbing a significant share of the carbon dioxide (CO_2) released primarily by the burning of fossil fuels and changing land uses.

Ocean acidification (OA) is accelerating rapidly, with enormous implications for the health and productivity of California's coastal and ocean ecosystems and the communities and industries that depend on them. From corroding shells and skeletons of marine organisms to disrupting normal fish behaviors, OA has the potential to alter marine food webs and ecosystems and the benefits they deliver to society, including California's $45 billion ocean-based economy.

Addressing this threat requires a sustained, multi-pronged approach to both mitigate acidification at a local and statewide scale and manage the resulting disruptions. This Action Plan lays out six strategies and related actions to identify and prepare for a full range of risks and impacts, reduce the causes of OA, improve the resilience of vulnerable groups, and minimize harmful effects. Among the strategies and actions:

1. **Prepare for a full range of OA risk and impacts**
   - Conduct a statewide vulnerability assessment
   - Make targeted investments in monitoring to inform decision making
2. **Activate responsible elements of state government**
   - Integrate OA into state policies, planning and operations
3. **Reduce the pollution that causes OA**
   - Identify and reduce local water-borne and airborne pollution that exacerbates OA
   - Develop technical tools
4. **Deploy living systems to slow OA and store carbon**
   - Restore and enhance seagrass meadows, kelp forests and salt marshes
   - Evaluate and advance aquaculture approaches that can help
5. **Build resilience of affected communities, industries and interests**
   - Establish a statewide advisory group
   - Advance resilience of shellfish aquaculture industry and fisheries industry
6. **Engage beyond state borders**
   - Import lessons from other geographies to speed and improve California's OA efforts

Ocean acidification is fundamentally a shared global water pollution problem driven largely by absorption of global CO_2 emissions. The effectiveness of global and regional efforts to reduce CO_2 emissions will play a large role in determining how much the oceans acidify and the environmental and social disruption that results.

In 2016, California became one of the founding members of the International Alliance to Combat Ocean Acidification (OA Alliance), an international network of more than 60 governments and organizations that have joined together to elevate the visibility of OA in public discourse and policy development and to push for the inclusion of strong ocean protection provisions in international climate agreements. This Action Plan fulfills one of California's obligations to the OA Alliance and may serve as a model for other jurisdictions seeking to undertake concrete actions to better understand, mitigate, and adapt to OA.

PART I

Introduction: An Ocean Acidification Action Plan for the State of California

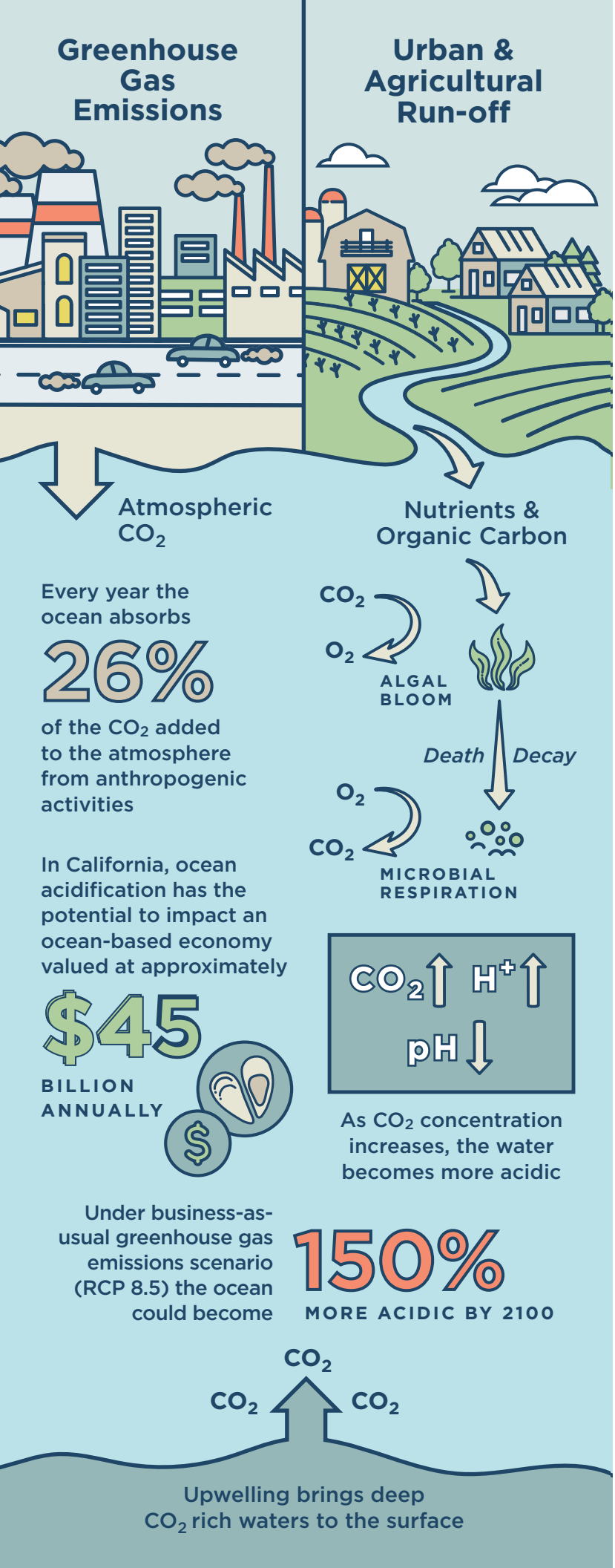
What is Ocean Acidification and Why is California Taking Action?

Ocean acidification (OA) is a complex, but actionable threat to California's coast and oceans that requires a sustained, multi-pronged approach to both mitigate acidification at a local and statewide scale, as well as manage the resulting disruptions. Global emissions of CO_2 since the start of the industrial revolution have been driving not only changes to the Earth's climate, but also fundamental shifts to the chemistry of the world's oceans. The oceans are acidifying because they are absorbing a significant share of the CO_2 released primarily by the burning of fossil fuels and changing land uses (Figure 1) on the following page. OA is progressing rapidly, with average surface acidity of the world's oceans expected to double from that of preindustrial levels by the end of this century. Of particular concern to California policymakers, scientists expect the west coast of North America to experience some of the earliest and most severe changes, because the wind-driven upwelling that fuels the region's high productivity also will bring increasingly acidified waters to the surface.

[1] For additional detail about the pattern, process, and impacts of OA see findings and reports of the West Coast Ocean Acidification and Hypoxia Panel available at http://westcoastoah.org/westcoastpanel/

[2] The world's oceans have absorbed about a third of the CO_2 released through human activities since the start of the industrial revolution. CO_2 dissolved in seawater goes through chemical reactions that cause a decline in pH and the availability of carbonate minerals, and an increase in the partial pressure of CO_2. These changes can have important effects on the calcification, physiology, and behavior of many marine species that can translate into system-level impacts on nutrient cycling, food web dynamics, and ecosystem processes. See: Somero, G.N. et al. 2016. What changes in the carbonate system, oxygen, and temperature portend for the northeastern Pacific Ocean: A physiological perspective. BioScience 66: 14-26; Klinger, T., et al. 2017. Using integrated, ecosystem-level management to address intensifying ocean acidification and hypoxia in the California Current large marine ecosystem. Elem Sci Anth 5:16.

[3] See also: Sievanen, Leila*, Phillips, Jennifer*, Charlie Colgan, Gary Griggs, Juliette Finzi Hart, Eric Hartge, Tessa Hill, Raphael Kudela, Nathan Mantua, Karina Nielsen, Liz Whiteman. 2018. California's Coast and Ocean Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCC4A-2018-011. http://www.climateassessment.ca.gov/state/docs/20180827-OceanCoastSummary.PDF



OA is part of a system of interacting stressors facing marine ecosystems along the California coast, challenging the ability of California natural resource managers' to meet their goals and vision for healthy, functioning ocean and coast. OA will have important effects on marine animals and plants that can translate into impacts on coastal and marine fisheries, ecosystems, food webs, and the benefits they deliver to society, including California's ocean-based economy valued at approximately $45 billion annually.

Harnessing International Momentum on OA

Today, California is actively participating in a groundswell of international action on OA, and climate change more broadly. Ocean acidification is fundamentally a shared global water pollution problem driven largely by absorption of global CO_2 emissions. The effectiveness of global and regional efforts to reduce CO_2 emissions will play a large role in determining how much the oceans acidify and the environmental and social disruption that results. In 2016, the state became one of the founding members of the International Alliance to Combat Ocean Acidification (OA Alliance), an international network of more than 60 governments and organizations that have joined together to elevate the visibility of OA in public discourse and policy development and to push for the inclusion of strong ocean protection provisions in international climate agreements (see box, on following page). This Action Plan fulfills one of California's obligations to the OA Alliance, is consistent with the OA Alliance's goals (see Appendix 1), and may serve as a model for other jurisdictions seeking to undertake concrete actions to better understand, mitigate, and adapt to OA.

FIGURE 1: Ocean acidification 101. Global carbon emissions are the dominant cause of OA, though local factors including nutrient and organic matter pollution, and land use changes can exacerbate conditions at local scales. Ocean acidification is triggering changes that are expected to have wide ranging and significant impacts on marine ecosystems and coastal communities.

Figure 1 adapted from The Nature Conservancy "Washington and Ocean Acidification" figure (Washington Marine Resources Advisory Council (2017). Facts from: NOAA PML, 2018; UNESCO, 2017; IPCC, 2018.

About the International Alliance to Combat Ocean Acidification

The International Alliance to Combat Ocean Acidification (OA Alliance) brings together jurisdictions across the globe to combat ocean acidification and changing ocean conditions as an immediate and critical threat to coastal economies and ocean ecosystems. Members benefit from working together to mitigate carbon emissions and other contributors to OA, sharing knowledge about the impacts, and learning how to adapt locally to the ongoing changes in ocean conditions.

Globally, the OA Alliance is:

- Supporting governments to take meaningful actions to address changing ocean conditions
- Pushing for inclusion of strong ocean protection provisions in international climate agreements and other relevant frameworks
- Creating a coalition of governments and partners to elevate the visibility and importance of ocean acidification in public discourse and policy development

OA Alliance members are encouraged to create an Action Plan that describes their unique contribution to advancing some or all the 5 goals of the OA Alliance as written in the Call to Action. The Alliance's Call to Action provides an immediate opportunity for parties across the globe to highlight ocean acidification as an imminent threat to coastal economies and ocean ecosystems.

For more on the OA Alliance, including the OA Action Plan toolkit, see Appendix 3 and visit https://www.oaalliance.org.

OA ALLIANCE International Alliance to **Combat Ocean Acidification**

OA Legislation in California

Assembly Bill No. 2139, Williams. Ocean Protection Council: ocean acidification and hypoxia (2016). This bill authorizes the OPC Council (OPC) to develop an ocean acidification and hypoxia science task force to ensure that council decision making is supported by the best available science. It also requires the OPC to take specified actions to address OA and hypoxia and adopt recommendations for further actions that may be taken.

In response to AB 2139, the OPC called for the creation of the California Ocean Acidification and Hypoxia Science Task Force (see here: www.westcoastoah.org).

Senate Bill No. 1363, Monning. Ocean Protection Council: Ocean Acidification and Hypoxia Reduction Program (2016). This bill requires the OPC, in consultation with the State Coastal Conservancy and other relevant entities, to establish and administer the Ocean Acidification and Hypoxia Reduction Program, and proposes authorization of funding for grants or loans for projects or activities that further public purposes consistent with the Ocean Acidification and Hypoxia Reduction Program.

Early progress on SB 1363 included OPC investments in OA monitoring in seagrass beds and convening of an OPC Science Advisory Team working group to explore the use of seagrass as an ocean acidification management tool in California (see here: http://westcoastoah.org/resources/california/)

Building on a History of OA Action in California

California has identified OA as a priority issue for over 10 years (Figure 2). The devastating failure of oyster hatcheries in the Pacific Northwest between 2006 and 2009 signaled the first OA-related warning sign in our region and led to the establishment of a Blue Ribbon Task Force and a landmark OA action plan for the State of Washington.[4] Research and observations since then have shown widespread shell corrosion among certain zooplankton and sensitivity of many shellfish to acidifying conditions, and suggest that commercially valuable fisheries along the West Coast could be at risk.[5]

The scientific foundation for this Action Plan was laid by California's prompt response to the oyster hatchery failures in the Pacific Northwest. In collaboration with Oregon, Washington, and British Columbia, California spearheaded the West Coast Ocean Acidification and Hypoxia Science Panel (Panel) – a multi-disciplinary regional effort to synthesize the state of knowledge and identify potential management options.[6] Following release of the Panel's findings in 2016, the California State Legislature passed two related bills – Assembly Bill 2139 and Senate Bill 1363 – that charged the OPC to test potential OA mitigation methods, be responsive to the Panel's recommendations, and ensure the state continues to receive the best available scientific advice through establishment of a science task force (see box, above).[7] Over the past two years, the OPC has made several strategic investments in OA-related science that is fundamental to taking effective action.[8]

[4] Washington State Blue Ribbon Panel on Ocean Acidification (2012). Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response. Washington Department of Ecology.

[5] See: Bednaršek, N., et al. 2017. Exposure history determines pteropod vulnerability to ocean acidification along the US West Coast. Nature Scientific Reports 7: 4526; Busch, S. and P. McElhany. 2016. Estimates of the direct effect of seawater pH on the survival rate of species groups in the California Current Ecosystem. PLoS ONE 11(8): e0160669; 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.

[6] Recommendations of the earlier West Coast Ocean Acidification and Hypoxia Panel generally focused on addressing local factors that affect OAH exposure, enhancing the ability of biota to cope with OAH stress, and expanding and integrating knowledge about OAH. See http://westcoastoah.org/westcoastpanel/

[7] The Ocean Acidification and Hypoxia Science Task Force serves as a responsive advisory body that provides scientific guidance to the OPC in an ongoing manner to inform continued actions on ocean acidification and hypoxia in California and along the West Coast. To learn more see http://westcoastoah.org/taskforce/about/

[8] For an overview of OPC OA investments since 2018, see: http://westcoastoah.org/resources/california/ and http://www.opc.ca.gov/opc-climate-change-program/ocean-acidification-2/

The Scope of the State of California Ocean Acidification Action Plan

The primary purpose of this Action Plan is to provide a roadmap for the State of California to take tractable and strategic actions and make targeted investments to reduce and prepare for the impacts of OA. The ten-year vision that follows lays out the state's aspirations for making progress on OA. Six strategies, developed around a 5-year timeline, form the organizing framework for the Action Plan, which is designed for integration into public agency operations and to inform decisions made by members of the private sector and scientific community.

Although it focuses on California's particular needs and opportunities, these are cast within a regional, national, and international context, where appropriate, to achieve state goals, advance global efforts and collaboration, and help other jurisdictions move forward on this challenging problem. Some actions in the Action Plan address OA as a stand-alone issue and others address OA within the context of other environmental drivers and changes, as appropriate to the policy or management circumstances (Box 1).

California's well-established policies for furthering good stewardship of our oceans and addressing climate change provide a supportive and enabling context for advancing state actions on OA (Box 2). Many existing programs, processes, and capacities can be leveraged to advance action on OA. Moreover, the state's experiences undertaking innovative approaches to ocean stewardship and climate change demonstrate California's ability to tackle tough, seemingly intractable problems, and they provide useful insights and models that this plan draws on to improve the speed and effectiveness of California's OA actions.

Looking Forward

Looking forward, this Action Plan is the first step in a much longer effort. This Action Plan acknowledges the complexity and jurisdictional challenges that arise as a result of the spatial disparity between the drivers and impacts: the major drivers of OA originate largely from land-based activities, while impacts manifest in ocean and coastal regions. It is recognized that long-term, comprehensive actions to mitigate OA must therefore span the land-sea interface. This Action Plan, while focused largely on mitigation and management actions for ocean and coastal systems, lays the groundwork for future actions that look beyond OA as solely an ocean issue.

Scientific understanding of OA is rapidly evolving, as is experience worldwide in identifying and implementing strategies to mitigate and adapt to OA. Periodic assessment of progress on the Action Plan and revisions to update and refine it should be undertaken at a minimum of every 5 years to incorporate what has been learned from California's experience and the experiences of others.

