SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT AUTHORITY

THEMATIC RESEARCH PLAN

FOR

CLIMATE CHANGE

Last Revised May 2016

Table of Contents

Introduction

Global climate change will fundamentally alter how aquatic systems are managed. As anthropogenic carbon dioxide emissions drive increasingly severe changes to ocean temperature and chemistry, water-quality managers will be tasked with developing long-term strategies and management responses that match the scale and scope of this global phenomenon. Although climate change drivers operate primarily at a global scale, the impacts will be managed at a local scale. To that end, managers must be prepared to confront the local impacts of climate change, including how climate change will fundamentally alter biological communities, how it will disrupt sensitive ecological areas along the coast, and how it will shift societal attitudes about how aquatic resources should be managed. As conversations about climate change become increasingly elevated to the forefront of public discourse, water-quality managers will have an unparalleled opportunity to be central to addressing an issue that is likely to become the defining water-quality management challenge of this generation. SCCWRP is helping Southern California water-quality managers to become leaders and visionaries in this arena, pursuing a multi-pronged research agenda aimed at developing next-generation solutions for monitoring, mitigating and offsetting the local impacts of global climate change.

Conceptual Model

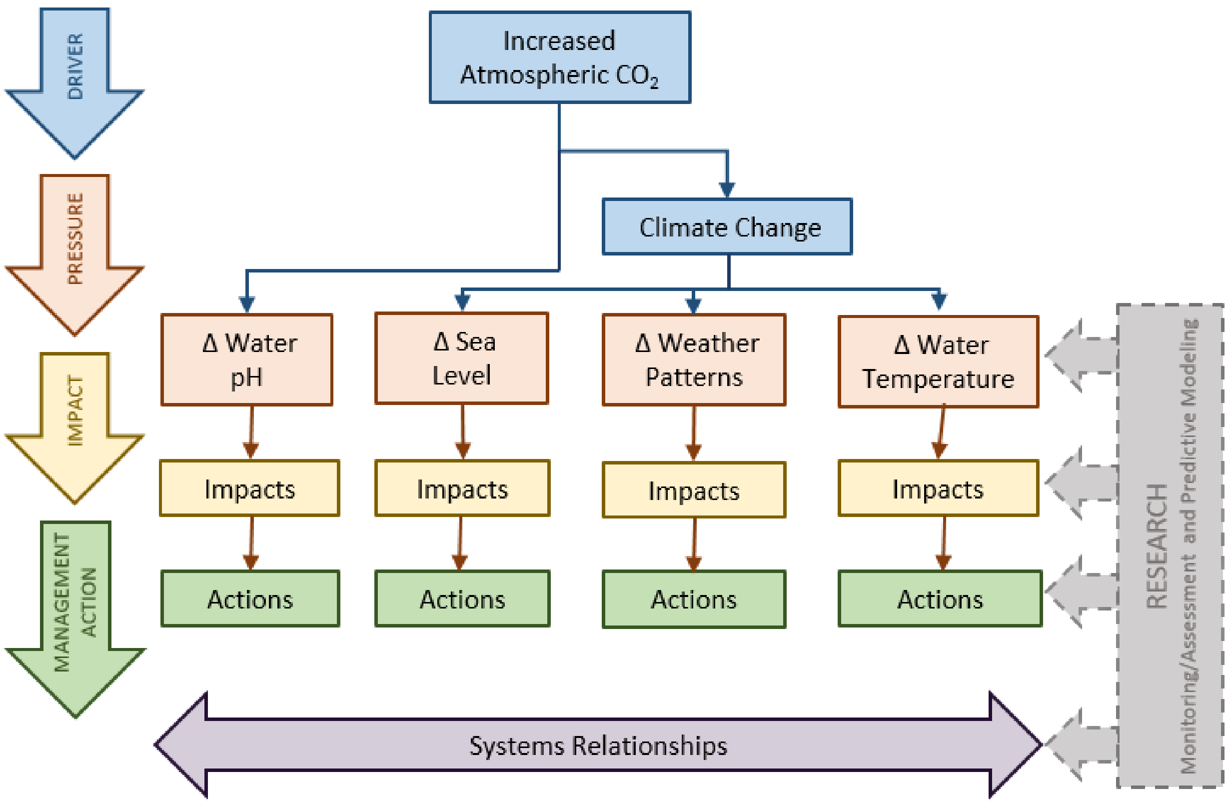
SCCWRP's conceptual model for climate change research revolves around the overarching driver of climate change, which is increased atmospheric CO_2 emissions from human activity. The increased CO_2 emissions trigger changes to the chemistry of the world's oceans (Δ **Water pH**), which has absorbed about one-third of anthropogenic atmospheric CO_2. The increased CO_2 emissions also trigger changes to climate patterns, which increase the intensity of sea level rise and coastal storm surges (Δ **Sea Level**), lead to more erratic rainfall and local weather patterns (Δ **Weather Patterns**), and trigger a gradual warming of ocean temperatures (Δ **Water Temperature**).

