Meeting Summary

Ocean Acidification: Setting Water Quality Goals

Uncommon Dialogue

October 17–18, 2016

Stanford University

Hosted by:

Stanford University's Woods Institute for the Environment and the Center for Ocean Solutions, the California Ocean Protection Council, and the Southern California Coastal Water Research Project Authority

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Executive Summary

In response to the West Coast Ocean Acidification and Hypoxia Science Panel's Recommendation 3 (Revise water quality criteria), 25 experts were convened at Stanford University on October 17–18, 2016 to chart a path toward development of ocean acidification (OA) water quality goals. Participants were asked to help develop goals that in the short term could be used as management tools for defining monitoring needs and for interpreting modeling and monitoring output, and in the longer term could form the foundation for water quality criteria.

The workshop had three objectives: 1) Identify the chemical parameters and biological indicators that are most appropriate for assessing the status of ocean acidification; 2) Prioritize the research needed to advance the parameters and indicators toward use as water quality goals; and, 3) Pinpoint the biggest impediments to development of criteria from these goals and actions that can be taken to lessen those impediments.

Top parameters and indicators for developing ocean acidification water quality goals

Participants identified **pH** and **carbonate saturation state** as the two chemical parameters that are the strongest candidates for near-term adoption as water quality goals. They reached this conclusion because these parameters have been documented through both laboratory and field studies to affect biota, and their widespread use in ongoing monitoring programs provides some context for how these parameters vary naturally in the ocean environment.

Participants also identified four taxa whose biological condition could serve as a biological indicator for near term application: pteropods, mussels, oysters, and rockfish. Pteropod shell condition rose above other candidate biological indicators because pteropods are widely distributed, methods to measure their shell condition have been established, and shell condition has been linked to organism growth and survival. Importantly, pteropod shell condition has already been shown to reflect the acidification status of coastal waters, so this ecologically important group is already manifesting negative effects from OA. Pteropod population trends are also predictive of higher-level ecosystem trends and therefore shell condition represents a measurable early-warning indicator of ecosystem health.

Priority research needs

Participants recognized that the recommended chemical parameters and biological indicators are not yet sufficiently advanced (e.g., specific numerical values, threshold conditions) for use as defined management goals or as criteria, so they developed research recommendations that would enhance their application. The top research recommendations were similar for both chemical parameters and biological indicators:

1) **Expand the linkage between chemical exposure and biological response**. Establishing biologically-relevant water quality goals requires understanding the linkage between chemical exposure and biological response. Participants identified that this should be initiated through literature review and integration of studies conducted to date focusing on four major taxa (pteropod, mussels, oysters, rockfish) for which data are readily available.
2) **Define natural variability in the parameters**. Marine organisms have tolerances of pH and carbonate saturation state outside of their optimum range. Quantifying the frequency and duration of "natural" fluctuations in OA chemical parameters, without the influence of anthropogenic activities, is an important element of OA water quality goal setting.
3) **Standardize and simplify operating procedures for measuring the parameters and indicators**. Many existing procedures require complex research techniques. To quantify changes in ocean acidification for regulatory purposes, managers require chemical parameters or biological indicators that users with a wide range of experience can consistently measure.
4) **Support co-located chemical and biological field measurements.** Most threshold development work is presently being conducted through laboratory exposure experiments. Appropriate field data are needed to not only validate laboratory observations, but capture the complex interplay among factors that are important in nature and cannot be replicated in the laboratory.

Impediments to new criteria

Workshop participants identified two primary impediments to developing new regulatory criteria. In addition to the research needs identified above, participants noted the following needs:

1) **Clearly establish the management need for new criteria.** Water quality managers indicated they are only interested in deploying the resources needed to develop OA water quality criteria if they are convinced that local nutrient and carbon inputs are a meaningful contributor to local acidification conditions and that local management actions would have a meaningful effect. Participants identified coupled physical-biogeochemical models that allow distinction of local and global emission effects as an appropriate means to assess the contribution of nutrients.
2) **Generate the motivation and resources required to conduct the necessary science and administer the criteria implementation process.** Participants noted that the suggested research and management activities will be expensive, and thus require broad public and legislative support. While achieving that is inherently a nonscientific activity, scientists can assist by better connecting acidification impacts to species and ecosystem services of public concern.

Meeting Background, Goals and Overview

Background

Oceans absorb approximately one-third of global anthropogenic carbon dioxide (CO_2) emissions. While the ocean's role in absorbing CO_2 has helped mitigate the effects of emissions on earth's climate, it has caused fundamental changes in ocean chemistry through a phenomenon known as ocean acidification (OA). While OA remains a global challenge, emerging research indicates that the West Coast of North America will face some of the earliest and most severe effects to its coastal ecosystems and the humans that depend on them.

