Ocean Acidification and Hypoxia Monitoring Network:
Tracking the Impacts of Changing Ocean Chemistry to Inform Decisions

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The West Coast Ocean Acidification and Hypoxia Science Panel

Introduction

From estuaries, rivers, deep fjords, and protected bays to coastal shelf systems and open ocean environments, marine ecosystems across the West Coast of North America are shaped by a wide range of natural and human-caused dynamics, such as powerful upwelling, warming temperatures, and nutrient runoff, among others. These dynamics in turn influence how the stressors of ocean acidification and hypoxia (OAH) are manifested across the region.

The range and effectiveness of solutions available to address OAH are proportional to our understanding of changes in ocean chemistry and the ecological vulnerability and resilience to these changes. Although scientific research on OAH has accelerated around the world, information necessary to ensure that regional, state, and local communities are best prepared to address changes in ocean condition remains limiting. A strategic monitoring program that allows for enhanced spatial and temporal coverage, projection of future conditions, and testing of management solutions, is essential for gaining the scientific information needed to guide priorities, innovations and actions, now and especially in the future as the risk and severity of OAH intensifies (Ocean Acidification and Hypoxia: Todays's Need for a Coast-wide Approach, 2014).

The West Coast OAH Science Panel recommends the establishment of a sustained, strategic and adaptive monitoring network that informs policy and management decisions at local, state and regional scales. There are a number of diverse monitoring efforts in place on the West Coast, but these programs were developed primarily to address local issues and need to be effectively knit into a cohesive network that is focused on addressing regional OAH management questions. A regional OAH monitoring network can link decision-makers with a common pool of scientific data and other information that will enable them to evaluate how, when, and where to act to serve society's best interest. This document provides: (A) a framework specifying the necessary attributes of a regional OAH monitoring network; and (B) specific steps to enable the creation of such a network with a focus on the West Coast of North America.

About this Document

The Pacific Coast Collaborative and the State of California have requested a strategic framework for monitoring that will provide rigorous decision-support to policymakers and managers at a West Coast, regional scale. This document presents key attributes of an ocean acidification and hypoxia monitoring network, and recommends pragmatic steps to implement this network on the West Coast of North America.

This document was produced by a working group of the West Coast Ocean Acidification and Hypoxia Science Panel, with support from California Ocean Science Trust, as part of a suite of products to inform decision-making. The information provided reflects the best scientific thinking of the Panel.

For additional details and products from the Panel, visit www.westcoastoah.org.

West Coast Ocean Acidification & Hypoxia Science Panel

California Ocean Science Trust

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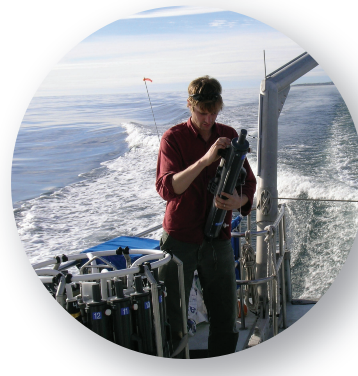
The proposed monitoring network is designed to include physical, chemical, biological, and ecological monitoring to track change, understand impacts, and evaluate management actions. It is designed to leverage and enhance existing assets (e.g., observing systems, ecological time-series), technologies, protocols, partnerships, data systems and management frameworks (e.g., protected areas) to recommend a strategic, efficient network. Four attributes characterize this network (further described below): (1) supports the needs of decision-makers; (2) measures an array of physical, chemical and biological variables; (3) builds on and enhances existing efforts; and (4) develops and sustains intellectual capacity.

Key attributes of an OAH monitoring network

#1: Supports the needs of decision-makers

Diverse decision-makers including water quality managers, living marine resource managers, coastal zone managers, and resource users share a common goal: to understand and track the effects of OAH to make decisions that mitigate impacts and facilitate adaptation to changing conditions. While the specific information needs of individual decision-makers vary within this broad context, Boehm et al. (2015) highlight that common themes emerge. Sound decision-making requires sustained and integrated monitoring of physical, chemical and biological measurements in order to assess OAH status, biological responses, and ecosystem health at a range of spatial and temporal scales. This collective need sets a foundation for the design of a monitoring network to inform decisions.