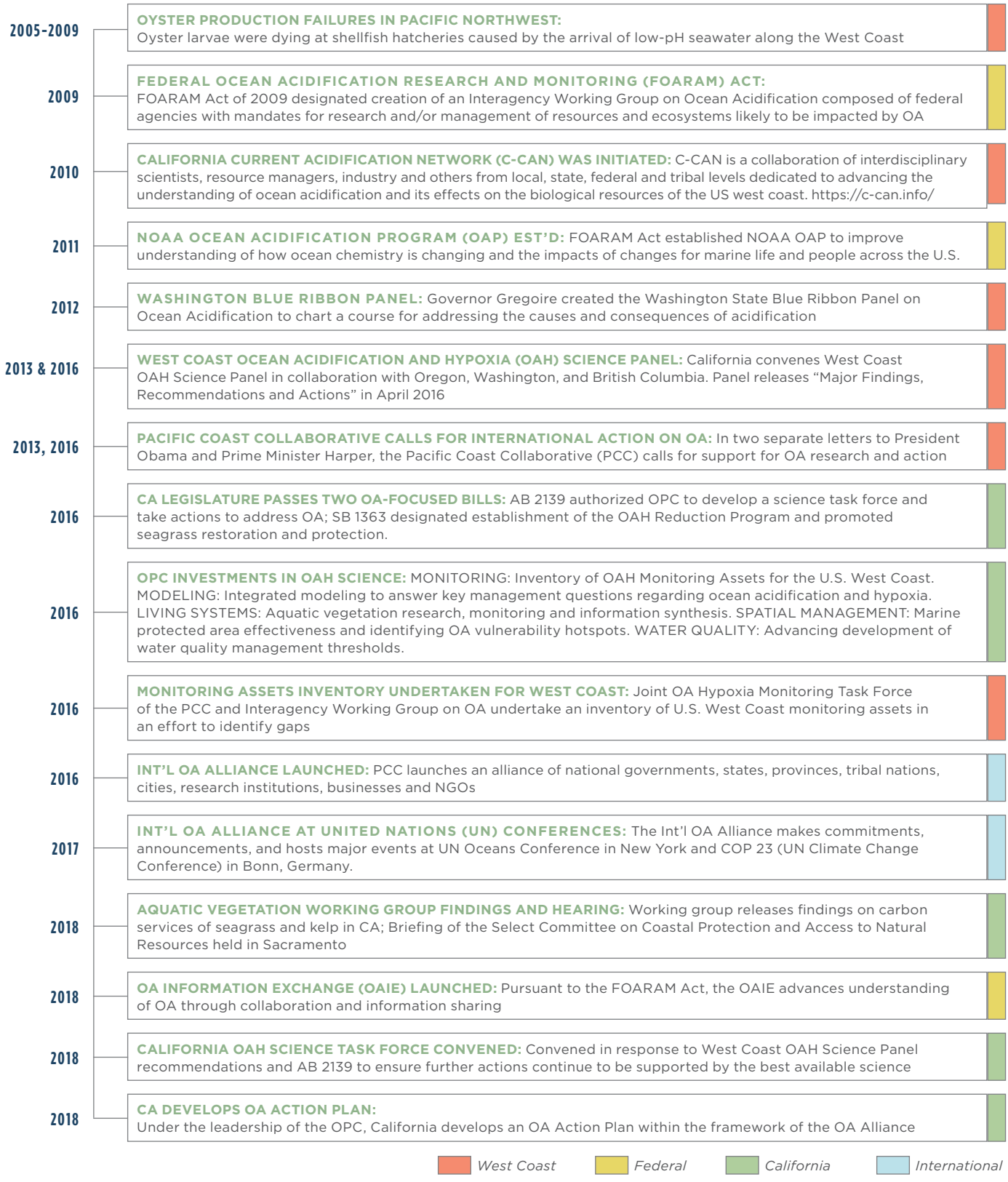


FIGURE 2: OA policy milestones. Since the oyster production failures in the Pacific Northwest, California has participated in a groundswell of action on OA in recent years, including investing in research and monitoring, passing state legislation, and identifying science-based options to address OA at regional and local levels. Meanwhile there has been significant progress on OA at regional, national, and international scales. The timeline above outlines these key milestones, though is not intended to be comprehensive.

BOX 1:

How the Plan Addresses Ocean Acidification within the Context of Other Environmental Changes

The world's oceans are acidifying because they are absorbing a significant share of the CO_2 released globally through human activities. The pace and intensity of OA along the California coast varies, however, from place to place and over time, in part because the acidification caused by the absorption of CO_2 emissions is superimposed upon naturally occurring pH variation caused by upwelling and the delivery of freshwater by rivers and streams. Also, locally generated pollution may amplify and speed OA in areas where nutrients and organic carbon from runoff and ocean discharges cause excessive algal growth and the breakdown of carbon-containing materials by bacteria. The ongoing and future changes in ocean acidity will have important effects on marine animals and plants that can translate into impacts on coastal and marine fisheries and ecosystems, and the benefits they deliver to society.

OA is just one of many significant environmental changes now occurring along the California coast, and it will act in combination with these other processes (Figure 3). Climate change is altering temperature and precipitation patterns and oceanographic processes.

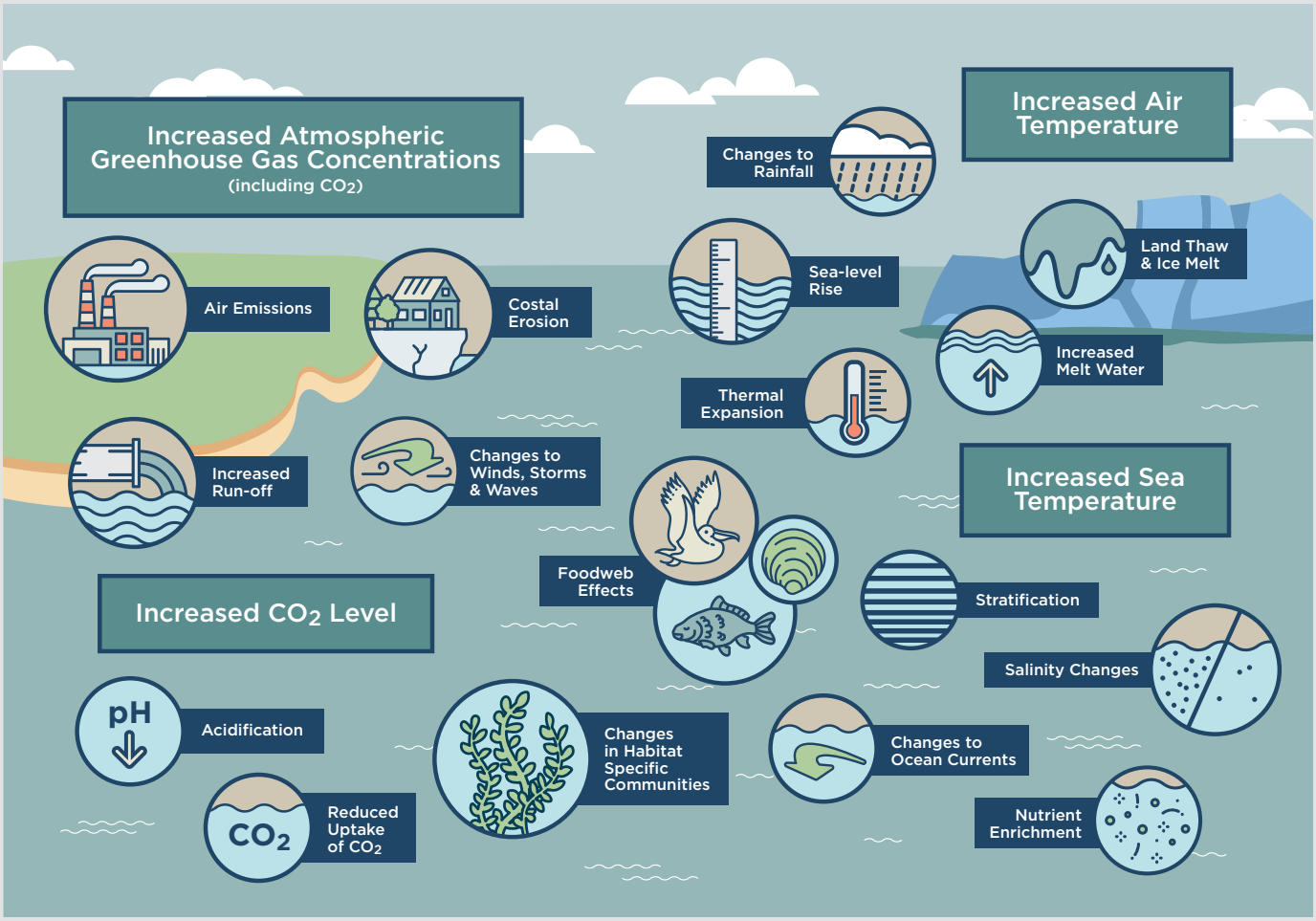


FIGURE 3: Ocean acidification is part of a system of interacting stressors facing marine ecosystems along the California coast. Effectively ameliorating and adapting to changes requires coordinated action by living marine resource, water, land, and air quality managers. For more on the science of OA and how OA interacts with other environmental changes, see findings of the West Coast Ocean Acidification and Hypoxia Panel (http://westcoastoah.org/westcoastpanel/). Figure from Sievanen et al., 2018; adapted from QSR 2010

BOX 1: *(Continued)*

Larger and more intense regions of low oxygen (hypoxia) are occurring in some areas. Sea-level is rising and coastal communities are responding by relocating and protecting infrastructure. Human uses and inputs to the oceans also are shifting, driven by population and land use change, shifting fisheries, and new uses of the oceans for food, energy, recreation, and habitation.

Some of the actions identified in this Action Plan focus specifically on OA, particularly those seeking to elevate attention to OA among policymakers, managers, and affected interests or to reduce the causes of OA. Other actions, such as those related assessing risks and adapting to OA or managing biological resources affected by OA, address OA within the context of other ongoing environmental changes, because the effects of OA cannot be considered or managed separately. In many cases, the strategies and actions undertaken to deal with OA will aid in addressing other key challenges, such coping with coastal hazards and adapting to climate change.

BOX 2:

Ocean Stewardship & Climate Change Policies in California

Ocean Stewardship

Two laws passed in 1998 and 1999, the Marine Life Management Act (MLMA) and the Marine Life Protection Act (MLPA), established innovative frameworks for securing the health and productivity of California's marine fisheries and ecosystems. Both take an ecosystem-based perspective, require consultation with affected constituencies and science-based decision-making, and emphasize adaptive approaches as a means of enabling action under conditions of uncertainty. Since 2009, California has advanced the sustainable management of numerous coastal fisheries under the MLMA through new management plans and rule-makings, and, under the MLPA designated the nation's first statewide network of marine protected areas (MPAs), fully protecting more than 9% of state waters. The separate Master Plans that guide implementation of each act are periodically updated, providing a mechanism for adopting improved scientific understanding and management tools. Recent updates to both have begun to integrate approaches for addressing climate change, OA, and other environmental changes by taking steps to maintain ecological and social resilience, adopting management flexibility, and systematically assessing and integrating changing conditions into management actions. Strategies #2, 4, and 5 of this plan call out actions related to California's fisheries management and MPA network and identify processes for engaging affected constituencies.

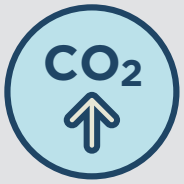
Mitigation of Greenhouse Gas Emissions

California's program to reduce greenhouse gas (GHG) emissions – including CO_2, the primary cause of OA – has evolved through several laws and Executive Actions starting in 2005. The current goal is to reduce state GHG emissions to 40% of 1990 levels by 2030, 80% below the 1990 levels by 2050, and just recently Governor Brown released an Executive Order calling for carbon neutrality as soon as possible and no later than 2045. Strategies for achieving these reductions, specified in the 2017 version of the state's 3-year Scoping Plan, include improving energy efficiency in the building and transportation sectors, transitioning to renewable fuels, reducing emissions from communities, agriculture, and other sectors, and capping emissions from various industries. The Greenhouse Gas Reduction Fund (GGRF) is a mechanism through which proceeds from the state's Cap-and-Trade auctions are invested to reduce GHG emissions and achieve other state goals. The State Legislature, in extending the Cap-and-Trade Program through 2030 in recent legislation, expressed its intent to use a portion of GGRF funds to support "climate adaptation and resilience," opening the door for agencies to consider actions that improve resilience while sequestering carbon or reducing GHG emissions. Policymakers have started to examine opportunities for better integrating coastal and ocean systems into this mitigation framework, and the most recent update to the Scoping Plan includes the potential for directing GGRF investments towards storing carbon in coastal areas and the oceans, such as in seagrass meadows and salt marshes. Strategies #3 and #4 of this plan identify actions for elevating OA and the role of coasts and oceans in the state's GHG reduction efforts and for advancing carbon storage and OA amelioration by natural, restored, and constructed living systems in California's coastal and ocean habitats.

BOX 2: *(Continued)*

Water Quality of Marine Waters

The State Water Resources Control Board is responsible for the development and updating of statewide water quality control plans, policies, and standards involving marine waters in compliance with the federal Clean Water Act and the Porter-Cologne Water Quality Control Act, among other laws and regulations. Relevant to this Action Plan, this includes the California Ocean Plan, which was last updated in 2015 and is reviewed every 3 years. It serves to protect the quality of the ocean waters for use and enjoyment by the people of the state, and requires control of discharge of waste to ocean waters and control of intake seawater. The State Water Resources Control Board participates in inter-agency coordination regarding marine pollution and resource management issues. Actions identified in Strategy #3 of this plan outline immediate next steps in understanding the role local sources of acidifying pollutants contribute to OA, and approaches to initiate sound management.



Climate Change Adaptation

Climate change adaptation in California has progressed along several avenues, reflecting the many different people and institutions involved in diverse kinds of adaptation activities. Each of the successive statewide adaptation strategies prepared since 2009 – currently referred to as the Safeguarding California Plan – has identified OA as a significant threat to California's coasts and oceans. The plan's OA actions, although not extensive – have progressively expanded beyond initial calls for improved science and monitoring to also include integrated vulnerability assessments and actions to improve fisheries resilience in the most recent 2018 update. These initial steps on OA helped prepare the ground for this Action Plan, which, in turn, sets out a broader range of actions that will inform the next steps of state agencies. Similarly, since 2006, successive California Climate Change Assessments have provided the state with critical scientific information about the impacts of climate change and potential adaptation options and provide a possible mechanism for supporting elements of the statewide OA vulnerability assessment. In the recently released 4th California Climate Change Assessment there is for the first time ever a chapter focused solely on ocean and coastal ecosystems, with attention paid to the state of science on OA and the associated impacts. These assessments – and this latest assessment – directly inform and strengthen State policies, plans, programs, and guidance, including subsequent updates to statewide adaptation strategies, to promote effective and integrated action to safeguard California from climate change.

In 2017, the Governor's Office of Planning and Research established the new legislatively-mandated Integrated Climate Adaptation and Resilience Program (ICARP). ICARP facilitates the work of the representative Technical Advisory Council (whose role is to help coordinate climate adaptation in the state) and also hosts a State Adaptation Clearinghouse to provide a centralized source of information and resources for decision-making at the state, regional, and local levels. Other state-supported mechanisms established to facilitate networking and learning among climate adaptation practitioners and scientist developing decision-relevant climate science include the biennial California Adaptation Forum organized by the Local Government Commission and periodic California Climate Change Science Symposia. Actions identified under strategy #5 of this plan identify ways to build off these mechanisms to help speed OA information sharing and to help build the state's OA constituency and networks.

BOX 2: *(Continued)*

Adaptation to Sea-Level Rise

Many state agencies make decisions that need to integrate sea-level rise (SLR) projections and uncertainties – some involving significant investments and long timelines related, for example, to infrastructure and transportation. In 2010, California sought to rapidly spur integration of best available information on SLR into decision-making of these diverse agencies while also providing a mechanism for updating the scientific basis for decision-making as improved information became available. The solution to this challenge was to convene a multi-agency working group to develop and enable broad adoption of overarching guidance on SLR that was flexible enough to be useful within the agencies' differing decision timelines and risk tolerances. The 2018 update to the State of California Sea-Level Rise Guidance incorporates the most up-to-date SLR science and broadens the document to address the needs of local decision-makers, in addition to state agencies. Actions in Strategy #2 of this plan for activating state government draw on lessons from method pioneered previously for SLR.

For additional details about these policies, programs and activities described above see:

- https://www.wildlife.ca.gov/Conservation/Marine/MLMA (MLMA);
- https://www.wildlife.ca.gov/Conservation/Marine/MPAs (MLPA);
- https://www.arb.ca.gov/cc/cc.htm (GHG emissions reduction);
- https://www.gov.ca.gov/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf (E.O. on carbon neutrality);
- https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB398 (recent legislation on Cap-and-Trade);
- https://www.waterboards.ca.gov/water_issues/programs/ocean/docs/cop2015.pdf (water quality of marine waters);
- http://resources.ca.gov/climate/safeguarding/ (climate change adaptation);
- http://www.californiaadaptationforum.org; http://californiascience.org (convening processes for climate adaptation);
- http://www.opr.ca.gov/planning/icarp/ (integrated climate resilience); and
- http://www.opc.ca.gov/2013/04/update-to-the-sea-level-rise-guidance-document/ (adaptation to sea-level rise).

PART II

Vision and Strategies for Action on Ocean Acidification

The State of California's 10-year Vision for Action to Address Ocean Acidification

As of the year 2028:

Mobilizing state government. California's policymakers, resource managers, public, and ocean industries understand that OA is a major impact of global CO_2 emissions, one that has as much potential to disrupt the health and productivity of our coasts and oceans as the changing climate. The people most likely to be affected by OA know what they have at stake and are actively helping the state to advance solutions. The State of California – working in partnership with the private sector, federal, tribal, and local governments as well as growing regional and international coalitions – has mobilized to reduce the causes and adapt to the unavoidable impacts of OA.