In 2013, the California Ocean Protection Council charged the California Ocean Science Trust with establishing the West Coast Ocean Acidification and Hypoxia Science Panel, comprising 20 leading scientific experts from California, Oregon, Washington, and British Columbia. The panel summarized the current state of knowledge on OA and hypoxia (OAH) and developed scientific consensus about available management options to address impacts of OAH on the West Coast. The panel's final report, "Major Findings, Recommendations, and Actions," was released in April 2016 and has since generated major interest and action in addressing OAH issues across the region.

One of the panel findings was that the existing water quality criteria for acidification are based on outdated science, as they were developed in 1986 and have not been updated since. Recommendation 3 of the panel is the development of new water quality criteria to serve as defined management targets and enable proactive management. The Ocean Protection Council Science Advisory Team convened to review and discuss the panel's final report and highlighted several priority areas of interest for near-term next steps, including Recommendation 3: Revise Water Quality Criteria based on "scientific consensus about which parameters are most appropriate for inclusion." Jonathan Bishop, Chief Deputy Director at the California State Water Resources Control Board, indicated interest in following up on this recommendation.

In response to this work, political momentum has increased to support the development of the best science to inform future OA water quality goals. For example, Senate Bill 1363 (SB 1363) establishes an ocean acidification and hypoxia reduction program. Assembly Bill 2139 (AB 2139) authorizes the Ocean Protection Council to develop an ocean acidification and hypoxia science task force and to work with other agencies to coordinate and ensure that water quality goals that address ocean acidification and hypoxia are developed and informed by the best available science. Both bills were signed into law in September 2016.

Meeting Goals and Overview

Building on this momentum, Stanford's Center for Ocean Solutions and the Woods Institute for the Environment partnered with the Ocean Protection Council and the Southern California Coastal Water Research Project Authority to host an Uncommon Dialogue on *Ocean Acidification: Setting Water Quality Goals.* Held on October 17–18, 2016, the meeting brought together 25 experts from the academic, NGO, philanthropic, and California, Oregon, and Washington state and federal management communities to chart a path toward development of new acidification water quality goals[1] and, in the long term, possible criteria. The discussion acknowledged that OA water quality goals are needed in the near term to assess whether OA is affecting marine waters and to interpret output from water quality models that are being developed to support management decisions. In the longer term, these goals could form the foundation for water quality criteria, though additional non-technical barriers to regulatory promulgation exist. Based on this understanding, the workshop focused on three goals:

1) Identify the chemical and biological indicators that are most appropriate for assessing the status of ocean acidification;
2) Prioritize the research needed to advance these indicators toward use as water quality goals; and,
3) Pinpoint the biggest impediments to criteria development and actions that can be taken to lessen these impediments.

The meeting was organized around three sessions that each began with plenary presentations by experts, followed by small group breakout discussions and plenary report outs. Session 1 reviewed the state of the science about which chemical and biological parameters would be most appropriate as OA water quality goals, and what we know about thresholds for each of these parameters. Session 2 evaluated the process and information requirements for establishing OA water quality goals, and prioritized gaps that must be filled to meet those requirements. Session 3 examined impediments water quality managers face in developing improved acidification water quality criteria, with the goal of developing a work plan for filling information gaps and overcoming priority impediments.

[1] Here, the term "water quality goals" is used to mean water quality metrics against which model output and monitoring data can be compared. The word "goals" is not being used in a context that is meant to refer to the goals described in the Clean Water Act. The term "water quality criteria" refers to water quality criteria or standards used to measure compliance with the Clean Water Act.

Session 1:
State of the science: The most meaningful acidification parameters and what we presently know about thresholds

Summary

Session 1 began with a series of overview talks on the state of the science around appropriate acidification parameters and their thresholds. Plenary presentations were given by Francis Chan, Associate Professor, Department of Integrative Biology from Oregon State University, on “Setting ocean acidification water quality goals: Some chemical perspectives” and George Somero, David and Lucille Packard Professor Emeritus in Marine Science from Stanford University on “Defining ‘thresholds’ for OA effects: mapping chemical parameters to biological responses.” These talks emphasized a huge opportunity for action on this issue, but they also recognized many scientific unknowns. For example, Francis raised challenges regarding our ability to accurately monitor OA impacts, define and detect variability, and deal with multiple stressors. George highlighted the differences, challenges, and value derived from lab versus field experiments, recognizing that both are necessary to develop biologically meaningful and attainable information on OA for use in water quality management.