Sustained data collection is essential for detecting and responding to slow progressive change in ocean chemistry and rapid or fluctuating dynamics. As the needs of decision-makers change and technical ability to monitor OAH evolves, monitoring systems will necessarily need to adapt to stay relevant. However, adaptation of monitoring must also preserve the ability for long-term data comparability that is generated through sustained data collection.

Integrated monitoring – i.e., monitoring that is cross-disciplinary and which connects seamlessly with research advances and modeling – offers the best approach to maximize returns on resource and funding investments. Moreover, to meet management and policy needs, an integrated monitoring network must also be scoped to encompass the human dimensions of adaptation and response. Explicitly linking a monitoring network with research to illuminate the vulnerability and adaptive capacity of coastal communities can both inform this research priority and be used to prioritize placement of monitoring assets.

#2: Measures an array of physical, chemical, and biological variables

A fully-realized OAH monitoring network will have the capability to track changes in physical conditions (e.g., salinity and temperature), water chemistry (e.g., oxygen, pH, pCO_2, aragonite and calcite saturation states), and biological processes that can modulate and be modulated by changes in chemistry (e.g., production and remineralization rates, species distributions, predator-prey relationships, biogeochemical responses). Knowledge of ocean currents, atmospheric forcing, and watershed effects is also important. Furthermore, monitoring of stressors should aim to partition global vs. local drivers of ecosystem change, because understanding the contribution of local stressors will provide context for developing local OAH reduction strategies.

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Chemical measurements should ideally allow a complete description of the carbonate system in addition to salinity, temperature, oxygen and nutrients. The most commonly available technologies currently permit continuous monitoring of pH and carbon dioxide partial pressure (pCO_2), while typically dissolved inorganic carbon (DIC) and total alkalinity (TA) are obtained from water samples. Any two of these allow full description of the carbonate system, including saturation states of aragonite and calcite. While existing regulatory structures focus on pH to gauge water quality, new research points to the importance of changes in other aspects of carbonate chemistry including aragonite saturation state, pCO_2, as well as pH, in determining impacts to marine life and their ecological interactions.

Technologies for monitoring DIC and TA as well as improvements for measuring pCO_2 and pH continue to evolve and monitoring systems should have planned flexibility for adopting new instrumentation as they become operational. In the near-term, the cost, available expertise, and robustness of measurement systems will limit the number of parameters and the number of observing sites that can be monitored. Proxy approaches for estimating saturation state from high quality dissolved oxygen concentration, temperature and salinity measurements offer an alternative that can be evaluated as part of a monitoring program. Because information needs vary among decision-makers and systems, OAH monitoring systems will also differ in chemical parameters that can be successfully measured and sustained. Input from the OAH community will be essential to ensure that the design of the observing network is scientifically-justified and sufficient to meet defined goals.

Changes in the abundance, distribution, and physiological conditions of marine organisms, as well as their rates of metabolism, calcification, dissolution and ecological interactions define the impacts of OAH on coastal ecosystems and the services that they provide. While biological and ecological measurements are core elements of effective OAH monitoring programs, their integration has lagged far behind the implementation of chemical measurement efforts. Established biological and ecological monitoring efforts are in place on the West Coast that could be utilized or expanded. Facilitating the engagement of that community can help to jump-start the development of indicator taxa, processes and best practice approaches for detecting and tracking impacts of OAH and management actions.

Monitoring should be prioritized in key locations that connect impacts with economically, culturally, ecologically, and/or socially valued resources. As a start, data collection can reveal hypersensitive regions that may be locations to focus future efforts. In addition, existing research reserves and marine protected areas (MPAs) offer opportunity for efficient integration of chemical and biological monitoring, and for near-term management actions in response to information gathered. Monitoring inside and outside protected areas offers the opportunity to examine conditions when potentially confounding stressors are removed (e.g., fishing).

#3: Builds on ongoing efforts

Observing OAH requires specific focus and in some cases new measurements, but these can leverage significant investments made to date by federal, state, local governments and academia to observe and monitor coastal environments, including:

1. **Observing assets:** Many current monitoring assets can be expanded and improved to focus on the combined stressors of OAH and their biological response (Figure 1).
2. **Procedure guidance:** Recently published documents from the Global Ocean Acidification Observing Network (GOA-ON; Newton et al. 2014) and the California Current Acidification Network (C-CAN; McLaughlin et al., 2015) provide focused guidance and requirements for ocean acidification monitoring, including identifying the necessary environmental, chemical and biological response variables and providing best practices guidance.
3. **Data access:** The U.S. Integrated Ocean Observing System (IOOS) working with the NOAA Ocean Acidification Program (OAP) has developed West Coast-wide capacity for data visualization and delivery from a variety of data providers (www.IPACOA.org), incorporating many of the assets in Figure 1, and can serve as a nexus to pull in other data streams, including OAH model output.