Advancing actions. California's efforts have resulted in significant reductions in the CO_2 emissions and other pollutants that cause OA. Through active stewardship, California's coasts and estuaries host robust eelgrass, salt marshes, and kelp forests that support thriving fisheries. Improved understanding of whether, where, and how eelgrass, salt marshes, and kelp can locally slow OA or sequester carbon is being applied in state policies and the aquaculture industry. Coastal communities and ocean industries have adopted new ways of doing business and are maintaining their vitality as ocean conditions change.

Advancing science. A robust scientific infrastructure exists for developing and delivering decision-relevant information about the current and future patterns, causes, and impacts of OA. Californians have a greatly improved understanding of how coastal and ocean conditions and ecosystems will respond to the effects of OA acting in combination with other ongoing ocean changes (including temperature, circulation, oxygen, freshwater inputs, human uses) and of potential options for sustaining biological productivity and ecosystem functions and benefits. This information is informing and improving the day-to-day actions, investments, and long-term planning of decision-makers across the public and private sectors.

Strategies

Six strategies form the organizing framework for the Action Plan. These focus on (1) preparing for OA risks and impacts, (2) activating responsible elements of state government, (3) reducing the pollution that causes of OA, (4) deploying living systems to locally slow OA and store carbon, (5) building California's adaptive capacities and resilience, and (6) engaging beyond state borders to accomplish more than California can on its own. Each of the six strategies is essential and all should be undertaken expeditiously. For each strategy, the Plan explains the underlying rationale, provides a 5-year plan and goals, and identifies a set of specific tractable actions that will need to be translated into operational steps by state agencies. Appendix 3 identifies potential measures for evaluating progress against the 5-year goals during the Action Plan's implementation.

Science and communications play integral roles in the Action Plan, and both are systematically embedded throughout the six strategies, reflecting the diverse ways that communications and science are essential for effective policy and management. Over the longer-term, a more fully formed and comprehensive outreach and communication effort will be essential to build an active constituency and meaningfully elevate and expand action on OA. Appendix 4 summarizes communications actions identified in the Action Plan, providing an initial framework to guide development of this broader communications plan. Similarly, successful implementation of the Action Plan will require new scientific knowledge and tools. Appendix 5 provides a science plan designed to supply this critical understanding that was developed by The Ocean Acidification and Hypoxia Science Task Force established in January of 2018 as directed by Assembly Bill 2139 (Williams).

STRATEGY #1

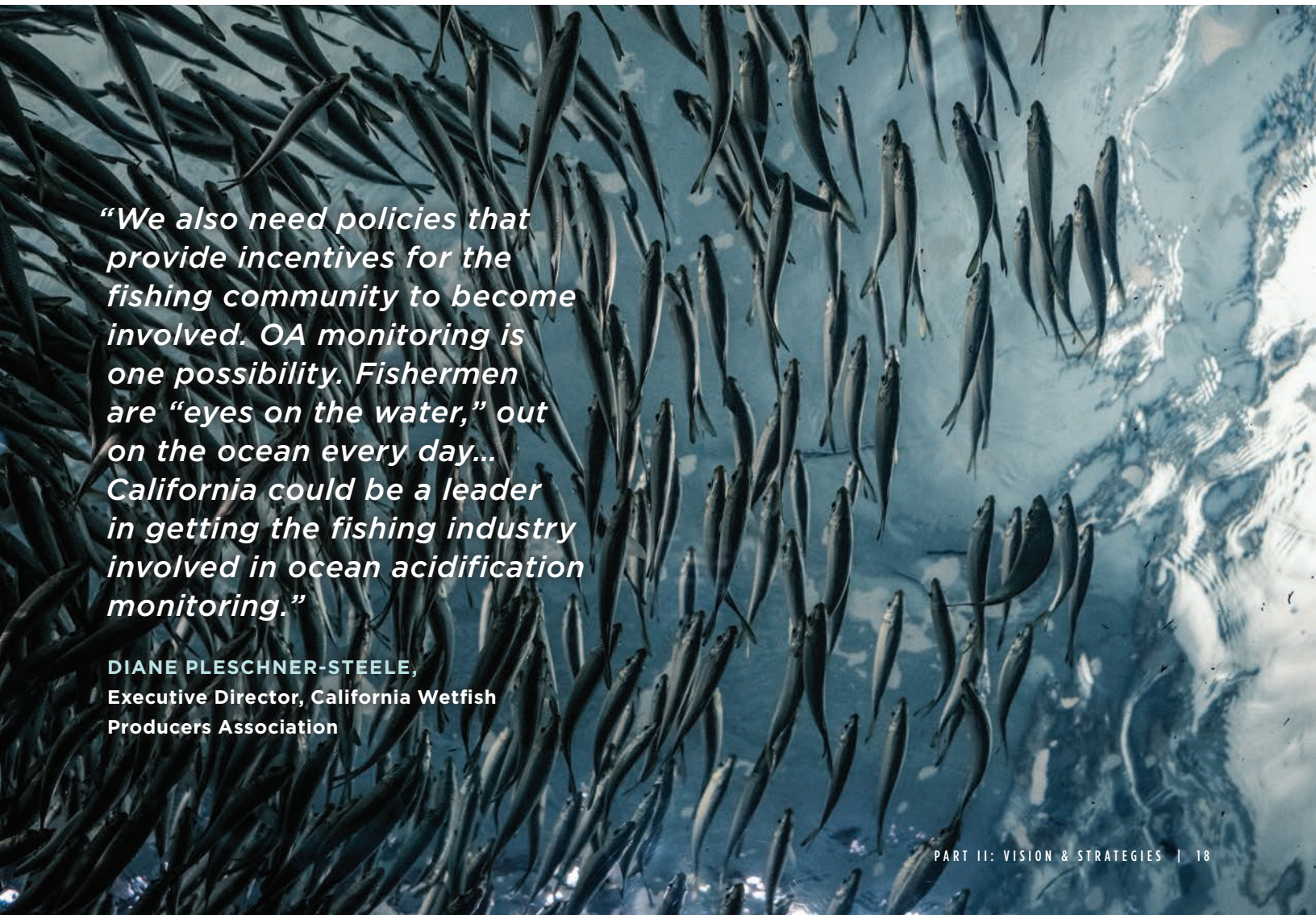
Prepare for the Full Range of OA Risks and Impacts

THE IMPLICATIONS OF OA for the health and productivity of California's coastal and ocean ecosystems, and the communities and industries that depend on these ecosystems, are enormous. From corroding shells and skeletons of marine organisms to disrupting normal fish behaviors, OA has the potential to alter marine food webs and ecosystems and to reduce or alter the productivity and predictability of marine fisheries and aquaculture operations. The production failures experienced by Pacific Northwest oyster hatcheries between 2006 and 2009 provides a small glimpse of what may lie ahead.[10]

[10] Washington State Blue Ribbon Panel on Ocean Acidification (2012). Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response. Washington Department of Ecology. https://ecology.wa.gov/About-us/Our-role-in-the-community/Partnerships-committees/Ocean-acidification-Blue-Ribbon-panel

Even so, we do not yet have a clear picture of what is at stake for California as OA conditions intensify in the coming decades. Identifying the risks that OA poses to California's interests and assets will be essential to help those who will be most affected prepare for the coming changes. This process will also help with developing management interventions and policies that can best help sustain the health and well-being of coastal ecosystems, communities, and economies. Prompt action now is likely to yield better outcomes, because options will decrease as OA conditions worsen.

OA is unfolding at a time when California's coastal and ocean environments are undergoing other significant changes. Warming temperatures, changing precipitation and freshwater flows, rising sea levels, declining oxygen, and changes to the types and intensity of human uses are just some of the shifts already underway. Realistic assessments of OA risks will need to consider the interacting effects of these various change processes acting in combination. In some cases, taking steps to reduce the effects of other factors (such as human uses and pollution) might help enhance the ability of natural systems or people to cope with OA. Conversely, efforts should be made to ensure that societal responses to other environmental changes are designed in ways that do not exacerbate OA risks. For example, coastal adaptation to sea-level rise should be undertaken in ways that do not unintentionally enhance nutrient runoff through land use change or degrade seagrass habitat through coastal armoring.



"We also need policies that provide incentives for the fishing community to become involved. OA monitoring is one possibility. Fishermen are "eyes on the water," out on the ocean every day… California could be a leader in getting the fishing industry involved in ocean acidification monitoring."

DIANE PLESCHNER-STEELE,
Executive Director, California Wetfish Producers Association

5-YEAR GOALS

The risks OA poses to California's assets and interests are well understood among policymakers, resource managers, affected industries and communities, and the public.

Decision-relevant monitoring information about OA is widely available, delivered in a usable form, and routinely applied to decisions across the public and private sectors.

Improved scientific understanding of how OA, and the interactions of OA with other environmental drivers, affects coastal and marine ecosystems is informing state resource, land use, and ocean and coastal management decisions.

ACTION 1.1

Conduct a statewide vulnerability assessment to identify the risks OA poses to California's biological resources, communities, and economies, within the context of other ongoing environmental changes and hazards, and to identify priorities and options for action to improve societal adaptive capacity.[11]

1.1.1. Assess current and future risks to species of high ecological and/or economic value to the state – including, but not limited to, Dungeness crab and salmon.

1.1.2. Assess current and future risks to ocean-dependent industries – including aquaculture, fisheries, and coastal tourism.

1.1.3. Identify those communities particularly vulnerable to the effects of OA. Conduct social and economic research to evaluate potential public policy interventions for bolstering these communities' resilience, adaptive capacity, and ability to pursue emerging opportunities.

1.1.4. Translate and communicate information about risks, vulnerabilities, and potential interventions to assist policymakers and affected communities and industries in prioritizing and undertaking actions for improving societal adaptive capacity.

[11] Since 2006, successive California Climate Change Assessments have provided the state with critical scientific information about the impacts of climate change and potential adaptation options and provide a possible mechanism for supporting elements of the statewide OA vulnerability assessment. See: http://climatechange.ca.gov/climate_action_team/reports/climate_assessments.html.

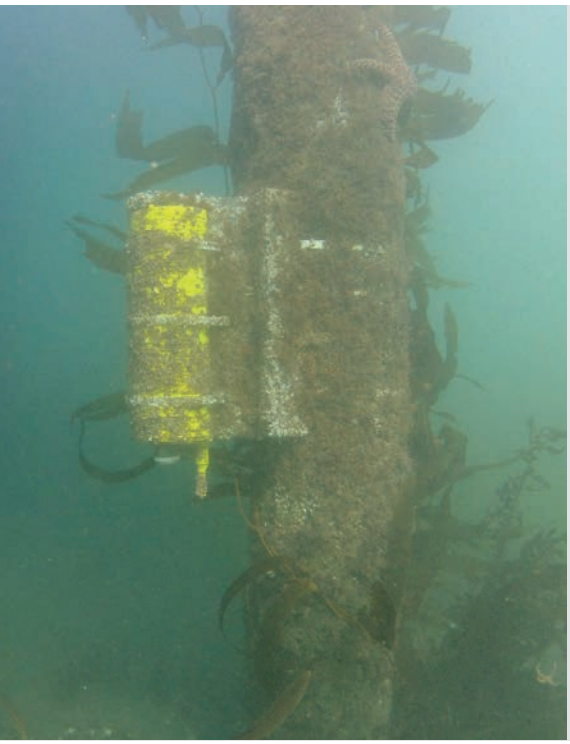
ACTION 1.2

Design and make targeted investments in a monitoring and observation system optimized to deliver decision-relevant information that serves user needs.

1.2.1. Building on existing efforts involving West Coast jurisdictions and the federal government (see box, below), finalize the system design for monitoring in state, federal, and coast-wide waters that will assist California in understanding and projecting future OA patterns and impacts on biological resources, communities and economies and in applying this information to decisions related to water quality (Strategy #3), the management of living marine resources (Strategy #4), and sustaining societal and ecosystem resilience (Strategy #5).

1.2.2. The monitoring and observation system design should be informed by an assessment of user needs and should: encompass near- and off-shore areas, including areas where discharges might exacerbate OA; couple environmental and biological monitoring (e.g., of fish stocks, ecosystems, and biological OA indicators such as pteropods); strategically integrate existing monitoring and observation assets; include support for maintenance of and training for sensor use; provide sufficient quality assurance/quality control; provide support for sensor innovation and technological advancements; include industry (e.g., fishing) and citizen science where feasible and beneficial.

1.2.3. Ensure adoption of and participation in monitoring design and implementation by relevant local, state, and federal agencies; where appropriate, identify opportunities to maximize the benefit of collected data to meet multiple needs (e.g., both state permit compliance and OA considerations).



West Coast Monitoring Inventory Undertaken to Identify Gaps

The Pacific Coast Collaborative (PCC) and the federal Interagency Working Group on Ocean Acidification (IWG-OA) have partnered to foster a West Coast ocean acidification and hypoxia (OAH) monitoring network that is scientifically grounded and responsive to management needs. A Task Force was established to proceed toward this goal by building a comprehensive inventory of OAH-relevant monitoring efforts, from Alaska to California. The intent is for the inventory to represent current chemical, physical, and biological monitoring efforts for future information gap analysis and subsequent strategic monitoring investment. The inventory and any subsequent information products will be available to the public so that all interested parties can directly access this work. For more information on the inventory, visit http://www.nanoos.org/news/index.php?item=WestCoastOaInventory180425

ACTION 1.2 (CONTINUED)
1.2.4. Make and encourage collaborators to make targeted and sustained investments in the monitoring and observation system. State investments should be targeted toward monitoring and observation activities that are critical for implementing state action priorities identified in this Action Plan and for making policy and management decisions related to anticipating, mitigating, and adapting to OA.
1.2.5. Enhance and expand coupled environmental and biological monitoring across the statewide MPA network to provide essential baseline information for understanding OA ecosystem impacts and potential contributions of MPAs to sustaining regional ecosystem functions and societal benefits under intensifying OA.
1.2.6. Provide open access to information developed through the monitoring and observation system via existing or new web-based platforms and data portal(s) that allow the OA information to be viewed and analyzed in combination with other environmental information.
1.2.7. The platform should be developed in ways that, over the longer-term, will support web-based mapping tools and visualizations that, among other things: show current and projected future OA trends, forecasts and scenarios; highlight areas historically subject to great pH variation; and identify "hotspots" where future OA changes will be faster and more intense.

"It is absolutely essential to have the monitoring. We're talking about generational problems, so we need to approach them that way, and go beyond the usual recommendations. OA monitoring needs to be done at the right scale and right granularity for it to provide useful predictive and preventative information. Upwelling and hypoxia events, for example, should be reported in ways that allow the industry to anticipate and respond effectively.And all hatcheries should be included in the system."

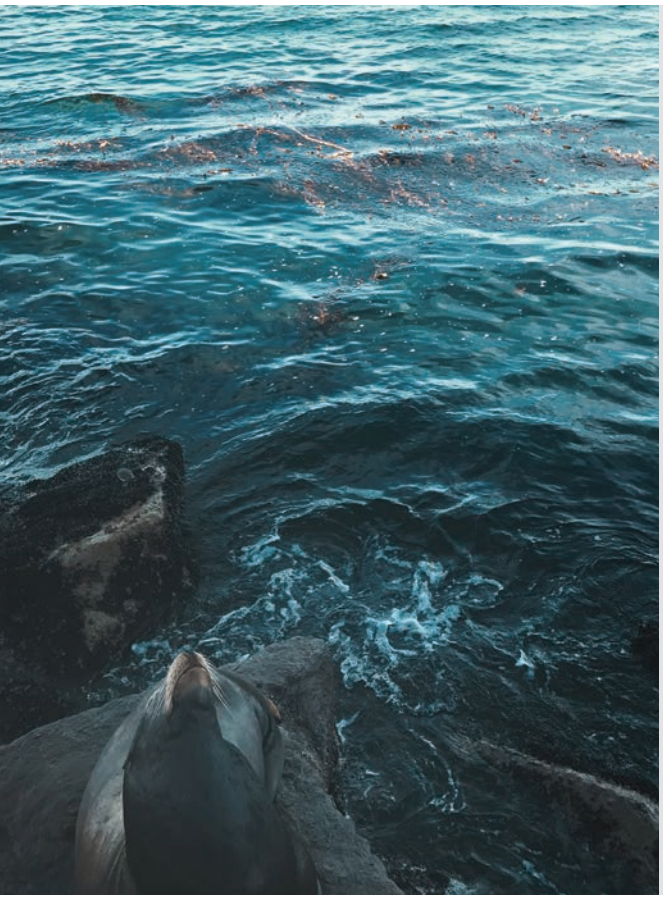
TERRY SAWYER,
Founding Partner & Vice President,
Hog Island Oyster Company

ACTION 1.3

Characterize how interactions between OA and other environmental changes will affect the structure, function, and societal benefits derived from California's coastal and ocean ecosystems.

1.3.1. Invest directly and through partnerships in building the scientific foundation for understanding and projecting the potential future ecosystem impacts of OA interacting with other change processes (e.g. temperature, runoff, hypoxia, human uses, land use change and changes to coastal infrastructure). Supported work should include research on food web impacts that can inform fisheries management. The statewide network of marine protected areas (MPAs) can potentially serve as a "living laboratory" for related research.