After the plenary talks, participants were split into two breakout groups—one focused on biological parameters and the other on chemical parameters—that were asked to develop a priority list of parameters on which to focus future research. Each breakout group was charged with answering the following questions:

1) If you had to select thresholds today, what are the most appropriate acidification parameters?
2) What do we know about thresholds for each of these parameters?

The group acknowledged the potential for utilizing the parameters and thresholds identified in these discussions for setting water quality criteria over the long term, but also recognized that there is a need in the shorter term to use the identified parameters as assessment end points for coupled bio-physical models, or as targets for monitoring. This session was intended to better inform decisions currently being made by the research and management community about the most appropriate parameters to monitor and model.

Session 1 Breakout Findings

Chemical Group

Chemical breakout participants identified **pH** and **carbonate saturation state** as the two parameters that are the most likely candidates for near-term adoption as water quality goals. Participants reached this conclusion because these parameters have been documented through both laboratory and field studies to affect biota, and their widespread use in ongoing monitoring programs provides context for how these parameters vary naturally in the ocean environment. These parameters were also highlighted as being relevant for management in estuarine and/or coastal waters within state jurisdiction. Participants also indicated that identifying a common threshold that accounts for both pH and carbonate saturation—e.g., a particular pH level that ensures the carbonate saturation state threshold remains at or above the values needed for biological functions like calcification in particular environments—would be valuable.

Before narrowing in on **pH** as a top parameter, participants discussed several candidate primary parameters (those carbonate system parameters that are measured directly), including **pH,** ***pCO₂*** → **pH, pCO_2, DIC (dissolved inorganic carbon), total alkalinity, and CO_3^{2-} (carbonate ions).** pH was discussed specifically as a good parameter for assessing OA-related effects for non-calcifying organisms. The group noted that of the current water quality standards in the California Ocean Plan relating to pH, the natural variation standard —0.2 pH units different from natural—is probably not an unreasonable goal for pH, but the absolute pH range in the Ocean Plan—within 6.0 to 9.0 at all times—is too wide a range to protect against harmful effects of OA. There was a great deal of discussion about what a “deviation from natural” threshold should be and consensus was not reached in the short time. The group discussed how the current “deviation from natural” standard is difficult to implement due to the scientific challenge of determining what is meant by “natural”. Several members of the group noted that the other primary parameters did not warrant further discussion at present: there is a lack of information about how DIC, total alkalinity and CO_3^{2-} affect organisms and while some research suggests that pCO_2 may positively influence the formation / persistence of harmful algal blooms and alter animals’ metabolic rates, evidence is limited. Some participants also identified that tools for monitoring of parameters such as DIC, pCO_2 and CO_3^{2-} were still too early in their development for widespread, routine application by non-specialists.

Similarly, before prioritizing **carbonate saturation state**, the group considered several candidate derived parameters (those parameters that are calculated from measured primary parameters): **carbonate saturation state, substrate inhibitor ratios (SIRs),** and the **Revelle factor**. Regarding these derived parameters, the group emphasized that carbonate saturation state (e.g., aragonite saturation state) is the most important for calcifiers. After lengthy discussion, the group did not agree on a specific carbonate saturation state threshold. Substrate inhibitor ratios and the Revelle factor were not considered further.

The group also briefly discussed the following supporting parameters (those parameters that could influence the carbonate system parameters): **nutrients, pressure, oxygen, temperature, salinity, and calcium ion concentration**. The group noted that a model output that incorporates these parameters could itself be a water quality goal (e.g., the pH and temperature dependent criteria for ammonia or the Biotic Ligand Model based criteria for copper). However, the supporting parameters were also not further discussed due to time constraints and the fact that they were not directly related to the group tasks.

Biological Group

Biological breakout group participants identified four priority biological organisms whose condition or health could be used as a biological indicator for OA: pteropods, oysters, mussels, and rockfish. The group identified **pteropod shell condition** as the most likely biological indicator for near-term application. Pteropod shell condition rose above other candidate biological indicators because it encompassed many of the desirable attributes for selecting candidate biota that the participants discussed. Specifically, pteropods are widely distributed, methods to assess their shell condition have been published, and shell condition has been linked to organism growth and survival. It also was emphasized that pteropod shell condition is significantly correlated with the OA status of coastal waters, i.e., pteropods are already manifesting strong responses to OA. In addition, pteropods play an important ecological role as a food source for fish, birds, whales and other organisms. As such, pteropod shell condition represents a measurable early-warning indicator that is predictive of higher-level ecosystem effects. One of the limitations of pteropod shell condition is that the organism's range is limited to nearshore and offshore waters, and would be less appropriate for semi-enclosed water bodies (e.g., estuaries or tidepools).