In some locations, this work has begun (Figure 1). The IOOS regional associations in WA, OR and CA have identified many of the existing networks of sensors and sampling stations (including federal, state, tribal, local, academic, private) and are providing streams of environmental data that can be visualized and incorporated into the observing network. Additionally, shorter term federally funded research efforts (e.g., NSF OMEGAS) have documented 'baseline' OAH data that are useful for making choices about when and where to collect data into the future.

Drawing on this existing capacity to meet the need for an integrated monitoring network means collecting biological response data that can be directly interpreted within the context of physical and chemical status data. In some cases, this can be accomplished by adding OAH measurements to existing biological time-series; in other cases, biological variables can be sampled where OAH monitoring is being conducted. Several existing biological data collection and monitoring programs, such as those conducted by state, federal and tribal fisheries and MPA programs, National Estuarine Research Reserve System (NERRS), Partnership for Interdisciplinary Studies for Coastal Oceans (PISCO), California Cooperative Oceanic Fisheries Investigations (CalCOFI), and National Marine Sanctuaries can be coordinated and aligned to facilitate more comprehensive OAH monitoring.

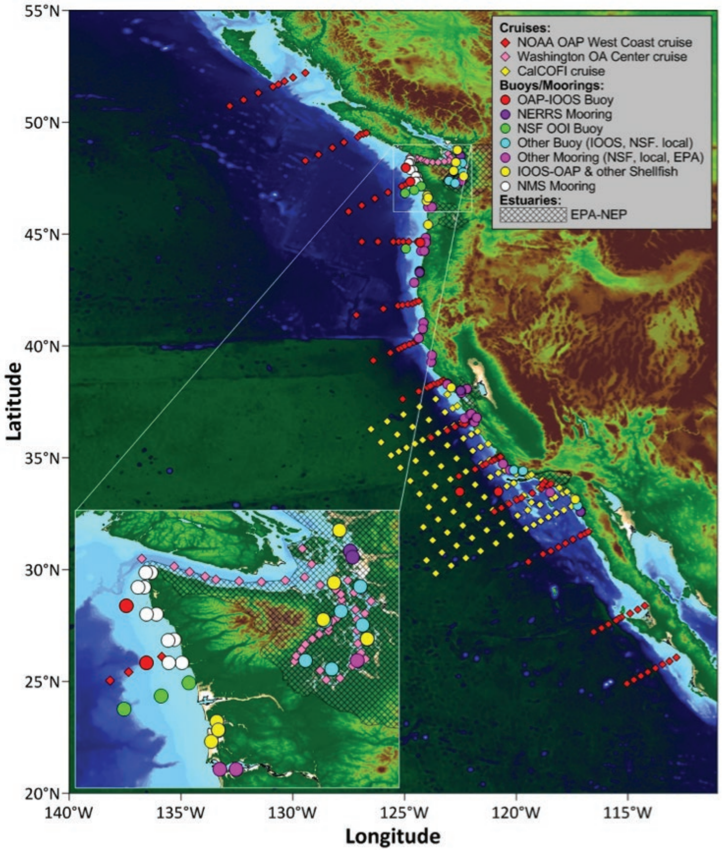


Figure 1. Partial inventory of ocean acidification and hypoxia monitoring assets.

This map is primarily composed of known water chemistry OAH monitoring. Some efforts include ecological variables, but these are underrepresented. Additionally, data quality varies substantially. Thus some assets are not appropriate for addressing some questions (see Box 1). Also note some assets may no longer be sustained and some cruises are periodic (e.g., every 2-3 years). The presentation of this map is for its use as a starting point, upon which to assess need.

Map: Dana Greeley, NOAA.

Additionally, monitoring and modeling efforts should be integrated and complimentary. Monitoring data provide critical calibration and validation input to models. Conversely, model output provides new insights to spatial variation, revealing potential gaps that are not represented by current monitoring data.