1.3.2. Identify and test, using models and other means such as field experiments and laboratory manipulations, potential policy and management interventions to slow or reduce OA ecosystem impacts. Examples might include adjusting other environmental drivers that affect ecosystem health (e.g., pollution, disturbance, resource extraction) and examining the extent to which MPAs aid in locally or regionally supporting ecological adaptation to OA (see box, below).



OA and California's Network of Marine Protected Areas

The need to safeguard the long-term health of California's marine life was recognized by the California Legislature in 1999 with the passage of the Marine Life Protection Act and the designation of California's network of marine protected areas (MPAs). MPAs may provide scientific reference points to assist with resource management decisions, and protect a variety of marine habitats, communities, and ecosystems for their economic and intrinsic value, for generations to come. MPAs might, for example, harbor populations of marine species that can help re-seed areas subject to transient OA extremes or include variants that are naturally more resistant to OA. MPAs that support healthy seagrass meadows and other coastal habitats are being explored for their role in local OA amelioration.

STRATEGY #2

Activate Responsible Elements of State Government

OVER THE COMING DECADES, intensifying OA along the California coast will interact with other ocean changes to significantly alter and potentially degrade coastal and ocean water quality and ecosystems and the well-being of communities and industries that depend on the coast and ocean.[12] Although state government could do much to anticipate, mitigate, and adapt to these changes, such efforts have only just begun.

[12] See findings and reports of the West Coast Ocean Acidification and Hypoxia Panel available at http://westcoastoah.org/westcoastpanel/

California's success in addressing OA demands the engagement of a much broader set of state agencies and programs – including all whose missions and actions will affect or will be affected by OA. The substantive coverage and missions of these agencies goes well beyond those that have already begun to address OA in a concrete fashion, and includes greenhouse gas emissions reduction, sea-level rise adaptation, land use and transportation planning and management, water management and quality, agricultural and seafood production, and wildlife conservation.

Broad engagement across agencies and sectors will ensure that the state is doing everything it can to limit harm to California's interests from OA, and that work on OA throughout state government is coordinated, well aligned, and effective.

California has taken on similar challenges in building approaches for addressing climate change, and its efforts have resulted in well-recognized models of successful multi-agency governance for reducing greenhouse gas emissions and adapting to climate change and sea-level rise.[13] The Action Plan has drawn on lessons from these experiences in designing the approach below for speeding transformational change in the state's approach to OA.

[13] http://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/ , https://www.arb.ca.gov/cc/ab32/ab32.htm , and http://resources.ca.gov/climate/safeguarding/ provide brief histories and relevant documents related to the development of California's approaches to sea-level rise, GHG emissions reduction, and climate change adaptation, respectively.

"The core mission of humanity needs to be reducing our carbon footprint…We must ensure that fishing industries are fuel efficient, for example. People have to realize that time is limited"

BRUCE STEELE,
Captain, F/V Halcyon

5-YEAR GOALS

All relevant state agencies are integrating the best available scientific information about OA into decisions and policies that have the potential to contribute to or to slow OA along the California coast or that deal with biological resources, industries, or communities likely to be affected by OA.

State governments have integrated relevant elements of the Action Plan into their operations to minimize harm to California's interests from OA and to anticipate and adapt to those harmful impacts that cannot be reduced.

ACTION 2.1

Fully integrate OA into California state government policies, planning, and operations

2.1.1. The OPC will convene and lead an interagency OA working group that includes senior-level staff from the full set of state agencies whose decisions affect or will be affected by OA.

2.1.2. The working group will, within one year: (a) Identify agency policies, decision-making processes, and investments that should consider information about potential impacts to coastal OA or possible effects of OA on managed resources or interests; (b) Articulate overarching state guidance, in the form of general operating principles and practices, that will assist the member agencies and programs in moving forward in addressing OA within their purview. Building on these initial tasks, as soon as possible, the working group will: (c) Specify how member agencies and programs will consider and implement the Action Plan and integrate OA into their policy and management decision-making; and (d) Provide opportunities for stakeholder input to inform the planning and decision-making process (see also Strategy #5).

2.1.3. Over the Action Plan's 5-year lifespan, the working group will track implementation progress and, at the end of this period, develop a revised plan in light of documented accomplishments, identified challenges, learning, and science advances.

2.1.4. To support the day-to-day policy and management decisions and actions on OA by member agencies and programs of the working group, the OPC, working in collaboration with the OAH Science Task Force, will oversee production of a science synthesis that translates current understanding and uncertainties about OA into actionable knowledge that is useful for agency and program decision-making.[14] This synthesis will include OA patterns and projections and the anticipated biological and socioeconomic impacts of OA in real world situations where OA interacts with other environmental drivers, many of which are also changing. The synthesis will be responsive to a charge from the OA working group, and will be updated a minimum of every three years in light of improved scientific understanding.

2.1.5. Improve understanding of OA and its significance among policymakers and leaders in California's legislature and public agencies, for example, through briefings, hearings, and as agenda items at public meetings.

2.1.6. Solicit input from, and share with policymakers outside of California (domestically and internationally) lessons, insights, and practical accomplishments from California's experience elevating attention to OA into the state's policy frameworks for climate change (mitigation, adaptation), ocean stewardship (fisheries, wildlife, marine protected areas), and coastal water quality.

[14] This synthesis would play the same role for OA that Rising Seas in California: An Update on Sea-level Rise Science is playing in the state's guidance on sea-level rise. See http://www.oceansciencetrust.org/projects/updating-californias-sea-level-rise-guidance/

"The future of the shellfish industry in California is somewhat uncertain. With capture fisheries in decline, the market is there, along with the need to feed a growing population…Permitting is the biggest challenge. It's expensive and you have to go through multiple agencies and the process is unclear…We need to be as nimble as possible - to be proactive in adapting to changes in the climate, while minimizing our own impacts."

TERRY SAWYER,
Founding Partner & Vice President, Hog Island Oyster Company

ACTION 2.2
Fully integrate OA into California state government policies, planning, and operations
2.2.1. Provide dedicated capacity and staff time to implement the Action Plan, evaluate progress, and periodically update and revise the plan at least every 5 years. The logical nexus for leading and coordinating implementation of the Action Plan is the OPC and the Coastal and Oceans Resources Working Group established as part of the state's Climate Action Team.[15] Individual agencies and programs participating in the OA working group will need to allocate staff time to contribute and build internal expertise about OA and its implications for agency policies and operations.
2.2.2. Identify and target funding to implement the Action Plan, including the priority science research needs in Appendix 5. Identify and pursue public funding, public/private partnerships, leveraged investments, and identify priorities for other funders (science, federal, private philanthropy).
2.2.3. Identify and coordinate with appropriate entities (e.g., Local Government Commission) to support action by local and regional (e.g., county) agencies and authorities.

[15] For more on the Coastal and Oceans Resources Working Group of the Climate Action Team see: http://www.opc.ca.gov/2010/07/coastal-and-ocean-climate-action-team-co-cat/).

STRATEGY #3

Reduce the Pollution that Causes OA

OCEAN ACIDIFICATION is fundamentally a water pollution problem. By far, the major driver is pollution of the world's oceans caused by absorption of global CO_2 emissions.[16] Consequently, the most important actions California can take to limit OA and its impacts are those aimed at reducing CO_2 emissions and securing carbon storage.

California already has a well-established program to reduce greenhouse gas emissions (see Box 2). Building upon the groundbreaking California Global Warming Solutions Act of 2006 (Assembly Bill 32), the state established a robust accounting framework, has set increasingly ambitious GHG reduction goals, and launched a strategic set of actions and investments to achieve these goals. California's current 2030 target of

[16] See findings and reports of the West Coast Ocean Acidification and Hypoxia Panel available at http://westcoastoah.org/westcoastpanel/.

reducing emissions to 40% below 1990 levels by 2030 is the most ambitious GHG reduction goal for North America.

The GHG reduction program scope, which initially emphasized measures to improve energy efficiency, reduce fossil fuel dependence, and limit transportation emissions, recently expanded attention to measures for promoting carbon sequestration on natural and working lands and reducing emissions from land and resource management practices.[17] Attention to coasts and oceans in these various approaches has been limited so far, and opportunities now exist to more systematically elevate attention to OA and to coastal and ocean systems in California's GHG reduction framework (see also Strategy 4).[18] California's Climate Change Scoping Plan, in particular, should fully integrate strategies for reducing OA.[19]

In addition to ongoing OA resulting from global CO_2 emissions, locally generated pollution has the potential to accelerate the rate at which coastal waters are acidifying, especially in semi-enclosed waters like estuaries and bays (see box, below). This local acceleration occurs when inputs of waterborne organic carbon and nutrients from ocean wastewater discharges, agricultural and urban runoff, and other sources result in additional contributions of CO_2 and other acidifying pollutants to coastal waters.

In places where local inputs are accelerating OA, reducing local pollution could help slow this process. Technical assessments of the magnitude and impacts of local contributions to coastal OA in California have begun, but have not yet been completed. Important questions remain related to: Where and what proportion of the OA occurring along the California coast is due to local water-borne or atmospheric pollution? How will these relative contributions change in the future? Which locations, if any, could or should be prioritized for reducing local inputs in order to slow the near-term pace of OA? Over the next few years, models currently under development

Nexus Between OA and Local Pollution

Nutrient pollution. Local discharge of organic carbon and nutrients can exacerbate OA when nutrients such as nitrogen and phosphorus are introduced to coastal waters. These nutrients can trigger proliferation of algae that, following their death, are decomposed by bacteria release CO_2, increasing acidity[1]. In addition to exacerbating OA, excessive nutrient and organic carbon inputs - through complex and interacting processes - also can contribute to harmful algal blooms and low oxygen (hypoxia), and these effects may be exacerbated by temperature increases caused by climate change[2].

Air pollutants. Absorption of local airborne emissions (including CO_2 and chemicals that directly acidify ocean waters such as nitrous oxides and sulfur compounds), from sources such as transportation and electric utilities, also has the potential to exacerbate OA locally.

Freshwater runoff. Freshwater runoff from impervious surfaces in some areas can worsen OA by flooding coastal waters with low pH water.

[1] See: Hales, B., Chan, F., Boehm, A.B., Barth, J.A., Chornesky, E.A., Dickson, A.G., Feely, R.A., Hill, T.M., Hofmann, G., Ianson, D., Klinger, T., Largier, J., Newton, J., Pedersen, T.F., Somero, G.N., Sutula, M., Wakefield, W.W., Waldbusser, G.G., Weisberg, S.B., and Whiteman, E.A. Multiple stressor considerations: ocean acidification in a deoxygenating ocean and warming climate. West Coast Ocean Acidification and Hypoxia Science Panel, California Ocean Science Trust, Oakland, California, USA. July 2015

[2] See: Breitburg, Denise, et al. "Declining oxygen in the global ocean and coastal waters." Science 359.6371 (2018): eaam7240

[17] See: California Air Resource Board (webpage). Natural and Working Lands Sector: GHG Reductions and Carbon Sequestration Goals for California's Forests, Ranches, and Farms. https://www.arb.ca.gov/cc/natandworkinglands/natandworkinglands.htm. See Forest Climate Action Team (2018). California Forest Carbon Plan: Managing Our Forest Landscapes in a Changing Climate). http://www.fire.ca.gov/fcat/downloads/CaliforniaForestCarbonPlaFinal.pdf)

[18] See: California Air Resources Board, et al. (2018). California 2030 Natural and Working Lands Climate Change Implementation Plan Concept Paper. https://arb.ca.gov/cc/natandworkinglands/nwl-implementation-plan-concept-paper.pdf See also Strategy #4 of this plan.

[19] See: California Air Resources Board (2017). California's 2017 Climate Change Scoping Plan. https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm

are expected to start providing answers. The results should aid in evaluating the potential benefits (in terms of slowing local acidification rates) of interventions to reduce or relocate local pollution inputs, including more costly or controversial interventions, such as changes to ocean wastewater discharges or adjusting agricultural practices to reduce fertilizer runoff.[20]

While this information is being developed, action still can be taken through various multi-benefit options that simultaneously reduce local inputs while achieving other policy or economic goals. For example, wastewater treatment plants undertaking infrastructure upgrades to improve energy or economic efficiency, or investing in water reuse to achieve water savings, could simultaneously make changes to reduce nutrient discharges. [21]

Over the longer-term, evaluating, communicating, and undertaking more aggressive steps to reduce the causes of OA will require development and adoption of scientifically robust and biologically meaningful OA indicators for California's coastal and ocean waters, and indicator values that could serve as management goals and regulatory triggers. Such indicators and values will support several important applications, including: evaluating, communicating, and tracking acidification in California's coastal waters; justifying management interventions by Regional Water Quality Control Boards; and developing criteria and objectives for regulating causal pollutants under federal and state law (the Clean Water Act and Porter-Cologne Water Quality Control Act) (see box, below).

Revising Water Quality Criteria

Water quality criteria are the management foundation of the Clean Water Act, providing interpretative thresholds to assess water body condition and to determine the level of discharge that will maintain a water body in ecologically acceptable condition. The West Coast Ocean Acidification and Hypoxia Science Panel recommended in its 2016 final assessment report that California's acidification water quality criteria be revised, as these criteria are outdated and not scientifically valid to protect biologically resources.[1]

Strategy 3.3 of the Action Plan focuses on the knowledge, tools, and research needed to support development of revised OA water quality criteria for California. Strategy 3.3 focuses on developing scientifically robust, biologically relevant OA assessment endpoints that can be used to track the speed and intensity with which OA is impacting coastal resources. Strategy 3.3 also outlines the role that spatial modeling and other analytical tools will play in providing critical context for determining appropriate assessment endpoints. The Science Strategy document supporting implementation of the Action Plan (Appendix 5) further expands upon these research needs. Recommendation 2.3 of the Science Strategy describes the specific types of studies that are needed to support development of OA assessment endpoints. These assessment endpoints will be of immediate value, enabling coastal resources managers to interpret OA monitoring data and modeling outputs that predict how local management actions could alter the trajectory of OA-related impacts. The assessment endpoints also will provide context for educating the public about the status of OA conditions in local waters.

The Action Plan focuses on building the scientific foundation for criteria development – rather than revising the criteria – in recognition of the need for additional research to achieve the level of rigor required to revise regulatory water quality criteria.

[1] Chan, F., Boehm, A.B., Barth, J.A., Chornesky, E.A., Dickson, A.G., Feely, R.A., Hales, B., Hill, T.M., Hofmann, G., Ianson, D., Klinger, T., Largier, J., Newton, J., Pedersen, T.F., Somero, G.N., Sutula, M., Wakefield, W.W., Waldbusser, G.G., Weisberg, S.B., and Whiteman, E.A. The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions. California Ocean Science Trust, Oakland, California, USA. April 2016.

[20] See description of modeling project at http://westcoastoah.org/resources/california/

[21] Note that water reuse improvements that do not also remove nutrients yield concentrated nutrient-rich effluents that could cause intensified local OA around ocean discharges.

5-YEAR GOALS

Attention to coastal and ocean systems and to OA is elevated and systematically addressed in California's GHG reduction efforts.

No-regrets, near-term options for reducing local sources of acidifying pollutants (voluntary, incentive-based, or permitting) have been identified and are fully employed.

The state has the technical tools it needs – including scientifically robust water quality indicators and appropriate models for assessing contributions of local and global CO_2 – to measure and evaluate OA-related changes occurring along the California coast, to select water quality goals, and to initiate management or regulatory action to slow these rates, if feasible and appropriate.

ACTION 3.1

Systematically integrate OA and coasts and oceans into California's GHG emissions reduction program.

3.1.1. Develop and amplify clear messages that identify OA as a major impact of global CO_2 emissions and reduction of OA as a major benefit of the state's GHG reduction efforts.

3.1.2. Identify, evaluate, and implement, as warranted, additional opportunities to reduce GHG emissions by coastal and ocean uses and related industries (such as tourism, recreation, desalinization, power plants, refineries, and other coastal industries) through voluntary, incentive-based, and/or regulatory measures and to secure carbon storage through systems such as seagrass meadows, salt marshes, kelp forests, and novel mechanisms such as kelp mariculture (see also Strategy #4).

3.1.3. Reduce the carbon footprint of seafood consumption in the state. The first step is to evaluate the potential for and the environmental, economic, and social costs and benefits of incentivizing consumption of locally sourced products (wild capture, aquaculture). If warranted, work with seafood certification and rating programs to integrate carbon footprint information into rating systems and public education products.

3.1.4. Identify and assign priority to emissions reduction actions that also have the potential to reduce or slow local rates of acidification. For example, management of nitrogen fertilizer on agricultural lands to reduce emissions of nitrous oxide (a greenhouse gas) also may reduce nutrient runoff that can intensify local OA, and submerged aquatic vegetation secured to deliver carbon storage may also ameliorate rates of local acidification (see also Strategy #4).[22,23] Many of these same actions are likely to yield additional water quality benefits, including reducing hypoxia in coastal waters.