- Δ **Water pH**: As the world's oceans absorb increased atmospheric CO_2 levels from human activity, seawater undergoes chemical changes that cause pH levels to fall, a phenomenon known as **ocean acidification (OA)**. To date, the ocean has absorbed about one-third of atmospheric CO_2 emissions generated by human activities, which has served to slow the rise of atmospheric CO_2 and simultaneously accelerate OA. In fact, the world's oceans are acidifying nearly 10 times faster than they have in any other period over the past 50 million years. Although global ocean pH has fallen just 0.1 units since the Industrial Revolution, pH is on a logarithmic scale, which means a drop of 0.1 pH units is equivalent to a 30% increase in ocean acidity. Falling pH levels and the underlying changes in carbonate chemistry have the potential to trigger a wide variety of physical, chemical and biological impacts, many of which will be of concern to water-quality managers. Calcifying organisms already are experiencing increased difficulty forming their protective shells, which could have widespread ramifications across marine food webs. The bioavailability of sediment contaminants, especially metals, is also potentially altered by changing water chemistry, which might eventually affect existing water-quality and sediment-quality standards.
- Δ **Sea Level**: Rising sea level and increasingly severe **storm surge** will present significant challenges for coastal regions. Median sea level has already risen over the past several decades,

and predictions are for about a half meter of sea level rise by 2050 and 1.5 meters by 2100. During winter periods, more frequent and severe storm surges can add another several meters to sea level. Additionally, sea level rise and storm surge will further stress vulnerable marsh areas, which already are experiencing difficulty maintaining a foothold at the land-sea interface because of human influences that have reduced the sediment supply levels upon which marshes depend for accretion, development and transgression. These combined effects will threaten coastal infrastructure, alter ecologically sensitive habitats, impact beneficial uses associated with beaches and other coastal areas, and threaten water supplies as salt water increasingly intrudes on groundwater.

- Δ **Weather Patterns**: Climate change has the potential to alter global weather patterns in a number of ways. The predominant thought process is that rainfall will become more erratic and concentrated, with drier areas becoming drier and the rainy season becoming shorter and more intense. Additionally, storms are expected to gradually shift away from equatorial regions and toward the poles. Finally, as global temperatures continue to rise, snow will melt earlier in the year, creating a domino effect of changes to the timing and intensity of peak flows from melting snow. Already, California's snow pack is melting as much as one month earlier than five decades ago. These fundamental shifts in weather patterns will trigger a wide range of biological, hydrological and physical impacts, include salinity changes, conversion of stream types (i.e., perennial to non-perennial), and loss of riparian zones on which biological communities depend. Altered hydrological flows also will affect the volume and concentration of runoff, leading to changes in sediment deposition and in contaminant loading. Finally, as wildfires become more frequent and severe in response to drier conditions, these events will trigger significant biological, hydrological and physical impacts.
- Δ **Water Temperature**: As the atmosphere warms, so do the world's oceans. The water column temperature of the ocean has risen 0.32^{o}F over the past 60 years, about 15 times faster than at any other time in the past 10,000 years. Rising water temperatures, in turn, are triggering changes to the thermocline, which is the layer separating warmer waters near the surface from deeper, cooler waters. Over the past 60 years, the thermocline in the California Current System has become deeper and increasingly stratified. Already, global ocean surface temperatures are rising faster than deeper waters, by 1.4^{o}F over the past century alone. As the thermocline continues to intensify, temperature stratification is expected to become more pronounced, leading to fundamental alterations to the bioavailability of sediment contaminants and the distribution and functioning of biological communities. Water temperature alone, however, may not be responsible for the impacts observed, as temperature can work in conjunction with OA and changing weather patterns to drive the observed impacts.

Climate Change Conceptual Model



Each of the four stressors (**Pressures**) induced by increased CO_2 emissions triggers a series of effects on biological communities and ecological habitats (**Impacts**), which, in turn, paves the way for proactive management strategies and approaches for monitoring, mitigating, and offsetting the effects (**Actions**). Because these pathways combine to exert cumulative effects on biota and habitats, synergistic and overlapping relationships also are considered (**Systems Relationships**).

- **Pressures**: For the four pressures, SCCWRP asks the same fundamental questions: What is the rate of change of the stressor? What is the predicted rate of future change, and what are the factors that most influence the rate of change? Some of these questions are beyond SCCWRP's core skill sets, especially developing atmospheric models. However, there are many opportunities to link modeling work developed by others to changes in aquatic environment stressors, including seawater pH and temperature.
- **Impacts**: The impacts of changing seawater pH, sea level rise, changing weather patterns and changing water temperature create opportunities to explore the mechanisms by which these changes lead to changes in biological communities and ecological habitats. SCCWRP will explore questions such as: What is the rate of change? What is the predicted rate of future change? These changes can be tracked and modeled to improve management decision-making.