Mussel recruitment and body condition were also identified as strong candidates because mussels are sensitive shell formers that can be easily sampled on either natural or deployable substrates. Mussels also occur close to shore and in estuaries, making them a good range complement to pteropods. While not as naturally abundant and easy to sample as mussels, the participants highlighted that **oysters** show a well-documented response to acidification and are amenable to further laboratory studies that could improve understanding of response. They are also of considerable economic interest.

Participants recognized that biological parameters can facilitate the development of water quality goals in two ways. The first is by identifying biological responses that are tied to chemical exposure using laboratory and field studies. The second is to use measures of biological community health (for example, benthic infaunal community diversity and function) as a goal.[2] To select the top candidates, the participants focused their discussion around three selection attributes that any candidate biota should have to be considered a priority, regardless of which of the two uses of biological information were being considered.

1) **Organism vulnerability to acidification.** The group desired to identify the "canary in the coal mine"—the biotic response that precedes, and is therefore protective of, responses by most other organisms. The primary attribute in this category is sensitivity, which provides a metric for selecting among several possible responses (calcification, dissolution, behavior, survival, growth, reproduction) and life stages. The second key attribute in this category is the organism's inability to acclimatize or adapt to increasing levels of acidity, which must be monitored to avoid underestimating the potential biological responses of more vulnerable species.
2) **Practical considerations.** The group was interested in identifying response organisms that are accessible (i.e., readily collected) and easy to identify. They emphasized that candidate organisms need to be abundant in state waters—i.e., within three miles of the coast—where state water quality managers have

[2] For example, participants noted that biological criteria are already being used in California as a focal point for sediment quality criteria, in which a healthy benthic infaunal community is the biological expectation.

jurisdiction. They also identified that candidate organisms should have a broad geographic distribution and preferably occur over a range of habitats (e.g., open ocean, nearshore, intertidal, estuarine).

3) **Ease of communication to the public.** The group highlighted that specific effects on the biological indicator must be reliably communicated to and understood by the general public. This could mean that a biological indicator is economically or ecologically important, such as a keystone predator, a habitat former, or a key food web component. While this attribute was considered less important than the organism's vulnerability to acidification, the group recognized that identifying a response that the public could understand would empower managers to use the information to make important and potentially expensive decisions.

Participants highlighted three additional biological responses for potential future use in biologically-based water quality goals, but which would depend on more research investment to develop further. First, **sea urchin condition** was selected because their depth distribution has been shown to be affected by acidification and water quality managers already frequently use the sea urchin fertilization test as an effluent assessment technique. Second, the group noted that existing biological criteria in California and the rest of the nation are developed mostly around community-level response, as opposed to individual species responses. Toward that end, the group identified the **microalgal community** and the **microbial guild** as candidates for community-level responses that are most sensitive to acidification. However, participants recognized that because of a high degree of variability in these communities, differentiating natural from affected communities would take at least a decade of research to resolve.

In addition to addressing the breakout session's primary charge of identifying priority candidate biological indicators, participants also identified several biological responses that are prime subjects for calibrating chemical water quality goals. Those candidates that were highlighted as good subjects for calibrating possible chemical goals through additional laboratory and field experiments included **pteropod shell condition** and **oysters** for the reasons identified above. In addition, **rockfish behavior** was reviewed and prioritized because participants were committed to identifying at least one response that was not based primarily on shell-forming ability and evidence suggests that changes in ocean chemistry—such as those that occur during upwelling of low pH water—influence rockfish behavior.

Session 2:
The process and information requirements for setting water quality goals

Summary

Session 2 led with plenary talks on the state and federal perspectives on the process and information requirements for setting water quality goals. Jonathan Bishop, Chief Deputy Director of the California State Water Resources Control Board, gave the California state perspective on "Ocean Acidification: Scientific Challenges and Opportunities for Water Quality Criteria Development" and Dana Thomas, Chief, Ecological and Health Processes Branch Office of Science and Technology, Office of Water, gave the

Environmental Protection Agency (EPA) perspective with her talk on “Criteria Development at EPA under the CWA.”