3.1.5. Evaluate and advance opportunities for directing investments of the Greenhouse Gas Reduction Fund towards actions that simultaneously improve resilience of industries and communities vulnerable to OA while reducing GHG emissions or improving carbon storage (see also Strategy #5).

[22] See: California Air Resources Board (2017). California's 2017 Climate Change Scoping Plan. https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm
[23] Many of these same actions are likely to yield additional water quality benefits by reducing hypoxia in coastal waters.

ACTION 3.1 (CONTINUED)

3.1.6. Continue to advance collaborative dialogue on ocean-based production of renewable wind energy, where it is compatible with sustaining healthy ocean ecosystems, fisheries, and coastal economies.

ACTION 3.2

Identify sources and reduce local water-borne and airborne pollution that can exacerbate coastal OA.

3.2.1. Expand incentives for, and strongly encourage if the science justifies, for coastal infrastructure upgrades that are designed to simultaneously reduce or eliminate nutrient- and carbon-laden ocean discharges that exacerbate local acidification. Incentivize and advance California's climate adaptation goals for the water sector by improving energy efficiency of water reuse and recycling, and reducing brine and nutrient discharges.[24]

3.2.2. Assess whether local sources of acidifying airborne emissions (e.g., nitrogen oxides, sulfur oxides) are affecting the rate of OA in select regions of the coast, such as near California ports and harbors or coastal electric power plants. Identify and implement options for reducing these airborne pollutants under state law, as appropriate, which may also yield public health benefits in some places.

3.2.3. Support and highlight the significance for OA of integrated watershed planning and land management and protection activities (e.g., runoff reduction, protection of upland wetlands and riparian areas) that are likely to yield improved downstream water quality in bays and estuaries where risks of intensified OA from local inputs are greatest. Target communications towards key audiences demonstrating these linkages and highlighting the multiple potential benefits for coastal water quality and productivity.[25]

ACTION 3.3

Develop technical tools for evaluating coastal OA and for attributing intensifying OA to causal pollutants.[26] Prioritize those tools that potentially support both near- and longer-term applications, including vulnerability assessments, public education, targeted management interventions, and regulatory action.

3.3.1. Build on initial efforts to develop a scientifically robust, well-vetted, and biologically significant set of coastal water quality indicators for evaluating OA conditions occurring along the California coast (see also Appendix 5 for additional information). Identify values and thresholds for these indicators that could serve as water quality goals and triggers for management or regulatory action.

3.3.2. Build on initial efforts to advance and validate spatially explicit models and analytical tools that aid in accounting for the relative contributions of different pollution sources (e.g., global CO_2 emissions, local water-borne nutrients or organic carbon, local airborne acidifying chemicals) to ongoing and future pH changes along the California coast and how these contributions might be affected by various interventions.

24 The primary incentive currently available is the Clean Water State Revolving Fund that offers low cost financing for water quality project that can be applied, among other purposes, to upgrading coastal wastewater treatment infrastructure. https://www.waterboards.ca.gov/water_issues/programs/grants_loans/srf/

25 Reducing nutrient and organic carbon inputs through actions taken in upstream watersheds can potentially not only slow rates of OA, but also help reduce eutrophication, oxygen depletion, and harmful algal blooms.

26 For more about initial investments of the Ocean Protection Council in this area see projects related to water quality and integrated modeling at http://www.opc.ca.gov/opc-climate-change-program/ocean-acidification-2/.

STRATEGY #4

Deploy Living Systems to Slow OA and Store Carbon

CALIFORNIA'S SEAGRASS MEADOWS, salt marshes, and kelp forests are home to diverse and abundant wildlife, provide habitats for commercially and recreationally important fisheries, and are important attractions for coastal tourism and recreation. Increasingly, they also are being recognized as critical to achieving the state's goals for climate change adaptation and mitigation. These habitats have the potential to protect shorelines from sea-level rise, sequester carbon, and locally ameliorate OA by removing CO_2 from ocean waters (seagrasses, kelp) and by removing nutrients and organic carbon from runoff (salt marshes).[27] The state currently supports and mandates the protection, conservation, restoration, and management of seagrass,

[27] Neilsen, K. et al. (2018). Emerging Understanding of the Potential Role of Seagrass and Kelp as an Ocean Acidification Management Tool in California. California Ocean Science Trust.

salt marsh, and kelp under a variety of authorities and funding mechanisms that reflect all of these diverse benefits.[28]

Looking ahead, California has an opportunity to deliberately leverage the collective benefits of the state's seagrass meadows, salt marshes, and kelp forests, and the plants that dominate these systems, for locally slowing OA and for storing carbon – at the same time as these living systems provide many other benefits. Doing so will require treating current and future protection, restoration, and management projects and places as a network of sites for "learning by doing" to help fill gaps in current understanding. Such approaches for taking action in the face of incomplete information are already well established in the state's ocean management policies (see Box 2).

Salt marsh capacities for storing carbon and removing waterborne nutrients, for example, have been well documented. Nevertheless, understanding of how nutrient removal by salt marshes might translate into reduced rates of OA in areas subject to agricultural or urban runoff is limited. Similarly, although we know that certain seagrasses and kelps can locally ameliorate OA, and that seagrass meadows also can sequester carbon, we do not yet know enough to prescribe specific practices or places for optimizing these OA and carbon storage benefits or for quantifying their effects (see also Appendix 5).[29] Early investments by the state in related research is already yielding important insights (see Figure 2).[30]

Implementing a larger and deliberative approach to learning from experience across the network of state investments in living systems (seagrasses, salt marshes, kelp) to help slow local OA and store carbon, would speed development of improved methods for managing these systems and accounting for their OA and carbon storage benefits. These gains would improve the state's ability to optimize future investments and overall effectiveness.

[28] Examples include: Within state marine protected areas implemented under the Marine Life Protection Act and state parks; Climate Ready Program grants administered by the California Coastal Conservancy (http://scc.ca.gov/climate-change/); Investments made under the Greenhouse Gas Reduction Fund to secure carbon sequestration; Leasing and licensing of kelp beds by the California Department of Fish and Wildlife; Management of Estuarine Research Reserves and State Parks; Research and development grants made by the California Ocean Protection Council (http://www.opc.ca.gov/opc-climate-change-program/ocean-acidification-2/).

[29] The potential carbon storage by kelp forests under natural conditions appears to be small, because kelps live on hard surfaces and do not accumulate organic materials in sediments like seagrasses and salt marshes do. However, kelp harvested and removed from natural and mariculture systems can provide greater and more lasting carbon storage under certain circumstances.

[30] For an overview of OPC OA investments since 2018, see: http://westcoastoah.org/resources/california/ and http://www.opc.ca.gov/opc-climate-change-program/ocean-acidification-2/

5-YEAR GOALS

Conservation and restoration of seagrass meadows, kelp forests, and salt marshes across all of California's estuaries and coasts are now state policy and are well underway and financed.

State investments into seagrass meadows, salt marshes, and kelp forests to secure OA amelioration and carbon storage benefits are strategic and effective.

Aquaculture production systems have been developed, tested, and adopted, if warranted, that integrate kelp and seagrass to reduce OA and enhance shellfish production and that endeavor to enable co-location of aquaculture with successful seagrass conservation.

ACTION 4.1

Implement a coordinated and strategic statewide approach to restoring, conserving, enhancing, and assisting in the migration of seagrass meadows, kelp forests, and salt marshes to achieve multiple state goals.

4.1.1. Map current and projected future habitat space for seagrass meadows, salt marshes, and kelp forests along the California coast using scientifically valid and reproducible methods that are verified through field surveys. Future habitat projections should include consideration of the state's most recent guidance on sea-level rise. Provide for permanent, centralized, online archiving and open access to the resulting information and maps to inform public and private management and permitting decisions.

4.1.2. Accelerate investment in conserving and restoring eelgrass beds, kelp forests, and salt marshes to the state estuaries and bays through funding for greenhouse gas mitigation, water quality, and natural resources protection. Where possible and advisable in light of sea-level rise, priority should be given to conserving existing eelgrass meadows, salt marshes, and kelp forests. Test and adopt methods to drive down costs and improve the success rate of management, restoration, and assisted migration of seagrass meadows, kelp forests, and salt marshes, as appropriate.[31]

4.1.3. Inventory and acknowledge the potential OA and carbon storage benefits of seagrass meadows, salt marshes, and kelp forests in the statewide network of MPAs. Integrate results from MPA monitoring of OA (see Strategy #2) into the learning framework for the state's system of seagrass meadows and kelp forests.

4.1.4. Use the growing network of state investments in place-based conservation and management of seagrass meadows, salt marshes, and kelp forests as a system for "learning by doing" to identify whether, where, and how effectively these natural systems can ameliorate OA and sequester carbon over near- and long-term timelines and attendant impacts on other species of management concern. Translate verified findings into prescriptive guidance to improve targeting of future investments and to develop best management practices.

4.1.5. Evaluate and promote innovative funding and financing mechanisms that are shown to yield verifiable benefits for the preservation, enhancement, restoration and management of seagrass meadows, salt marshes, and kelp forests.

[31] See: Nielsen, K., Stachowicz, J., Carter, H., Boyer, K., Bracken, M., Chan, F., Chavez, F., Hovel, K., Kent, M., Nickols, K., Ruesink, J., Tyburczy, J., and Wheeler, S. Emerging understanding of the potential role of seagrass and kelp as an ocean acidification management tool in California. California Ocean Science Trust, Oakland, California, USA. January 2018.

ACTION 4.2

Evaluate and advance aquaculture approaches that optimize OA amelioration and carbon storage, while benefiting shellfish production.

4.2.1. Develop and evaluate the effectiveness of technologies and management practices designed to allow shellfish aquaculture to co-exist with the conservation of thriving eelgrass beds.

4.2.2. Build on initial efforts to develop, test, and apply coupled aquaculture production systems that enhance shellfish production by integrating seagrasses or kelps to locally ameliorate OA.

4.2.3. Continue to develop, evaluate, and refine kelp-farming aquaculture as a way to locally ameliorate OA while producing commercial products, such as food, biofuels, agricultural amendments, and water pollution treatment services.

4.2.4. As warranted by evaluations of feasibility, cost effectiveness, risks, and benefits, expand applications of the above approaches by investing in technical training and greater support of extension to the aquaculture industry, such as through California Sea Grant and/or the University of California Cooperative Extension.

ACTION 4.3

Explore the potential of other innovative options for deploying living systems to ameliorate OA and/or store carbon while delivering other societal benefits.

4.3.1. Evaluate current evidence demonstrating the ability of other natural and constructed living marine and aquatic systems (e.g., non-kelp algae and oyster reefs) to locally ameliorate OA and/or store carbon while delivering other benefits such as food production and shoreline protection from sea-level rise.

4.3.2. Support pilot efforts to test these approaches in real-world settings as warranted.

STRATEGY #5

Build Resilience of Affected Communities, Industries, & Interests

MOUNTING AN EFFECTIVE CAMPAIGN to reduce OA's harmful impacts on California's natural assets and people will require action across government, industry, and conservation entities working with a shared understanding of the risks and an effective set of options. The people most at risk, as well as those who directly or indirectly contribute to OA, must participate in developing, launching, and ensuring the success of collaborative solutions that will improve and sustain societal resilience and the resilience of coastal and marine ecosystems as the oceans acidify (see box, on following page).

Today in California the significance of OA is not yet well appreciated by the general public, beyond the scientific community and a relatively small set of policymakers, stakeholders, and environmental NGOs. This contrasts with places like Washington

What is a resilient California?

The state is applying the following definition of resilience:

Resilience is the capacity of any entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience.

In this regard, resilience is understood to advance capacity to prepare and recover based on continual learning, flexibility and adjustment as it takes action to prepare for the impacts of ocean acidification at the state, regional, and local level:

Further, California developed an operational approach to "resilience" in establishing the Integrated Climate Adaptation and Resiliency Program (ICARP) called for in SB 246 (Wieckowski, 2015).

Through ICARP, the state has further defined a vision for a resilient California, which includes the following characteristics: All people and communities respond to changing average conditions, shocks, and stresses in a manner that minimizes risks to public health, safety, and economic disruption and maximizes equity and protection of the most vulnerable. Natural systems adjust and maintain functioning ecosystems in the face of change. Infrastructure and built systems withstand changing conditions and shocks, including changes in climate, while continuing to provide essential services.

For details see http://opr.ca.gov/planning/icarp/resilient-ca.html, http://opr.ca.gov/planning/icarp/tac/ and http://resources.ca.gov/docs/climate/safeguarding/update2018/safeguarding-california-plan-2018-update.pdf

State and tropical island nations like Fiji, where the imminent and obvious risks posed by OA to key economic interests (e.g., oyster aquaculture and coral reef tourism) have heightened public concerns and driven industry engagement. Although the significance of OA for California is great, the state has not yet experienced high profile or newsworthy events directly linked to OA. Understanding of OA risks and response options across the industries that will be most directly affected – aquaculture and fisheries – is uneven, and OA is not yet a high priority for the leaders of coastal towns, cities, or counties.

Our challenge in California is not simply to communicate information about OA more effectively and to more audiences; it is to broaden ownership of the problem and of its solutions, so that the solutions implemented by the state are equitable and socially acceptable as well as technically and financially feasible. The importance of doing so has been amply demonstrated through California's extensive experiences managing ocean fisheries and ecosystems and undertaking climate change mitigation and adaptation. Many more people will need to bring their energies and ideas into the mix for us to succeed.

Fortunately, California's past decade of experience with climate change has yielded good models for engaging diverse interests and government entities at all levels (local to statewide) to help build adaptive capacity and resilience. These generally involve establishing mechanisms to surface and address the needs of affected groups; developing and facilitating the sharing of knowledge, tools, and guidance; and maintaining ongoing interactions to ensure alignment of state-led programs with the goals and challenges faced by local and regional entities. The legislatively mandated Integrated Climate Adaptation and Resiliency Program, established in 2015 in the Governor's Office of Planning and Research, performs these functions for the state's climate change efforts and could help support similar efforts related to OA and assist in integrating OA with existing planning, hazard mitigation, and climate and sea-level rise adaptation efforts.[32]

[32] For more about the Integrated Climate Adaptation and Resiliency Program see http://opr.ca.gov/planning/icarp/.

5-YEAR GOALS

California has a well-informed, well-functioning, and highly collaborative OA constituency that is helping to identify and advance innovative and effective strategies for sustaining community, industry, and ecosystem resilience as OA intensifies.

Drawing on the knowledge and talents of people from industry, public agencies, tribes, and the scientific community, aquaculture and fisheries management in California is adapting to OA through improved technologies, tools, and management flexibility.

The constituency for California's coastal and ocean ecosystems is advancing tractable options for securing ecosystem resilience as the oceans acidify.

ACTION 5.1

Engage interested parties from across the public and private sectors to share learning and take action to address OA

5.1.1. Establish a representative statewide advisory group that includes the diverse interests that will affect and be affected by OA as well as technical and policy experts – including fishing, aquaculture, agriculture, tribes, municipalities, counties, water management, conservation, wastewater treatment, state and federal agencies, and scientists from relevant disciplines. This group will advise the state on its policy, management, science, and communications priorities and strategies, starting with the Statewide Vulnerability Assessment described in Strategy #1.

5.1.2. Use California's convening and knowledge-sharing processes for climate change adaptation and science in California to share and accelerate innovation and learning about OA. Possible options include the biennial California Adaptation Forum, the online Adaptation Clearinghouse, and periodic California Climate Change Symposia.[33]

5.1.3. Develop a campaign to raise public awareness about OA and its causes, impacts, and solutions in California. The campaign should clearly specify the communication goals, target audiences, anticipated outcomes, and impact measures, and should incorporate a means of evaluating effects.

5.1.4. Establish guidance and extension-type technical support to speed integration of OA into planning and operations of potentially affected communities and industries (e.g., coastal cities and towns; tribes; ports and harbors; aquaculture, fisheries, coastal tourism industries). Deliver targeted industry- and community-specific advice and information products.

[33] The biennial California Adaptation Forum gathers together climate adaptation practitioners (http://www.californiaadaptationforum.org). The online Adaptation Clearinghouse provides a centralized information repository and is hosted by the Integrated Climate Adaptation and Resiliency Program (http://www.opr.ca.gov/clearinghouse/adaptation/). The state periodically convenes California Climate Change Symposia to share the results of research supported to inform state adaptation and mitigation strategies (http://californiascience.org).

ACTION 5.2
Advance resilience of the shellfish aquaculture industry
5.2.1. Facilitate partnerships that bring together members of the shellfish aquaculture industry and the scientific community to fully understand implications of OA for the industry and to solve practical problems. Examples include development of durable, low cost, and easy to use monitoring technologies; technical training in OA monitoring equipment; and development of OA resistant brood stock.
5.2.2. Build upon existing and develop new OA monitoring capacities and instrumentation at hatchery locations in California at the right level of spatial and temporal resolution to assist industry in anticipating and responding to OA by leveraging ongoing partnerships.
5.2.3. Partner with aquaculture experts in the National Oceanic and Atmospheric Administration to facilitate producer access to federal information resources, including monitoring and observations, science findings, and spatial analysis and planning to enhance the siting and management of aquaculture facilities in light of OA projections.