- **Management Actions**: There are a number of potential management actions that managers can use to both lessen exposure to changing conditions, as well as to lessen the impact of changing exposure. SCCWRP will seek to identify and evaluate the likely success of these management actions.
- **Systems Relationships**: Systems relationships describe the pathways by which disparate research elements are considered collectively to gain integrated insights and to synergistically guide management action. SCCWRP will work to cross-prioritize efforts across the major research areas, integrate data from multiple indicators, and develop watershed-scale linkage models to tell integrated stories about climate change and its impacts.

Research Directions

Although researchers have strong conceptual understanding of the drivers, pressures and impacts of climate change, considerable opportunity remains to advance its scientific foundation and pave the way for informed management action. SCCWRP's research agenda for climate change is organized around the four main pressures that drive climate change: Δ water pH, Δ sea level, Δ weather patterns, and Δ water temperature. Collectively, these four areas come together to define a multi-pronged plan for addressing management information needs for tackling global climate change in a way that effectively utilizes SCCWRP's expertise and resources. The level of investment in these research areas will be informed by their relative importance to SCCWRP member agencies.

Δ Water pH

Accomplishments

SCCWRP's accomplishments to date on ocean acidification (OA) are focused around more accurately measuring and tracking OA through testing and calibration of next-generation pH ocean-profiling sensor technologies. SCCWRP demonstrated that the margin of error associated with using glass electrodes to measure pH – a decades-old but widely used technology – makes it impossible to achieve the precision required to address California's regulatory thresholds. By contrast, ISFET (ion sensitive field effect transistor) sensors are within the acceptable margin of error, but have not yet been adapted for ocean profiling (Martz 2015). SCCWRP has played an instrumental role in shaping the region's OA monitoring strategies and research programs, playing a key role in preparing guidance documents for the California Current Acidification Network (C-CAN), which helped coalesce stakeholders around a shared vision and principles for West Coast monitoring (McLaughlin 2015), and the West Coast Ocean Acidification and Hypoxia Science Panel, which issued a series of state of the science summary papers and identification management options (Chan et al. 2016). SCCWRP also has been a principal player in a sweeping, multi-year program to build a series of coupled physical-biogeochemical models capable of discerning the relative contribution of local anthropogenic actions vs. global processes on OA in the Southern California Bight and beyond.

Ongoing Research

SCCWRP is working to identify and roll out next-generation OA monitoring technology, which, in turn, can pave the way for expanded OA monitoring efforts. OA is projected to intensify over time, underscoring the need to develop next-generation solutions that can more accurately measure and track ocean pH and that can provide comprehensive, region-wide assessments of OA.

> ***Project:*** **Evaluating XPRIZE's next-generation pH sensor prototypes**
> SCCWRP is facilitating a collaborative project with its POTW member agencies to test the efficacy of next-generation pH sensor prototypes developed through an international XPRIZE competition. The goal is to determine whether these new technologies can be adapted for use in nearshore regulatory monitoring, potentially allowing them to replace the glass electrodes that have been the standard bearer for ocean pH profiling for decades. The project involves testing the XPRIZE instruments alongside their traditional counterparts during routine monitoring of the Southern California Bight.

To shed light on how OA already may have impacted the higher-trophic species that managers are working to protect in the Southern California Bight, SCCWRP is analyzing historical Bight data dating back to the 1970s. The projects are examining shifts in the abundance and spatial distribution of biota over time.

> ***Project:*** **Historical analysis of Bight sea urchins to track potential OA impacts**
> SCCWRP is part of a team using 20 years of historical data collected through the Southern California Bight Regional Monitoring Program to examine changes in the distribution and integrity of the sea urchin community, which is particularly sensitive to ocean acidification. The data sets, which span 1994 to 2013, can provide insights into whether OA already has triggered changes in spatial distribution (i.e., habitat compression) and in the spatial patterns of shell integrity (i.e., thickness and size). The project also involves correlating carbon isotope data with shell integrity.

> ***Project:*** **Historical analysis of infaunal macrobenthic communities to track potential OA impacts**
> SCCWRP is using historical Bight data dating back to the 1970s to systematically examine the potential influences of hypoxia, ocean acidification and other stressors on benthic infauna. The goal is to identify and characterize changes in benthic community structure, to use statistical and autecological approaches to interpret the observed changes, and to arrive at conclusions about which stressors and forcing factors were responsible for the changes.