Jonathan Bishop noted that California’s Ocean Plan currently has water quality criteria for pH—relating to both variance from natural levels and absolute limits—but that the current criteria are ineffective for limiting harmful changes in acidity due to lack of existing information on natural variability. While recognizing the need for improvements in these criteria, Jonathan discussed the high information burden for revising or establishing criteria and the lengthy and politicized administrative process that must occur prior to adoption. Dana Thomas echoed Jonathan’s remarks regarding the investment of time and resources that must precede adoption of new or revised water quality criteria, and explained the detailed scientific information requirements and procedures for criteria development at the federal level. Jonathan also noted that due to these limitations, as well as the global causes of acidification, the state would likely only pursue a change to water quality criteria if tangible improvements in water quality could result from limiting localized terrestrial inputs that exacerbate broader ocean acidification effects.

The group then returned to chemical and biological breakout sessions to build on session 1 discussions regarding existing knowledge about chemical and biological parameters. The primary charge for the session 2 breakout groups was to identify pressing research needs that must be filled to meet the information requirements for water quality goal development outlined by the state and federal representatives during plenary. Each group was asked to discuss and prioritize the top research projects that federal, state, and philanthropic funders could support to aid research around the priority parameters and thresholds identified by each group during session 1.

Session 2 Breakout Findings

Both the chemical and biological breakout groups discussed and prioritized similar research needs, including defining and quantifying natural variability in the parameters, standardizing operating procedures for measuring the parameters, expanding our understanding of the linkages between chemical exposure and biological response, and conducting co-located chemical and biological field measurements.

Chemical Group
The chemical group discussed and prioritized the following research questions:

1) **Do model organisms respond to absolute or relative changes in pH and carbonate saturation state, or some combination of both?** The group hypothesized that relative change, rather than absolute change, generally leads to effect, but that an in-depth review of the available literature on this question is necessary. To begin, the group highlighted the need to conduct a meta-analysis of the peer-reviewed and grey literature to define magnitude, duration, and frequency of effects from both pH and carbonate saturation state. Group members discussed the meta-analysis should focus on coastal waters (within California’s 3-mile

jurisdictional limit) and noted that the analysis would be most relevant if it emphasized the three representative organisms identified as priorities by the biological breakout group—pteropod shell condition, mussel recruitment and body condition, and oysters. Group members also discussed extending this analysis to dissolved oxygen and temperature, as concern was raised about the need to better understand impacts of multiple stressors.

2) **What experiments can we develop to fill important data gaps identified in the meta-analysis described in (1)?** The group discussed it is unlikely that the meta-analysis would provide enough information to move forward without additional experimentation. Thus, participants highlighted the need to conduct additional lab and field experiments to fill any priority knowledge gaps identified through the meta-analysis.
3) **How do we measure and describe natural variability in pH and carbonate saturation state along the coast?** Marine organisms have tolerances of pH and carbonate saturation state outside of their optimum range. Quantifying the frequency and duration of "natural" fluctuations in OA chemical parameters, without the influence of anthropogenic activities, is an important element of OA water quality goal setting. The group discussed the complexity behind describing natural variability and prioritized the need for more research to address this, given that such a description is essential in implementing both existing and potential future water quality goals. Complexities and unknowns highlighted by participants that should be addressed included:
   - What is the time period from which we are measuring 'natural' variability (e.g., pre- versus post-industrial, present day, etc.)?
   - How do we define and quantify natural variability from one location to the next, and within the water column given that we know it can be very localized, stratified, and inconsistent over time?
   - Would a reference system approach, as have been used with other water quality criteria, work for pH and carbonate saturation state? How can we use models or observational data to classify variability for different areas along the coast at different times and include sentinel sites representing priority habitat types?
   - When thinking about water quality goals and possible future criteria, do we need a "deviation from natural"-type standard or can we define an absolute standard? Could we monitor an indicator species instead of measuring deviation from natural?
4) **What are the standard operating procedures for measuring carbonate parameters (including pH) and deriving carbonate saturation state?** The group stressed the need for technology development and standard operating procedures to facilitate consistent and accurate measurements. New replicable and scalable procedures are necessary for non-specialists who are employed to do routine monitoring and implement criteria and measurements of compliance in the field.