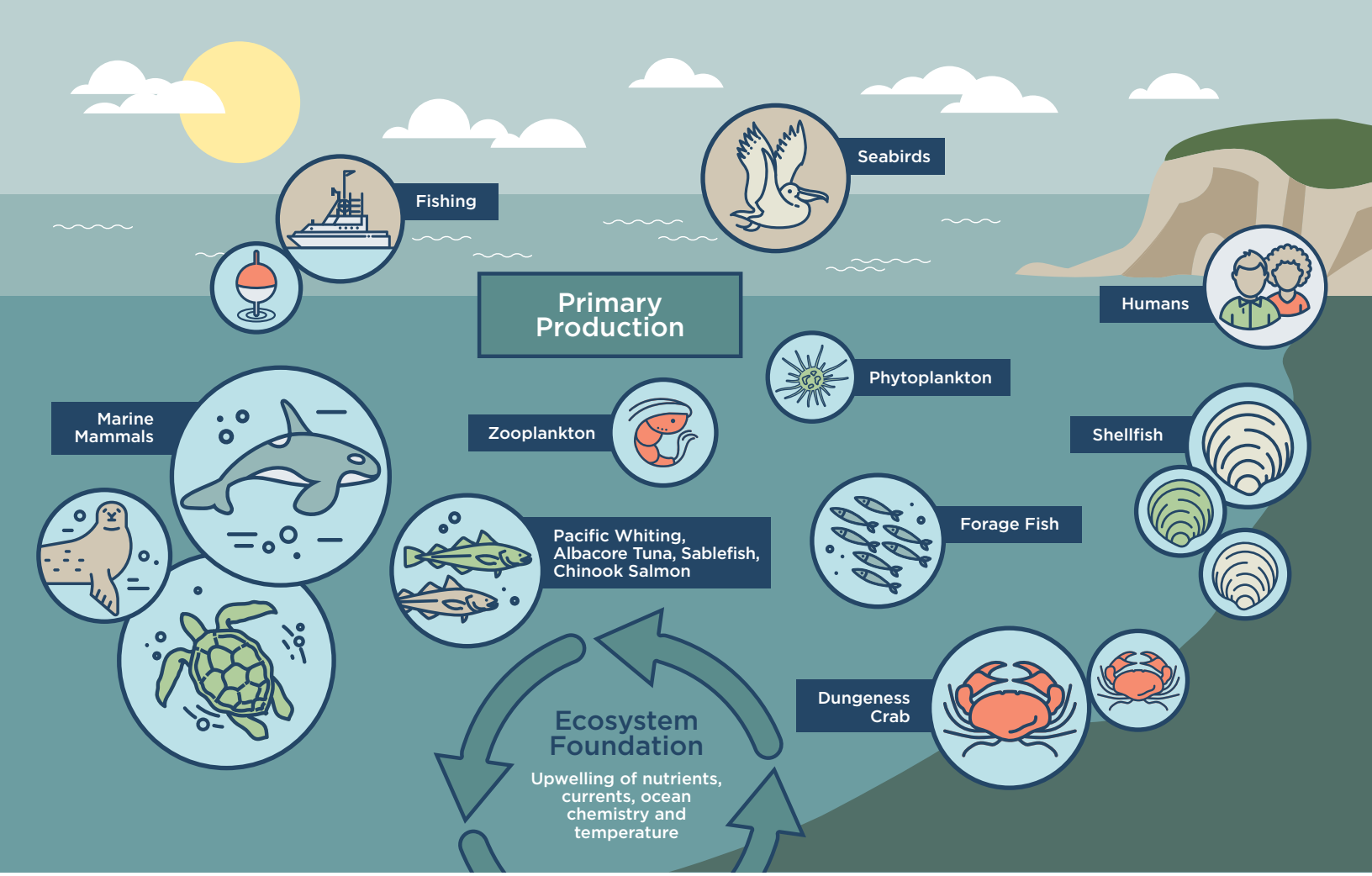


FIGURE 4: **Ocean acidification threatens a highly interconnected marine foodweb.**

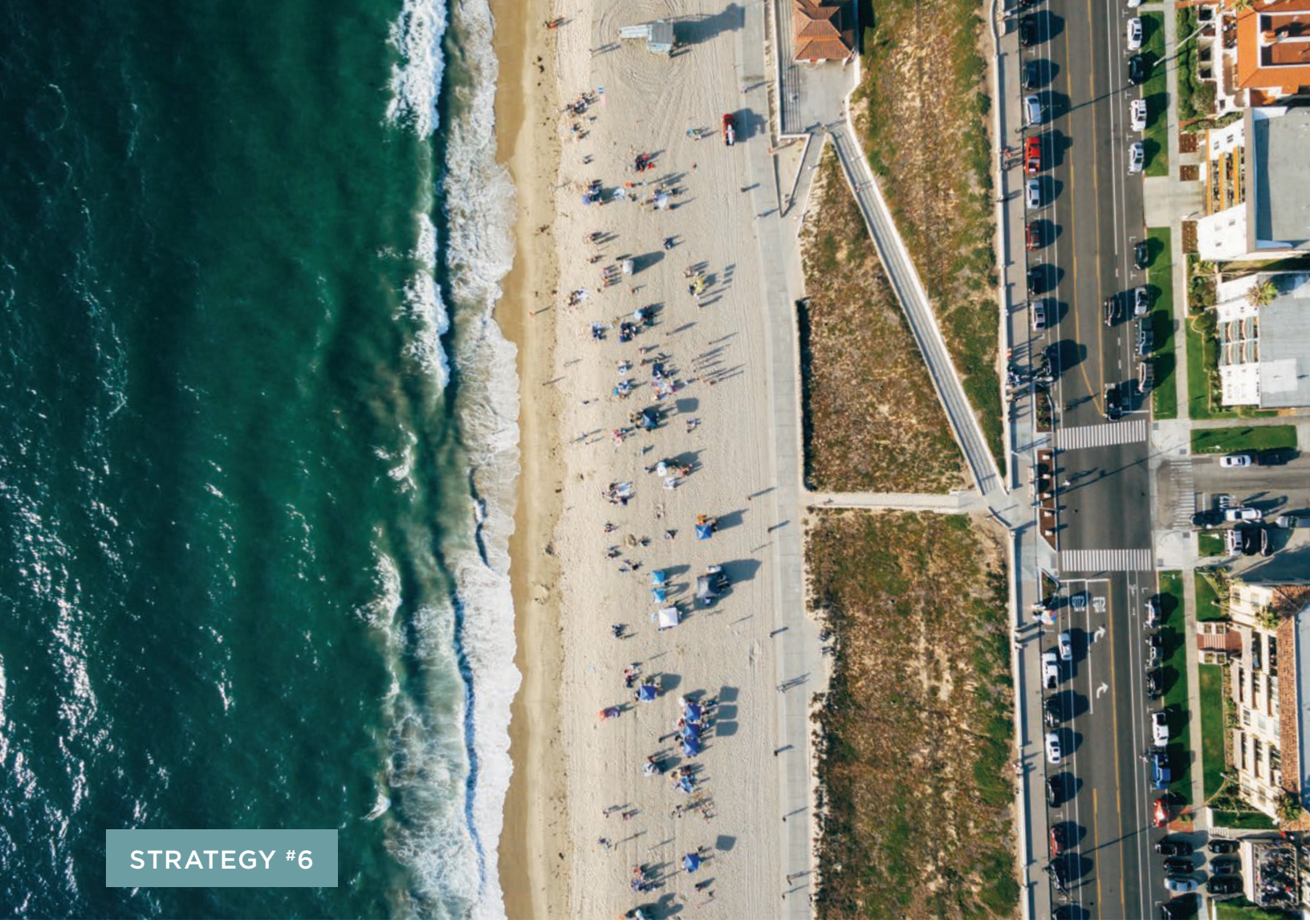
ACTION 5.3
Advance resilience of the fisheries industry
5.3.1. Implement provisions of the revised Marine Life Management Act Master Plan that call for adaptive fisheries management under changing and uncertain conditions. Develop policy mechanisms to support regulatory flexibility as conditions shift and/or new information becomes available.
5.3.2. Develop science-based practices for how OA can best be integrated into the state's evolving tools for flexibly managing changing fishery resources, such as scenario-based models to explore alternative management options and science-based triggers and thresholds for decision-making.
5.3.3. Advance capacities of members of the fishing community to identify and respond to shifts in the relative abundances of different target species.
5.3.4. Encourage the Pacific Fisheries Management Council to continue to take steps to better understand the implications of OA for West Coast fisheries and to integrate this understanding into fisheries management science and decisions.
5.3.5. Support science to understand and develop scenario-based projections of the effects of OA acting in concert with other environmental changes on California's fishery food webs (Figure 4), productivity, and ecosystems. Translate this information into a form that makes it useful and usable to members of the fishing community and to state managers for making fisheries-related decisions.

VOICES FROM THE FISHING COMMUNITY

"The fishing industry in California hasn't yet been engaged on ocean acidification, although there is lots of interest. When the oyster industry got engaged in Washington, that created a huge push because the public believes "if the fishermen are worried, then we should be too." Fishermen will react once they understand the threat...more information is needed about effects on species that are commercially and recreationally important. And this information should be brought to the fishermen, rather than expecting fishermen to attend meetings of public agencies and scientists."

BRUCE STEELE, Captain, F/V Halcyon

ACTION 5.4
Advance resilience of coastal and ocean ecosystems
5.4.1. Establish a representative working group of those public and private sector interests that depend on or sustain a deep interest in the health of natural coastal and ocean ecosystems – including tourism, recreation, coastal municipalities, harbors, parks and reserves, and conservation organizations, and relevant scientific experts.
5.4.2. Convene the working group in coordination with agency partners to examine the implications of OA for ecosystem resilience and societal benefits within the context of other ongoing environmental changes and to identify and weigh the feasibility and acceptability of potential public policy options to help sustain ecosystem resilience as conditions acidify.
5.4.3. Communicate findings of the working group to public and private sector leaders and support pilot projects to test the identified options.



STRATEGY #6

Engage Beyond State Boundaries

BECAUSE THE CALIFORNIA Ocean Acidification Action Plan is a state plan, Strategies #1-5 appropriately focus on anticipating and meeting state needs. They dovetail with and expand upon the efforts already undertaken by California to combat greenhouse gas emissions, adapt to climate change, and secure the health and productivity of ocean ecosystems and fisheries in a changing world. Although essential, these state-focused strategies and actions are not enough.

OA is playing out on a global stage, and will affect every nation and community whose economic and social wellbeing depends upon healthy oceans. And the primary cause of global OA is global GHG emissions. Just as California has helped over the past decade to advance the growth of international efforts to reduce emissions, so too it must help build the momentum of international, national, and regional efforts to combat OA. The state

has much to contribute, but also will benefit greatly. By working beyond state boundaries, California can learn much from experiences in other jurisdictions and geographies and accomplish more than it could on its own.

Through membership in the Pacific Coast Collaborative, California already is working cooperatively with the states of Oregon, Washington, and Alaska, as well as British Columbia, on climate change and emissions reductions.[34] The West Coast scale is the right one for addressing certain OA issues, because of the region's shared ocean systems, biological resources, and policy and economic interests. The West Coast was the organizing geography for California's initial efforts to address OA through the West Coast Ocean Acidification and Hypoxia Science Panel. Looking ahead, it makes good sense, for example, to build technical capacities for observing and understanding OA at this regional scale, which should be expanded to include Mexico.

At the national level, the NOAA Ocean Acidification Program has been supporting important work on OA since its establishment in 2011 by investing in observation networks and monitoring instrumentation, research on species sensitivity, oceanographic and ecosystem modeling, social science, education, and communication, and stakeholder engagement.[35] The program provides California with a good entry point for linking to federal OA research, development, and applications capacities. The Pacific Coast Collaborative and the federal Interagency Working Group on Ocean Acidification have initiated a strong partnership on regional monitoring and observation. More broadly, the federal government will significantly influence whether and how the state achieves many goals outlined in the Action Plan, through its management of fisheries and ecosystems in federal waters and diverse programs and responsibilities that affect water quality and runoff.

The recent establishment of the International Alliance to Combat Ocean Acidification (of which California was a founding member), with 60 members representing governments, industry, academia and non-profit organizations, and the development an OA action plan for 14 countries in Latin America and the Caribbean, signal growing attention to OA worldwide.[36] The opportunity now is to transform this elevated attention into a coherent international initiative that speeds progress and enhances the collective success of all participants.

[34] For more on the Pacific Coast Collaborative see http://pacificcoastcollaborative.org.

[35] For further information about the NOAA Ocean Acidification Program see https://oceanacidification.noaa.gov/WhoWeAre.aspx. The program helps support the recently launched Ocean Acidification Information Exchange (https://www.oainfoexchange.org/index.html), an online forum for collaborative, multi-sector, teams that are tackling technical, communication, or policy and management issues related to OA.

[36] For more about the OA planning effort for Latin America and the Caribbean see https://www.iucn.org/news/secretariat/201804/latin-american-and-caribbean-countries-threatened-rising-ocean-acidity-experts-warn .

5-YEAR GOALS

Regional collaboration on OA-related policy, science, and communications across the West Coast is robust, with efficient, effective, coordinated responses across the region.

California state agencies are partnering closely with relevant federal agencies to leverage investments and to ensure actions in state and federal waters are well aligned and coordinated where needed.

California is helping to lead an international coalition that is spurring worldwide action on OA and improving attention to oceans in international climate negotiations.

ACTION 6.1

Participate in and help to lead West Coast regional initiatives that will yield significant efficiencies, speed learning, and advance collective progress in reducing the causes and impacts of OA across the California Current.

6.1.1. Develop integrated monitoring and observation capacities and fill critical information gaps essential for building regional understanding of OA patterns, processes, and future scenarios (see also Strategy #1).

6.1.2. Support, lead, and engage in regional venues, such as the Pacific Coast Collaborative, for rapidly sharing the improved scientific understanding and policy and technical innovations and insights derived from participating governments' investments and experiences developing and implementing action plans.

6.1.3. Improve alignment, where beneficial, between California's actions and the actions taken by other West Coast jurisdictions to improve the region's aggregate efficiency and impacts.

6.1.4. Collaborate with other West Coast states to speak with one voice in identifying priority needs and partnering opportunities with the Federal government, including those related to ocean resources management (e.g., fisheries, aquaculture, renewable energy) and science (e.g., monitoring and observations, spatial planning).

ACTION 6.2

Build national-level partnerships that will simultaneously improve California's success in implementing this Action Plan while advancing federal OA-related efforts.

6.2.1. Continue collaboration with the NOAA Ocean Acidification Program and the federal Interagency Working Group on Ocean Acidification to coordinate research and monitoring investments and efforts.

6.2.2. Participate in national-level forums and teams, such as the Ocean Acidification Information Exchange, that facilitate knowledge sharing and collaborative problem solving among different regions of the United States.

6.2.3. Build cooperative partnerships with California's National Marine Sanctuaries, National Estuaries, and National Estuarine Research Reserves and others that will aid in accomplishing the Action Plan goals.

6.2.4. Seize opportunities for leveraging California's Action Plan and OA accomplishments to support national OA efforts under the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM) and the Strategic Plan for Federal Research and Monitoring of Ocean Acidification.[37]

ACTION 6.3

Help build the international coalition to raise global understanding of OA and to spur actions to both adapt to and reduce the causes of OA.

6.3.1. Provide continued leadership and support for the International Alliance to Combat Ocean Acidification, and partner closely with relevant international ocean climate initiatives and alliances where applicable.

6.3.2. Amplify and share the California model for elevating attention to OA in climate change mitigation and adaptation and ocean stewardship policies and actions, including through participation in the Conference of the Parties convened under the United Nations Framework Convention on Climate Change.[38]

6.3.3. Import lessons from other geographies that will help to speed and improve California's OA efforts.

[37] The text of FORAM can be found at https://www.congress.gov/111/bills/hr14/BILLS-111hr14ih.pdf.
[38] See https://unfccc.int .

PART III

Conclusion: Moving Forward with Bold Action

THIS ACTION PLAN has laid out a course of action that, when it is successfully implemented, will fundamentally alter how Californians view and address OA. The state will have the political will and knowledge to take effective action to reduce OA causes, to improve the resilience of vulnerable groups, and to manage marine resources in new ways that minimize harmful social and environmental impacts while bolstering resilience. To be effective, these improvements must address OA within the context of the changing climate, escalating and shifting human uses, and other changes that are significantly altering California's coastal and ocean environments and ecosystems.

Historically, attention to the oceans in state, national, and international policies to mitigate greenhouse gas emissions (the biggest cause of OA) and to adapt to climate change has been somewhat low. At the same time, ocean resource managers have been slower in developing practical frameworks and tools for anticipating and adapting to climate change than their counterparts who manage land and freshwater resources. California's Ocean Acidification Action Plan will help to bridge this gap by taking concrete steps for addressing OA within the context of the state's ambitious and well-established policies for ocean management and climate change. This innovative approach will continue the state on the path already forged by California's national and global leadership on reducing greenhouse gas emissions.