#4: Develop and sustain intellectual capacity

Considerable attention is given to the technological infrastructure of monitoring systems, such as buoys, sensors, data banks, and software. However, much of the success of monitoring systems relies on the human capacity that keeps the system running, quality assured, and data analyzed and interpreted. Maintaining this intellectual capacity requires both sustained support for expert practitioners and knowledge exchange and training that can be facilitated within a monitoring network "community of practice."

A community of practice focused on users of the observing sensors with analysis experts is an effective means of spreading knowledge and thus building capacity. In this context, user guides, training programs, workshops, partnerships, and on-line user Q&A threads are all useful tools to implement for this purpose. Exchange of information and protocols among members of this community will facilitate best practices in measurement, data quality control and reporting. In addition, regular communication and connections among managers, scientists, system operators, and end-users can be facilitated within a monitoring network, increasing attention on continued alignment of monitoring activities with decision-making needs. Also, such communication can foster comparability in analytical procedures and in analysis of data sets. Training programs to ensure correct use of techniques, for example, in measurements of the diverse aspects of carbonate system chemistry are an important contribution of this community-wide approach.

Investments in data synthesis, analysis and data distribution are critical pieces of a monitoring network. Developing data distribution and analysis capacity in parallel with data collection, again, with provision of training for data providers, will enable more information to reach multiple audiences of biologists, chemists, managers, shellfish growers, and fishers. Finally, regular communication and connections among managers, scientists, system operators, and end-users can be facilitated within a monitoring network, increasing attention on continued alignment of monitoring activities with decision-making needs.

BOX 1. Types of questions an OAH monitoring network can answer

Long-term monitoring data can provide input to answer a number of questions that resource managers want to know the answers to, such as:

1. What are the trends in OAH with time? How rapidly is change occurring?
2. What is the variation in OAH in the region? How does this compare to other sites? How does this change seasonally? How is this different in estuaries and the nearshore versus offshore?
3. What are the effects of OAH on biota? Is OAH impacting biota now? What are the most sensitive species, populations, or ecological properties to OAH?
4. Are human activities aside from the atmospheric input of CO_2 contributing to OAH? What are these and where?
5. When management actions have been taken to offset changes in OAH or to enhance ecological resilience, are these resulting in their anticipated effect?
6. Can corrosive conditions in the nearshore or at hatcheries be anticipated by conditions offshore?

The optimal monitoring design for answering these questions differs according to the questions being asked. Since a West Coast OAH monitoring network would need to address all of these types of questions, the network will necessarily utilize different approaches. Some monitoring designs address more than one question. Thus it is essential to bring decision-makers and scientists together in a forum to identify information needs, and then to work towards an appropriate monitoring design, as per the recommended implementation steps (Box 2).

To address questions in the first category of Box 1, the highest quality (i.e., climate quality measurements of the GOA-ON Plan) measurements are needed. Data collection at representative sites with high-frequency data is best suited to trend identification. For the second category, better spatial characterization is needed, with at least seasonal coverage at an increased number of sites (these may be "weather quality" measurements of the GOA-ON Plan). Model results calibrated with monitoring data enhance our ability answer questions in the second category. For the third category, coupled biological and chemical data (at least "weather" quality) from the same location is needed, including identified indicator species of interest. For the fourth category, monitoring must address if human stressors are contributing, such as eutrophication, overfishing, and land-use changes. Comparisons of conditions (chemical and biological) in protected areas with those outside are useful. For the fifth category, it is largely the monitoring types discussed so far that are needed, but uninterrupted time series measurements are key. For the sixth category, a regional knowledge of mechanisms associated with OAH and corrosivity is needed. Large-scale regional data analysis is required and combination with modeling to understand mechanisms is advantageous.

Implementing a West Coast OAH monitoring network

Key foundational pieces and effective capabilities for a West Coast-wide OAH monitoring network are available today. New technologies will likely increase our capabilities through time. However, integrated OAH monitoring as described above does not require de novo development of broad suites of, for example, ecological and fisheries monitoring approaches and can instead utilize many existing techniques and programs, enhancing where variables are missing and stimulating analysis of integrated data sets.

Box 2 provides recommended steps to develop and implement an integrated OAH monitoring network with the attributes described above. The Panel acknowledges the value of a participatory process - including scientists, managers, industry and stakeholders - to implement this network, and recognizes that an iterative learning process will be needed to integrate regional, state and local perspectives and needs.