Other related questions and issues were discussed, but not prioritized, including how the scientific community could ultimately come together to reach consensus about an OA water quality goal. For example, could the community use a similar approach to the IPCC assessment model to reach a consensus? The group also discussed how such a process could enable the creation of broad-reaching communication mechanisms that OA researchers could rely on to proclaim when a chosen parameter reaches a specific threshold—when ocean chemistry has “tipped” to a point of serious harm to the ecosystem. The group also highlighted the importance of understanding and communicating the location of key OA reference sites (sites that are not impacted by OA and therefore can be used as a baseline) and hotspots (sites that are particularly vulnerable to upwelling or discharges) to help inform where to prioritize management. The topic of source attribution was discussed at length given that California does not want to create water quality criteria if it is determined that localized discharges to the coastline do not significantly exacerbate OA. While the issue was acknowledged, a broader discussion was deferred to session 3, as it represents a large impediment to creating and implementing water quality criteria, but not necessarily to filling needed research gaps with regard to creating OA goals. Finally, there was some discussion of how science could inform permissible thresholds (including magnitudes, durations during which the magnitudes are exceeded, and frequency of exceedance) for chemical parameters. The group recognized the potential to look at how thresholds were derived for other contaminants such as fecal indicator bacteria, but mentioned that this topic is more related to the Session 3 on barriers for criteria development.

Biological Group

The biological group identified the following three research questions that would need to be addressed for the development of any potential biological water quality goals:

1) **What is the reference condition and natural variation from reference?** The group was clear that failure to achieve water quality goals must not result from natural spatial or temporal variation or measurement error in the biological response. Therefore, as discussed by the chemical group, it is necessary to define natural variability and other factors, such as measurement error, that could influence establishment of “normal” and ongoing monitoring of biological responses.
2) **What is the connection between the measured response and population level effects?** The group noted that for a response to elevate to a water quality goal, there must be clear demonstration that the measured response affects species survival/fitness.
3) **Can we define consistent, repeatable measurement technologies that are feasible to deploy at a regional scale?** As highlighted by the chemical group above, research methods that are deployable by a limited number of specialized researchers and equipment are insufficient. Non-specialists who are employed to do routine monitoring must be able to easily implement research methods and technologies.

The group discussed that the emphasis among these three research needs will differ depending on the potential biological indicators, but that these questions need to be answerable for all biotic responses considered. The group also recognized that addressing these questions requires emphasizing co-location of chemical parameter and biological indicator measurements.

The group also discussed the specific research needs for the three potential biological indicators prioritized in session 1—pteropod shell condition, mussel recruitment and body condition, and oysters—within the context of the three questions outlined above.

For pteropods, the group emphasized that question 1 about reference condition and natural variation was the most important, as more extensive work has been done to-date on answering questions 2 and 3 regarding this biotic response. They proceeded to recommend the following three high priority studies:

1) Establish a monitoring program that provides co-located chemical and biological measurements over 5 or more years to establish the natural spatial and temporal variability in pteropod density and shell pitting and the chemical parameters pH and carbonate saturation.
2) Use stored samples or sediment cores to establish historical levels of pitting in pteropod shells. This study would have a goal of establishing natural temporal variability of pteropod density and shell pitting. The group was clear that they were interested in the natural level of variability in present times, not during the pre-industrial period.
3) Conduct bioenergetics studies that quantify the costs to the pteropod for having to continually repair its shell at different levels of acidification exposure.

For oysters and mussels, the group prioritized research questions 2 and 3 about sampling methods and relationship to fitness, and developed the following four research questions for both species:

1) As with pteropods, establish a monitoring program that provides co-located chemical and biological measurements over 5 or more years to establish their natural spatial and temporal variability.
2) Determine which metrics (e.g., growth, calcification, respiration, and dissolution rates) are most sensitive to acidification. Conduct these as comparative studies between/among oyster and mussel species to determine which is most sensitive.
3) Develop consistent, repeatable measurement methods for the most sensitive metrics.
4) Develop connections between the most sensitive measurement parameters and population level effects.

Session 3:
The greatest impediments to criteria development

Summary
The third and final session focused on impediments to targeted research and criteria development and ideas for overcoming those impediments. Caren Braby, Manager, Marine Resources, Oregon Department of Fish & Wildlife, Rochelle Labiosa, Scientist, Water Quality, Environmental Protection Agency, and Miyoko Sakashita, Oceans Director, Center for Biological Diversity shared their reflections in plenary on where we might see the greatest impediments to criteria development moving forward, even if all

the necessary scientific research is conducted. Each speaker provided their perspectives and context as state, EPA-regional and NGO representatives.

Each speaker noted that prioritizing action and funding to address ocean acidification requires the attention and support of the public at a time when many other important issues are competing for attention. Other key barriers identified included limitations in government budgets and staff capacity, the high evidentiary and informational burdens, and the lengthy public engagement and procedural process required to develop criteria.