Effective implementation of the Action Plan will require broad adoption and assertive action by all those, inside and outside of state government, who have important roles to play. Over the coming year, the Action Plan will be widely shared across the state, regionally, and at international forums. Related information and communication tools will be available via http://www.opc.ca.gov/oa-action-plan/ for use by anyone seeking to advance and contribute to California's efforts. Ultimately, though, the speed and success of California's efforts to combat OA will depend on commitments of leadership, capacity, and funding from across state government, the legislature, and the private sector. By holding ourselves accountable for results, we can make progress in better understanding and addressing OA, and in doing so secure a better future for all Californians.

Appendix 1:

Correspondence of the State of California Ocean Acidification Action Plan to goals of the International Alliance to Combat Ocean Acidification

The International Alliance to Combat Ocean Acidification (OA Alliance) brings together jurisdictions across the globe to combat ocean acidification and changing ocean conditions as an immediate and critical threat to coastal economies and ocean ecosystems. Individual OA Alliance members are committed to supporting the work of the OA Alliance broadly, and are committed to taking meaningful local actions by crafting their own Ocean Acidification Action Plan that describes their own unique contribution to advancing some or all the 5 goals of the OA Alliance as written in the Call to Action. The Call to Action identifies the five goals that the Alliance is working to further:

- Advance scientific understanding of ocean acidification
- Take meaningful actions to reduce causes of acidification
- Protect the environment and coastal communities from impacts of a changing ocean
- Expand public awareness and understanding of acidification
- Build sustained support for addressing this global problem

The Call to Action provides an immediate opportunity for parties across the globe to highlight ocean acidification as an imminent threat to coastal economies and ocean ecosystems, while the Action Plans will help governments create actionable responses to threats in their regions and will help affiliate members best leverage their expertise and resources on this issue. To help jump-start the development of Action Plans, the International Alliance to Combat Ocean Acidification provides an "Action Toolkit" with numerous options for addressing OA through improved scientific understanding and public awareness, mitigation and adaptation, and regional and international collaboration. The Toolkit provides members with examples and suggestions of both regulatory and non-regulatory actions, and is meant to be a source of inspiration and a listing of suggested actions that members might consider when crafting their own Action Plan. The OA Alliance is continuing to develop the Action Plan toolkit and supporting resources for both government and affiliate members to utilize.

Several other states have or are currently taking steps to address OA as members of the OA Alliance or as part of broader ocean initiatives, including Washington, Oregon, Maryland, Maine, and New York. International efforts on OA include Monaco's Action Plan and regional vulnerability assessments and planning for the Pacific island region and Latin America and the Caribbean.

For additional details on the OA Alliance, the Call to Action, or the Toolkit, please see: https://www.oaalliance.org/

The Five Goals Of The International Alliance To Combat Ocean Acidification

STRATEGIES FOR ACTION IN THE STATE OF CALIFORNIA OCEAN ACIDIFICATION ACTION PLAN	ADVANCE SCIENTIFIC UNDERSTANDING	REDUCE CAUSES OF OA	BUILD ADAPTATION & RESILIENCE	EXPAND PUBLIC AWARENESS	BUILD SUSTAINED INTERNATIONAL SUPPORT
#1 – PREPARE FOR THE FULL RANGE OF OA RISKS AND IMPACTS	●		●	●	
#2 – ACTIVATE RESPONSIBLE ELEMENTS OF STATE GOVERNMENT	●		●	●	●
#3 – REDUCE THE POLLUTION THAT CAUSES OA	●	●	●	●	
#4 – DEPLOY LIVING SYSTEMS TO SLOW OA AND STORE CARBON	●	●	●	●	
#5 – BUILD RESILIENCE OF AFFECTED COMMUNITIES, INDUSTRIES, & INTERESTS	●	●	●	●	
#6 – ENGAGE BEYOND STATE BOUNDARIES	●	●	●	●	●

Appendix 2:

Consultation and Review Processes that Informed the State of California Ocean Acidification Action Plan

The Action Plan benefited greatly from the efforts of many people who generously contributed their time and thoughtful input into the Action Plan's development.

The Action Plan's development was informed by the ideas and advice of more than 70 people from across the aquaculture and fisheries industries, state and national governments, private philanthropy, and the scientific community. Most were consulted through phone or in-person interviews that solicited their views about the plan's 10-year vision, specific tractable actions to include in the plan, and how to ensure the plan's adoption and successful implementation.

California's newly convened Ocean Acidification and Hypoxia Science Task Force [established under Assembly Bill 2139 (Williams, 2016)] provided scientific and technical input to the draft plan development related to monitoring and observations, applications of living systems, and water quality issues and developed the supporting science plan (Appendix 5). The initial draft of the Action Plan was reviewed for scientific feasibility by the OAH Science Task Force and for policy feasibility by a group of policy experts.

Additionally, helpful insights and concepts from parallel efforts in other jurisdictions and guidance developed by the International Alliance to Combat Ocean Acidification were adapted for application to the California context.

Interviewees

Sara Aminzadeh, *Executive Director, California Coastkeeper Alliance, formerly*

Clarissa Anderson, *Executive Director, Southern California Coastal Ocean Observing System (SCCOOS)*

Matthew Armsby, *Program Officer/Attorney, Resources Legacy Fund*

Debbie Aseltine-Neilsen, *Senior Environmental Scientist Specialist, Marine Region, California Department of Fish and Wildlife*

Susan Ashcraft, *Senior Environmental Scientist and Marine Advisor, California Fish and Game Commission*

Betsy Behl, *Division Director, Health and Ecological Criteria Division, US Environmental Protection Agency*

Jonathan Bishop, *Chief Deputy Director, California State Water Resources Control Board*

Elliot Bourgeault, *Senior Policy Analyst, Climate Action Secretariat, British Columbia, Canada*

Caren Braby, *Program Manager, Marine Resources Program, Department of Fish and Wildlife, Oregon*

Maria Brown, *Superintendent, Greater Farallones National Marine Sanctuary, National Oceanic and Atmospheric Administration*

Mark Carr, *Professor, Ecology & Evolutionary Biology Department and Institute of Marine Sciences, University of California, Santa Cruz*

Margaret Caldwell, *Deputy Director, Oceans, Conservation and Science, The David and Lucile Packard Foundation*

William Craven, *Chief Consultant, California State Senate*

Aimee David, *Director of Ocean Conservation Policy Strategies, Monterey Bay Aquarium*

William Douros, *West Coast Regional Director, Office of National Marine Sanctuaries, National Oceanic and Atmospheric Administration*

James Eckman, *Director, California Sea Grant, formerly*

Julia Ekstrom, *Climate Adaptation Program Director, Coastal and Marine Sciences Institute, University of California, Davis*

Chad English, *Program Officer, Conservation and Science, The David and Lucile Packard Foundation*

Rebecca Fitzgerald, *Manager, Water Quality Standards and Assessment Section, California State Water Resources Control Board*

Alex Harper, *Program Manager, Central and Northern California Ocean Observing System*

Elliot Hazen, *Associate Researcher, National Marine Fisheries Services at Long Marine Lab, Institute of Marine Sciences*

Tessa Hill, *Professor, Department of Earth & Planetary Sciences, and Associate Director – Academic Programs, Bodega Marine Laboratory, University of California, Davis*

Gretchen Hofmann, *Professor and Chair, Department of Ecology Evolution and Marine Biology, University of California, Santa Barbara*

Sara Hutto, *Ocean Climate Program Coordinator, Greater Farallones National Marine Sanctuary, National Oceanic and Atmospheric Administration*

Claire Jahns, *Clair, Assistant Secretary for Natural Resources Climate Issues, California Natural Resources Agency*

Emily Jeffers, *Staff Attorney, Oceans Program, Center for Biological Diversity*

Martha Kongsgaard,
Kongsgaard-Goldman Foundation

Kristy Kroeker, *Assistant Professor, Ecology & Evolutionary Biology Department, Institute of Marine Sciences, University of California, Santa Cruz*

Dan Laffoley, *Senior Advisor, Marine Science and Conservation, International Union for the Conservation of Nature, and Marine Vice Chair, World Commission on Protected Areas*

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Appendix 3:

Measures for Assessing Progress in Implementing the State of California Ocean Acidification Action Plan

STRATEGY	5-YEAR GOALS	MEASURES OF PROGRESS
1 **Prepare for the Full Range of OA Risks and Impacts**	• The risks OA poses to California's assets and interests are well understood among policymakers, managers, affected industries and communities, and the public. • Decision-relevant monitoring information about OA is widely available, delivered in a usable form, and routinely applied to decisions across the public and private sectors. • Improved scientific understanding of how OA, and the interactions of OA with other environmental drivers, affects coastal and marine ecosystems is informing state resource, land use, and ocean and coastal management decisions.	• New policies and investments are being made to address key risks and gaps in adaptive capacity identified through the state's OA vulnerability assessment. • California and the state's federal, academic, and regional partners along the west coast are developing a monitoring & observation (M&O) system optimized to deliver decision-relevant information. • Elements of the M&O framework that are critical for making policy and management decisions in California are receiving sustained support. • Information delivered by the M&O framework is openly available on the web and can be manipulated and displayed graphically with user-friendly decision-support tools that meet the needs of key audiences and users. • Improved understanding of potential impacts of OA interacting with other environmental changes on ecosystems and food webs is informing state resource management decisions.
2 **Activate Responsible Elements of State Government**	• All relevant state agencies are successfully integrating the best available scientific information about OA into decisions and policies that have the potential to contribute to or to slow OA along the California coast or that deal with biological resources, industries, or communities likely to be affected by OA. • State government is doing as much as it can to minimize harm to California's interests from OA and to anticipate and adapt to those harmful impacts that cannot be reduced.	• The state interagency OA working group is convened regularly, with high participation by all relevant agencies and programs, and is highly effective. • All relevant agencies – whose decisions affect or will be affected by OA – have adopted the state OA guidance, integrated relevant elements of the OA Action Plan into their operations, and are making related decisions informed by the best available OA science. • State government is actively working to reduce the global and local causes of OA. • State government actively supporting adaptation to OA in the management of coastal and ocean biological resources and among affected industries and communities. • Policymakers and leaders in state government and the Legislature understand the significance of OA and are promoting steps to reduce the causes and improve resilience. • California's experience activating state government to address OA is helping to inform approaches adopted by other states and nations.

STRATEGY	5-YEAR GOALS	MEASURES OF PROGRESS
3 **Reduce the Pollution that Causes OA**	• Attention to coastal and ocean systems and to OA is systematically addressed and elevated in California's GHG reduction efforts. • Near-term options for reducing local sources of acidifying pollutants (voluntary, incentive-based, permitting) have been identified and are fully employed. • The state has the technical tools it needs – including scientifically robust water quality indicators and thresholds and appropriate models for assessing contributions of local and global CO_2 inputs – to measure and evaluate OA-related changes occurring along the California coast, to select water quality goals, and to initiate management or regulatory action to slow these rates, if feasible and appropriate.	• Opportunities to reduce GHG emissions through coastal and ocean-based activities, industries, and infrastructure have been systematically examined, and feasible options have been initiated. • Funding decisions by the Greenhouse Gas Reduction Fund is supporting carbon sequestration in coastal and ocean systems, considering OA impacts, and advancing resilience of communities and industries vulnerable to OA. • Impacts of CO_2 emissions on OA and resulting environmental and societal impacts are widely understood and acknowledged in state emissions reduction efforts. • A significant increase has occurred in voluntary or incentivized efforts to curtail nutrient and organic carbon pollution in coastal bays and estuaries at high risk to OA. • The state has the technical tools it needs for measuring and evaluating acidification changes along the CA coast and for developing OA-related water quality goals and standards. • The state has identified priority locations where interventions are needed to reduce sources of nutrient and organic carbon pollution and is taking steps to reduce these sources through regulatory and non-regulatory means.
4 **Deploy Living Systems to Slow OA and Store Carbon**	• Restoration of seagrass meadows across all of California's estuaries is now state policy and is well underway and financed. • State investments into seagrass meadows, salt marshes, and kelp forests to secure OA amelioration and carbon storage benefits are strategic and effective. • Kelp and seagrasses are well integrated into aquaculture production systems to reduce OA and enhance shellfish production. • Aquaculture production systems have been tested and adopted, as appropriate, that integrate kelp and seagrasses to reduce OA and enhance shellfish production and that endeavor to enable co-location of aquaculture with successful seagrass conservation.	• Targeted efforts are underway – guided by maps of current and potential future habitat – to restore seagrass meadows across California's estuaries. • Scientifically verified principles and practices guide and enhance the effectiveness of state investments into seagrass meadows, salt marshes, and kelp forests to secure OA and carbon storage benefits. These principles and practices are routinely updated to incorporate new information. • Economically viable methods have been developed that integrate seagrasses and kelps into commercial aquaculture to help modulate OA. • Methods to enable the coexistence of aquaculture with healthy seagrass meadows have been tested and verified or rejected. • Other innovative options for using living systems to ameliorate OA and/or store carbon while delivering other benefits are being tested.

STRATEGY	5-YEAR GOALS	MEASURES OF PROGRESS
5 **Build Resilience of Affected Communities, Industries, & Interests**	• California has a well-informed, well-functioning and highly collaborative OA constituency that is helping to identify and advance innovative and effective strategies for sustaining community, industry, and ecosystem resilience as OA intensifies. • Drawing on the knowledge and talents of people from industry, public agencies, tribes, and the scientific community – aquaculture and fisheries management in California is adapting to OA through improved understanding, technologies, and management flexibility. • The constituency for California's coastal and ocean ecosystems is advancing tractable options for securing ecosystem resilience as the oceans acidify.	• The representative statewide advisory group has been convened and chartered and is advising the state on OA priorities, improving understanding among key constituencies, and developing collaborative strategies that cross sectors and interests to reduce and respond to OA. • The diversity of interests participating in the advisory group has expanded, reflecting broadening appreciation of OA's significance, who will be affected, and what can be done to reduce local rates and impacts. • Action on OA is accelerating in California. OA is now a prominent element of state-sponsored meetings and online resources designed to speed information sharing about climate change impacts and response options and ocean management. • Good understanding about OA exists across the aquaculture and fisheries industries, and industry members are actively monitoring OA and developing approaches for reducing OA impacts through industry, public, and scientific partnerships. • A well-informed constituency for sustaining ecosystem resilience has coalesced and is promoting policies to achieve this outcome.
6 **Engage Beyond State Boundaries**	• Regional collaboration on OA-related policy, science, and communications across the West Coast is significantly strengthened, resulting in substantial improvements to the speed, efficiency, and effectiveness of participating members' OA efforts. • California state agencies are partnering closely with relevant federal agencies to leverage investments and to ensure actions in state and federal waters are aligned and coordinated where needed. • California is helping to lead an international coalition that is spurring worldwide action on OA and improving attention to oceans in international climate negotiations.	• Governments along the west coast of North America are implementing a regional system for integrated OA monitoring and observation. These governments are making targeted investments to build the system. • West coast states speak with an effective unified voice in identifying OA priorities and partnering with the federal government. • Effective regional, national, and international mechanisms and venues are in place that speed sharing of OA information, technical advances, and policy insights. The State has established capacities and mechanisms for contributing to and benefiting from these processes. • State and federal actions affecting or responding to OA in ocean waters off of California are aligned and coordinated, where appropriate. • International progress on OA, as measured by growth of the international coalition and development of OA action plans, is accelerating.

Appendix 4:

Communication and outreach framework to support implementation of the State of California Ocean Acidification Action Plan

Effective implementation of the Action Plan will require development and execution of a strategic outreach and communication plan to engage decision-makers and end-users in implementation, and build an active constituency to maximize impact. Each strategy outlined in the Action Plan may have differing communication goals, audiences, and timelines and will require a combination of OA-focused events and briefings, online and traditional media, and targeted on-the-ground community outreach. Below is an overview of the primary audiences and communication needs organized around each strategy that will serve as a framework for the development of a more comprehensive communications plan following adoption of the Action Plan. While the target audiences listed below focus primarily on California decision-makers and stakeholders, the role of the academic community, tribes and tribal, NGOs, and philanthropic organizations should also be considered as part of the development and execution of a communications plan. The communications plan should utilize and build upon existing communication venues as appropriate based on target audiences, including the OA Information Exchange, the California OAH Science Task force website and webinar series, the OPC listserv, the OA Alliance website, and C-CAN, among others. The communications plan should also consider development and use of a centralized online venue that allows users to track Action Plan progress and implementation across each strategy (see Appendix 3), and identify where additional support and resources are needed. The communications plan should also identify resources and funding required to support communication and outreach needs on behalf of the Action Plan.