Key foundational pieces and effective capabilities for a West Coast-wide OAH monitoring network are available today.

BOX 2. Steps to implement an OAH monitoring network on the West Coast of North America

1. Define OAH information needs.

a. Cultivate and enhance existing partnerships between regional planning and management bodies, monitoring practitioners, data managers, decision-makers, and stakeholder users to better define OAH information needs across ecosystem types and for diverse uses, as well as to actively coordinate efforts.

2. Align existing monitoring efforts and assets with information needs.

a. Assess the geographic distribution, data quality, and operational status of presently existing OAH and ecological monitoring (e.g., Figure 1; inventory collaboratively produced by the West Coast IOOS associations and NOAA at the request of the West Coast Governors Alliance).

b. In partnership with decision-makers and modelers, evaluate how present and planned monitoring assets are positioned to address current management questions and those anticipated in the future (i.e., where the gaps are).

c. Establish community protocols for submitting new data into common data portals (e.g. IOOS, BCO-DMO, DataONE) and identify how to best obtain other data sources needed (e.g., biological assessments). Work with the modeling community to make modeling output accessible via the same common portal.

d. Coordinate monitoring networks, integrating intellectual capacity, people and instrumentation.

e. Incorporate data streams and information products into management frameworks.

3. Evaluate and prioritize needs for new investments.

a. Conduct workshops among members of the local scientific and stakeholder communities, and federal representatives to identify gaps in monitoring capability and management information needs.

b. Identify and prioritize gaps in monitoring capability and evaluate how the existing and proposed observing assets could be integrated and managed to fulfill decision-making needs. Use OAH forecast models to evaluate existing and proposed observing assets.

c. Assess the feasibility of adding new measurements and analytical capacity to existing observing systems.

d. Establish regular communication and connections among managers, scientists, system operators, and end-users to iteratively assess the strength of alignment between monitoring activities and decision-making needs.

4. Enhance consistency among programs through training and quality assurance and sustain the intellectual capacity to carry out OAH monitoring.

a. Provide consistent and widely accessible training on measurement techniques, QA/QC procedures, and data archiving.

b. Support and sustain a West Coast-wide networked community of practice that assures the intellectual capacity to maintain OAH monitoring.

5. Commit to sustaining time-series data collections and common data portals, and adapt programs and protocols to reflect new knowledge and needs.

a. Develop monitoring programs that incorporate both commitments to core long-term observations and resource flexibility to implement new programs, protocols, and measurements.

b. Assure synergy between monitoring and modeling needs. Models need validation data from monitoring; modeling can yield insights on new monitoring needs or where redundancies exist.

c. Develop or enhance means for accessing diverse data sets and model output that inform OAH management. Establish community protocols for submitting new data and model output into common data portals.

6. Communicate information widely.

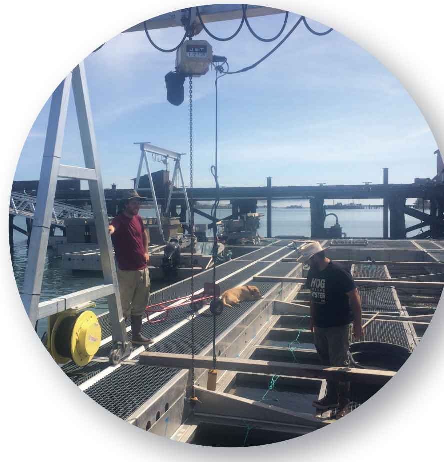
a. Develop tools and technologies to promote greater two-way communication regarding observations and analyses, and data synthesis products.

b. Incentivize regular information exchange activities that engage the broader user community.

Conclusion

The demand for new information will grow as OAH increases in intensity and frequency along the West Coast. Regional and local partnerships in place today across the West Coast exemplify the social constructs needed to support monitoring efforts and align them with decision-making needs. Because the West Coast is already facing some of the earliest impacts of OAH, investments made now in monitoring capabilities and partnerships will yield critical information that can be used today to guide management actions and policy decisions. Investments made now along the West Coast can serve as an invaluable test bed for the development of monitoring programs that can be replicated across the nation and globe.

The Panel acknowledges the value of a participatory process - including scientists, managers, industry and stakeholders - to implement this network, and recognizes that an iterative learning process will be needed to integrate regional, state and local perspectives and needs.



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