The two culminating breakout groups focused on next steps in criteria development and impediments to progress both within California and at the west coast and federal scales. For this session, the larger group was divided into one group comprising California representatives and a second that included the rest of the meeting attendees (i.e., those from Washington, Oregon and the Federal Government). The primary charge for both groups was to discuss impediments to criteria development and identify the actionable next steps that would lessen these impediments. Both groups were asked to specifically detail what could be accomplished over what timeframes, and to match key actions to resource needs and timelines.

Session 3 Breakout Findings

California Group

The California group grounded their discussions by first recognizing that the state is well positioned to lead the effort on OA criteria development. The Ocean Protection Council has allocated funding to help start the OA criteria revision process and the State Water Resources Control Board expressed interest in revising the criteria if the science was adequate to support a change. For the California delegation of scientists, managers, funders, and NGOs, the most obstructive impediments to moving forward were:

1) **Verification that local sources and inputs are a meaningful contributor to local ocean acidification** and that criteria development and its protracted timeline is worth the investment.
2) **The need for sustained—and increasing—funding sources** that can match the resources necessary to fulfill scientific and regulatory procedural requirements. Across the state and federal governments, funding that supports these and similar science-based regulatory processes is in strong competition with other efforts, and is therefore either expiring or flat-lined annually.
3) Lack of knowledge on the **natural variability of pH and carbonate saturation** in state waters.

The group landed on these top three impediments by voting from a longer list of impediments. There was overwhelming consensus that these were the top three because without overcoming these challenges, we would either be unable to move forward with criteria development or would not feel compelled to initiate the long process of revising criteria. For example, without being able to adequately measure deviation from natural variability in the highly variable California Current (impediment 3 listed above), managers will lack information necessary to justify the potentially lengthy, cumbersome and politically-charged criteria revision process.

The group proceeded to identify what is already being done or can be done to address the top three impediments. To address impediment 1, a model to verify local sources of OA is currently being developed with regional investment.[3] In the next year or two this model will provide estimates of the extent to which local sources and land-based nutrient loading contribute to a worsening of local acidification conditions. A critical next step will be interpreting model results to decide whether to move forward with criteria revision. The timeline for this effort would culminate with summarizing model results by 2019.

Regarding dedicated funding (impediment 2), the group discussed the potential utility of state legislation that clarifies any needs for water quality criteria revision and, depending on such needs, allocates new funding and dedicated resources for the effort. The group also stressed the need for more tightly interwoven state and federal funding goals and parallel, transparent, and well-vetted processes for these efforts. For potential legislative efforts, the group discussed a tentative goal of advancing new policy and funding by the end of 2018, with a need to begin identifying and engaging with supportive constituencies in the near future. The group also discussed the importance of decisionmaker education and outreach undertaken in partnership with affected constituents such as oyster growers and seafood companies.

To determine how to measure and describe natural variability in pH (impediment 3), the group reiterated the need to conduct the research studies outlined by the chemical breakout group. The group confirmed the importance of conducting a meta-analysis to illustrate how organisms respond to absolute and relative changes in pH and carbonate saturation state. The group also recognized the importance of identifying how to measure and describe natural variability in pH and interpret natural conditions as written in California’s existing pH criterion.

Oregon, Washington, and Federal Government Group

The breakout group comprising representatives from Oregon, Washington, and the Federal Government identified the following as top impediments to water quality criteria revisions:

1) **Clearly defining the need to act, the roles, and the action path for all audiences** (e.g., federal, state, industry, NGO).
2) **Developing the necessary science** to support an actionable path to beneficial outcomes (i.e., directly connected to species and ecosystems of concern).
3) **Defining the possible beneficial outcomes**.

[3] The Ocean Protection Council, along with the National Oceanic and Atmospheric Administration (NOAA), has recently invested in a regional model hosted by University of California, Los Angeles who is partnering with the Southern California Coastal Water Research Project, the University of Washington, and NOAA-Pacific Marine Environmental Laboratory.

With regard to impediment 1, the group highlighted large variation in water quality problems and political will across the region and country. This variation is tied closely to differences in how the issues are prioritized across different geographic scales. Additionally, because of the varying timelines on which states, regions, and groups want to act, the group emphasized there is not consensus on how acidification issues should be addressed (e.g., implement OA water quality criteria under the Clean Water Act or pursue some alternative method).

With regard to impediment 2, the group noted that short-term research that quantifies natural spatial and temporal variability across habitats could improve the implementation of existing water quality criteria for relative changes in pH while revised criteria are developed. In addition, the group noted that public support for action depends on establishing and communicating clear scientific linkages between potential regulatory efforts and beneficial outcomes for the species and ecosystems that people care about across the region.