STRATEGY	PRIMARY AUDIENCES	COMMUNICATION NEEDS
1 Prepare for the Full Range of OA Risks and Impacts	STATE FISH AND WILDLIFE MANAGERS AND AGENCY SCIENTISTS; TRIBES AND TRIBAL GOVERNEMNTS; FISHING COMMUNITY	• Translate and communicate information about risks vulnerabilities, and potential interventions to assist policymakers and affected communities and industries in prioritizing and undertaking actions for improving societal adaptive capacity.
2 Fully Mobilize State Government	ALL STATE COASTAL AND OCEAN AGENCIES; TRIBES AND TRIBAL GOVERNMENTS; STATE LEGISLATURE	• Improve understanding of OA and its significance among policymakers and leaders in California's legislature and public agencies. • Share with policymakers outside of California (domestically and internationally lessons and insights from California's experience elevating attention to OA into the state's policy frameworks for climate change (mitigation, adaptation), ocean stewardship (fisheries, wildlife, marine protected areas), and coastal water quality.
3 Reduce the Pollution that Causes OA	STATE WATER QUALITY MANAGERS; STATE AIR QUALITY MANAGERS	• Develop and amplify clear messages that identify OA as a major impact of global CO_2 emissions and reduction of OA as a major benefit of the state's GHG reduction efforts. • Target communications towards key audiences involved in watershed and land management demonstrating the potential linkages between upstream management and downstream OA.

STRATEGY	PRIMARY AUDIENCES	COMMUNICATION NEEDS
4 Deploy Living Systems to Slow OA and Store Carbon	**RESTORATION, CONSERVATION AND PERMITTING AGENCIES AND MANAGERS; STATE FISH AND WILDLIFE MANAGERS; AQUACULTURE INDUSTRY**	• Share innovative aquaculture production methods through technical training and extension.
5 Build Resilience of Affected Communities, Industries & Interests	**ALL STATE COASTAL AND OCEAN AGENCIES; STAKEHOLDERS; FISHERIES AND AQUACULTURE INDUSTRY; TRIBES AND TRIBAL GOVERNMENTS**	• Establish a representative statewide advisory group to engage in shared learning and identifying needed actions. • Leverage California's convening and knowledge-sharing processes for climate change adaptation to share and accelerate innovation and learning about OA. • Develop a campaign to raise public awareness about OA causes, impacts and solutions. • Establish extension-type technical support to speed integration of OA into planning & operations of potentially affected industries. • Advance capacities in the fishing industry to identify and respond to shifting relative abundances of fished species. • Communicate findings of the working group on ecosystem resilience to public and private sector leaders.
6 Engage Beyond State Boundaries	**REGIONAL AND INTERNATIONAL POLICY BODIES (E.G., INT'L OA ALLIANCE AND THE PACIFIC COAST COLLABORATIVE); FEDERAL AGENCIES (SEE IWG-OA MEMBER AGENCIES)**	• Support, lead, and engage in regional venues for rapidly sharing improved scientific understanding and policy & technical innovations and insights. • Seize opportunities for leveraging California's OA Action Plan and OA accomplishments to support national OA efforts. • Amplify and share the CA model for elevating attention to OA in climate change mitigation & adaptation and ocean stewardship policies and actions. • Import lessons from other geographies to speed and improve California's OA efforts.

Appendix 5:

Science strategy to support implementation of the State of California Ocean Acidification Action Plan

This science strategy document summarizes the research that will be necessary to support full implementation of the California Ocean Acidification Action Plan within the next five years. These science recommendations were developed at the request of the California Protection Council by the California Ocean Acidification and Hypoxia Science Task Force (www.westcoastoah.org) – made up of eight leading national scientific experts on ocean acidification who are assisting California policymakers in their efforts to address acidification. The Task Force developed eight recommendations that are intended to provide a tractable set of near-term research priorities to jump-start capacity-building for OA management in California. The Task Force recognizes that the scientific knowledge required to guide future decision-making on OA will require additional, longer-term research investments, and may be dependent on scientific advances and innovations that the Task Force has not yet foreseen. However, the eight recommendations in this document are intended to be immediately actionable by policymakers and coastal resources managers.

Science Recommendations

I. Why should we care about OA?

Task Force answer: OA will fundamentally alter ecological and economic systems that presently benefit Californians.

Task Force recommendation: Enhance understanding about where and when effects will most immediately manifest to help plan and prioritize California's mitigation and adaptation actions.

OA will continue to intensify in the coming decades in California's coastal ocean, even if global CO_2 emissions were to stabilize at current levels. This progression will result in ecological harm to an ever-widening suite of marine life, habitats and fisheries, particularly as OA acts in combination with other environmental stressors such as ocean warming and hypoxia. OA is expected to challenge and potentially compromise the ability of resource managers – from the water quality sector to the conservation and fisheries sectors – to meet their agency missions. However, existing science is not able to fully answer how ocean chemistry will change over time, the locations that are most vulnerable to change, and how the changes will trigger ecosystem and socioeconomic effects. By more fully quantifying anticipated effects, managers will be better equipped to develop a long-term strategy and optimally allocate limited resources.

RECOMMENDATION A1.1: Identify the pattern of OA exposure in California, its progression, and the locations where the earliest and most detrimental changes in ocean chemistry will occur.

Decision makers in California should prioritize developing a map of statewide OA exposure. This exposure map should: (1) explain the extent and severity of OA exposure in State waters and how it is likely to change over time; (2) help improve and validate the performance of circulation and biogeochemical models; and (3) identify the overlap between exposure and habitats of management concern, including essential fish habitats, marine protected areas, and waters that receive effluent discharges. Building a statewide OA exposure map will require strategic expansion of OA monitoring, particularly in highly vulnerable subsurface waters, in under-observed regions, and in specific locales such as benthic spawning and nursery habitats that support the State's fisheries. Completion of the exposure map will also rely on modeling efforts that generate projections of future OA dynamics that are applicable to management decision-making processes. Insights gained from these efforts will delineate risks (Strategy 1 in the Action Plan or S1), broaden engagement by agencies and stakeholders (S2, S5), and identify priority areas for local pollution controls (S3) and adaptation actions (S4, S5).

RECOMMENDATION A1.2: Characterize the vulnerability of marine life, habitats, and ecosystems of interest to California stakeholders.

OA science has focused primarily on characterizing changes to ocean chemistry; we are still early in the process of understanding which species within California's diverse ecosystems and productive fisheries are most threatened by these chemistry changes. For example, of the 200 species that support the bulk of California's commercial and recreational fisheries, less than 10 have been studied for OA sensitivity. This deficit can be largely and quickly corrected by conducting experimental and observational studies on a range of species of priority social concern expected to be harmed by OA's progression. A first-order understanding of vulnerability will need to grow quickly into a more complete picture of risks, where the scope, likelihood, and timing of population- and ecosystem-level impacts are made clear to decision-makers. Investments can start by supporting studies that quantify the sensitivity of responses in life stages that are most important for population dynamics, and that can be readily incorporated into management models. New understanding of vulnerability will accelerate and broaden stakeholder and agency engagement (S1, S2, S5). Also, because many marine life populations cross jurisdictional boundaries, improved knowledge of vulnerability will bring together neighboring states and federal agencies to develop coordinated actions beyond California's borders (S6).

RECOMMENDATION A1.3: Quantify the societal and economic consequences of OA.

Although OA's impacts on marine ecosystems will be felt by human communities, comparatively little effort has been invested to quantify the social and economic impacts of OA. This fundamental knowledge gap impedes the ability of coastal resources managers to explain OA's anticipated impacts to policymakers, stakeholders, and the public at large. By building on efforts to define exposure and biological vulnerability (Rec. 1.1 and Rec. 1.2), researchers can project social and economic risks in ways that can be readily incorporated into planning decisions. The Task Force recognizes that there are multiple approaches to quantifying socio-economic impacts that capture different facets of a community's values. A first step is to convene a series of workshops to identify a suite of socio-economic metrics that are (1) likely to be sensitive to OA; (2) amenable to study and quantification; (3) important to affected communities; and (4) useful in planning decisions. Quantifying social and economic risks directly facilitates completion of S1, empowers agencies to make investments commensurate with their anticipated benefit (S2), and guides community planning for building resilience (S5).

RECOMMENDATION A1.4: Characterize OA's contribution to coastal ecosystem impacts in relation to other stressors.

OA will intensify in the coming decades against a backdrop of other ocean changes, including expansion of hypoxic zones and ocean warming. Because such compounding stressors can hasten the timing and/or magnify the scope of OA impacts, research is needed to understand other changes in ecosystem condition that can act as stressors. Managers need this multi-stressor approach to understand the full costs of actions or inaction, and to decrease the risk of setting exposure targets that are not sufficiently protective or that only address part of the problem. Additionally, insights from multi-stressor work can help improve the design of OA vulnerability studies (Rec. 1.2). Research should identify the expected timing and magnitude of changes in ocean temperature, dissolved oxygen, productivity, and coastal upwelling currents; this work can build off investments in modeling and monitoring (Rec. 1.1). The information gained can then inform ways to expand OA vulnerability studies identified in Rec 1.2 so that they more realistically incorporate exposure to multiple stressors. The goal is to bound uncertainty as to the impacts of OA within the context of a changing ocean, so managers can gain improved understanding of the risks posed by OA relative to other management priorities – both now and in the future. Multi-stressor research is crucial in preparing the State for the full range of OA impacts (S1), engaging a broad range of agencies in prioritizing OA actions (S2), and identifying opportunities to lessen stressors that can exacerbate OA impacts (S3).

II. What can we do about OA?

Task Force answer: Local solutions that provide multiple ecosystem and stakeholder co-benefits can be implemented to offset and reduce OA's impacts.

Task Force recommendation: Identify effective local solutions for slowing OA's progression and building resilient ecosystems.

California has in place ambitious greenhouse gas reduction goals and a multi-pronged action plan for reducing atmospheric carbon dioxide emissions, which is the primary driver of OA globally. Alongside these actions, the State is evaluating a range of local and regional management strategies that have the potential to slow OA's progression and reduce the scope of anticipated harmful ecosystem changes. Although these strategies cannot wholly undo OA's impacts, some solutions have the potential to blunt OA's impacts, and to buy time for California's coastal ecosystems as nations work to reduce carbon dioxide emissions globally. They also have the potential to provide multiple ecosystem co-benefits.

California is a leader in supporting research to determine which local solutions will be most effective and where they are most effectively implemented. Moreover, the State has established a management structure through the Ocean Protection Council to ensure this research is done in close collaboration with local management agencies and relevant stakeholder groups. Thus, multiple coastal resource management sectors – from water quality, fisheries and aquaculture to habitat protection and restoration – stand ready to work collaboratively to transition local OA management solutions into widespread adoption and use.

RECOMMENDATION A2.1: Identify where local pollution control actions will most effectively slow local acidification rates.

Nutrient and carbon inputs from wastewater treatment plant discharges and agricultural runoff contribute to coastal acidification and hypoxia, but reducing these pollution sources is an expensive proposition that will not be equally effective everywhere. Managers need to focus on locales where oceanographic conditions are most susceptible to these land-based discharges, and where conditions are sufficiently close to the edge of biological vulnerability such that reducing inputs will result in meaningful improvements. To understand when and where local pollution reductions will provide the greatest gains in water quality, managers need access to information from robust, validated coupled physical-biogeochemical models. Multiple efforts to advance models for the West Coast are already underway. Although researchers will start sharing initial model outputs over the next year to stimulate conversations about potentially effective management options, the models require further investment before they can support decisions about nutrient reduction actions, which could cost billions of dollars. These investments fall into three main categories: (1) technical investments, including expanding the models into additional habitats and coupling them with ecosystem models that expand predictions beyond chemistry to understand ecological, fisheries, and socioeconomic impacts; (2) socioeconomic investments, which involve quantifying the costs associated with achieving the water quality benefits predicted by the models to provide socioeconomic context for decision-making; and (3) stakeholder engagement investments, which involve bringing vested interests together (e.g., resource managers, wastewater treatment facilities, coastal development planners, agricultural interests, citizen groups) to collaboratively use the models to set collective priorities and identify co-benefits among various management options. Investments in OA modeling will inform how to optimally reduce the pollutant inputs that cause OA (S3).

RECOMMENDATION A2.2: Explore how to maximize carbon reduction through natural and constructed living systems.

Strategy 4 of the Action Plan involves construction of living systems or biological infrastructures, such as kelp forests and seagrass beds, that remove CO_2 from seawater through photosynthesis. In addition, seagrass and

salt marsh habitats can serve as active carbon sinks, where organic carbon is sequestered in plant material and sediments. These habitats also may be able to store and/or remove nutrients that could otherwise indirectly exacerbate OA. Furthermore, adding filter feeders to the system – through construction of bivalve reefs (e.g., oysters, mussels) – may further enhance nutrients and organic carbon removal from the water column. Although these living systems have been shown in limited experiments to provide benefits to a variety of marine life – including ones known to be sensitive to OA or that are commercially valuable – research is needed to further quantify the benefits, and to recommend specific best practices and locations for optimizing OA mitigation and carbon storage capabilities. This research could also help inform the design of "living seawalls" (i.e., coastal vegetation), which is being pursued in California to combat the threat of sea-level rise. This work will involve two types of research. One will consist of site-specific pilot studies where field-based experimental manipulations of biological infrastructures are used to quantify the OA mitigation and habitat provisioning benefits of different types and combinations of biological infrastructure, and elucidate the system-dependent settings where benefits are likely to be maximized. The second will involve modeling to assess how to best place individual remediation projects into a network of solutions that provide maximum cumulative value through optimal project type, size, and siting. Knowledge gained from these studies will inform development of tailored strategies for support and constructing living systems that optimally slow OA, store carbon, and provide ecosystem co-benefits (S4).

RECOMMENDATION A2.3: Develop the scientific foundation for managers to set ecologically protective water quality targets for OA.

Strategies 3 and 4 of the Action Plan are focused on improving water quality, but assessing the effectiveness of those strategies – and even determining the level of investments needed – requires agreement on a management target. Such targets are usually established through water quality criteria, but California's acidification criteria are more than 40 years old and are neither based on current science nor ecologically protective of coastal ecosystems. Indeed, damage to marine life has been documented at thresholds that are well within the present criteria's legally permissible range. Recognizing these limitations, the State has already invested in research to identify OA response thresholds for a few sensitive species. Although this initial threshold work will be immediately applicable in management decision-making once it is completed, such as assessing the effectiveness of living system construction (Rec. 2.2), additional research is needed to achieve the level of rigor required to revise regulatory water quality criteria, as these criteria will drive potential nutrient discharge controls and other key management decisions. The additional studies needed to meet the higher bar of regulatory scrutiny consist of three complementary approaches: (1) laboratory testing to expand the number of species and exposure scenarios for which we understand biological response; (2) verification of laboratory experimental results through field studies that quantify the relationship between chemical exposure conditions and distribution of biota; and (3) studies that account for potential interactions of OA with co-occurring stressors such as hypoxia, where co-exposure can magnify marine life sensitivity to OA. Building the scientific foundation for potential OA water quality targets will support ongoing efforts to delineate risks (S1), broaden engagement by agencies and stakeholders (S2, S5), and identify priority areas for pollution controls (S3), and adaptation actions (S4, S5).

RECOMMENDATION A2.4: Evaluate the use of existing management tools to preserve, support, and enhance the resilience of fisheries and ecosystems in the face of intensifying OA.

Two categories of actions are available to address OA. Managers can reduce stressors (S3, S4), or they can employ resilience management to assist ecological systems and dependent industries and communities in resisting and recovering from OA. Environmental scientists have a generalized understanding of how factors such as a diversified gene pool, broad population age structure, and intact ecological communities can help promote biological resilience. However, little research has been conducted on the specific biological attributes that can confer resilience against OA in California's coastal ecosystems. Similarly, there is limited understanding of the factors that make fisheries and communities more resilient to OA, and how socio-economic resilience scales from biological resilience.

Although resilience management represents a broad research frontier, near-term investigations should focus on screening for whether existing management interventions – such as marine protected areas, spatial quotas, habitat restoration, fishery mobility, and catch shares – can meaningfully influence biological and socioeconomic resilience to OA. The aim would be to identify a set of tractable actions with existing management benefits that can be readily employed to lessen OA's impacts. Strategies for enhancing resiliency will be crucial for broadening engagement by managers and other decision-makers (S2), who will need to work together to achieve greater resilience within affected industries and communities (S5).

Planning for Future Science Needs

The science recommendations in this document are limited to near-term research that will support implementation of the Action Plan. Projects that take longer than three years to complete, or are not directly related to Action Plan implementation, were not included. However, there is need to develop a broader foundation of knowledge that will inform the implementation and development of potential future management strategies. For instance, more research is needed before managers can directly manage the resilience of ecosystems and coastal communities, or consider developing action strategies around geoengineering approaches for mitigating OA. California should develop a forward-looking research strategy that extends beyond the time-frame from the investments suggested in this document.

In the coming years, the task of synthesizing and communicating new scientific knowledge that can refine or create new opportunities for actions on OA will also be increasingly important. Policymakers and coastal resource managers need a mechanism to access that knowledge, and more importantly to have necessary assistance in translating research findings into clear, actionable management options. The Task Force thus supports the Action Plan's call for periodic scientific syntheses to translate scientific understanding into new actions. The Task Force further recommends that this synthesis – and associated engagement opportunities with broader management, stakeholder and research communities – be used to inform updates to a forward-looking research strategy. By supporting science-to-action syntheses and continued assessments of science direction and progress, California can ensure that research priorities continue to be in close alignment with decision-making needs and that decision-makers continue to be effectively served by the best available science.

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