Related to this, the group developed consensus around the need to define the beneficial outcomes of revising water quality criteria (impediment 3). Specifically, scientists and managers must pinpoint how criteria revision could help protect regionally important species that are vulnerable to OA. Building on this, the group identified the need for tools that help the public visualize how OA affects important species and places. For example, the group raised the idea of developing annual ocean acidification stories or report cards for the west coast states that outline how OA is affecting the region today and highlight governmental actions that can be taken to mitigate ocean acidification. The group mentioned that this type of public outreach product would help contextualize and illustrate the effects of OA on the highly dynamic California Current System for the public and decisionmakers alike, and help justify ongoing research and requests for necessary future funding.

With regard to timing, the group noted the importance of pursuing parallel pathways to address OA given the protracted timeline and scale of effort required to revise water quality criteria. The implementation of these endeavors will depend upon the progress made within California in the next several years. Other states and the federal government look to California to assume a leadership role in the effort to develop OA water quality criteria and recognize that a future coordinated response across the regions will be the most impactful. In 2017 and beyond, the group highlighted the need for significant improvement to regional and national monitoring networks to ensure that there is long-term coupled biological and chemical monitoring. Realizing this goal will require significant investments in monitoring efforts, clear protocols about what to measure and how to best do the analyses, and open access information products that share the west coast OA story across the region and country.

Appendix A

Ocean Acidification: Setting Water Quality Goals
Uncommon Dialogue
October 17-18, 2016
Stanford University, Jen-Hsun Huang Engineering Center, Room 305

Hosted by:
Stanford University's Woods Institute for the Environment and the Center for Ocean Solutions, the California Ocean Protection Council, and the Southern California Coastal Water Research Project

Meeting Goals:
- Initiate a process for identifying appropriate chemical and biological indicators and thresholds to assess ocean acidification.
- Identify priorities for short-term research needed to support criteria development.

Monday, October 17

12:00 – 1:00 PM	Check-in and lunch
1:00 – 1:45 PM	Welcome, introductions, workshop goals and agenda review
1:45 – 2:45 PM	**Plenary Session 1**: State of the science: The most meaningful acidification parameters and what we presently know about thresholds *Francis Chan – An introduction to potential chemical indicators* *George Somero – A mapping of chemical parameters to biological responses*
2:45 – 3:00 PM	Introduce breakout session 2 and take a break
3:00 – 4:30 PM	**Breakout Session 1:** If you had to select thresholds today, what are the most appropriate acidification parameters and what do we know about thresholds for those parameters? *Group A: Chemical parameters (Room 305)* *Group B: Biological parameters (Room 306)*
4:30 – 5:15 PM	Breakout group report out and discussion
5:15 – 5:30 PM	Close and overview of Day 2

5:30 – 7:00 PM	**Dinner:** Group shuttle to Spalti Ristorante, 417 California Ave, Palo Alto

Tuesday, October 18

8:00 – 9:00 AM	Breakfast
9:00 – 9:15 AM	Overview of the day and questions
9:15 – 10:15 AM	**Plenary Session 2**: The process and information requirements for setting water quality criteria *Jonathan Bishop - State of California perspective* *Dana Thomas – EPA perspective*
10:15 – 10:30 AM	Introduce breakout session 2 and take a break
10:30 – 12:00 PM	**Breakout Session 2:** What are the greatest research needs to improve our use of thresholds and to create a path toward criteria? *Group A: Chemical parameters (Room 305)* *Group B: Biological indicators (Room 304)*
12:00 – 12:30 PM	Break, get lunch, reconvene
12:30 – 1:30 PM	**Working lunch**: Breakout group report out and discussion
1:30 – 2:30 PM	**Plenary Session 3**: The greatest impediments to criteria development *Caren Braby – State perspective* *Rochelle Labiosa (invited) – EPA regional perspective* *Miyoko Sakashita – NGO-legal perspective*
2:30 – 2:45 PM	Introduce breakout session 3 and take a break
2:45 – 4:00 PM	**Breakout Session 3:** Development of a roadmap, timeframe, and next steps *Group A: California participants (Room 304)* *Group B: Federal and regional participants (Room 305)*
4:00 – 4:45 PM	Breakout group report out and discussion
4:45 – 5:15 PM	Next steps and wrap up
5:15 – 6:30 PM	**Reception:** Faculty Lounge, Y2E2 Third Floor

Appendix B

Ocean Acidification: Setting Water Quality Goals
Uncommon Dialogue
October 17-18, 2016
Stanford University, Jen-Hsun Huang Engineering Center, Room 305

Participant List

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