To model how local runoff and discharges may be exacerbating OA on the North American West Coast, including the Southern California Bight, SCCWRP is part of an initiative to develop and validate coupled physical-biogeochemical models that predict how OA and hypoxia (OAH) will change in response to local inputs of nitrogen and other nutrients. The model will be able to make predictions in response to various input scenarios, including climate change. The modeling work is described in greater detail in the Eutrophication research theme.

Priorities for Future Research

As OA intensifies on the West Coast in the coming decades, the need for OA-related research will continue to expand in lockstep. SCCWRP intends to play a key role across many of these OA research areas, including improving the science behind OA assessments and helping to outfit all West Coast marine labs with next-generation OA monitoring technology. SCCWRP's goal is to significantly improve OA data collection and to be able to paint a much more precise picture of how the West Coast is being impacted by OA.

Future focus area: **Providing the scientific foundation for updated OA-relevant water-quality criteria**
Existing water-quality criteria, which were developed four decades ago, are not ecologically relevant for managing for OA, as the criteria are based on the premise that pH should not fall below 6.5. In fact, diverse biological impacts routinely manifest at pH levels above 7.5, meaning that water-quality criteria are inadequate and not grounded in current science. The West Coast Ocean Acidification and Hypoxia Science Panel, in its final report released in April 2016, determined that the existing OA water quality criteria are scientifically unfounded and recommended they be replaced. SCCWRP hopes to be part of the scientific team that will provide the scientific foundation needed for development of updated, OA-relevant water-quality criteria. This may include ocean chemistry parameters other than pH, especially aragonite saturation state and partial pressure of CO_2 (pCO_2); emerging evidence suggests that such parameters may be more biologically relevant endpoints than pH to assess OA's effects.

Future focus area: **Developing a scientific foundation for biological criteria to assess OA**
SCCWRP is interested in linking biological community and population effects to specific OA stressors, which would require the development of biological criteria that relate to effects on growth, survival, reproduction and other metabolic functions. Pteropods, with their thin aragonitic shells, might be used as one such sentinel organism, as they are among the first in a marine community to be impacted by OA. However, much work remains to be done to provide a causal linkage between OA stress and biological response for this taxa, or any of a series of other potential biological sentinels.

SCCWRP also is interested in developing approaches to help marine biota adapt to and better withstand OA impacts. These approaches might include participating in modeling studies examining the effectiveness of carbon sequestration, particularly in wetland areas, to offset rising dissolved CO_2 levels. SCCWRP also is interested in understanding the domino effect of secondary impacts that are created when managers take action on OA. For example, introducing new genetic varieties and species into an ecosystem have been known to cause unintended harmful ecological and economic consequences that have outweighed their benefits.

Future focus area: **Identifying OA hotspots and potential refugia in the Southern California Bight**
SCCWRP is interested in understanding how both OA hotspots and OA refugia could improve the adaptive capacity of marine organisms to cope with OA. OA hotspots might be used to protect a species' genetic tolerances to withstand OA, while OA refugia might provide a safe location for species to develop enhanced diversity and productivity. Organisms could be translocated in and out of these areas to best position them for protection and adaptation.

Δ Sea Level

Accomplishments

SCCWRP has established a comprehensive program for mapping and assessing wetlands across California (Lackey 2013) that, if adopted, could provide a baseline against which to assess future effects of sea level rise.

Ongoing Research

To understand how sensitive ecological areas will be more vulnerable to rising sea levels and more intense and frequent storm surges in the future, SCCWRP is developing models that estimate how marshes will respond to a combination of sea level rise, marsh accretion, and marsh migration, where migration is possible. The goal of this modeling work is to help inform the development of regional and site-specific restoration goals and to help prioritize future management response to sea level rise. Ultimately, multiple decision-support and visualization tools could be developed to help managers understand how various restoration and management alternatives are anticipated to affect specific wetlands of interest.

***Project:* Developing an SLR decision-support tool to inform wetland restoration strategies**

SCCWRP is part of a team that is designing a decision support tool to aid coastal managers in assessing the vulnerability of coastal wetlands to SLR and informing wetland restoration strategies. The proposed Sea Level Rise Decision Support System (SLR DSS) will allow wetland managers to evaluate the relative vulnerability of coastal ecosystems to the effects of sea level rise, based on projections of sea level rise and simple models of physical and biological responses. This tool will allow proposed wetland conservation and restoration actions to be evaluated in terms of their likely effect at reducing vulnerability and supporting sustainable habitats. These analyses of alternative future scenarios can then be used to help inform development of both site-specific and regional goals and performance objectives. The SLR DDS intends to use simple visual aids and compiled documentation to help managers better evaluate the threat to coastal habitats posed by SLR.

***Project:* Visualizing at-risk coastal areas through SLR vulnerability maps**

SCCWRP is working with partners on ways to visualize Southern California coastal areas vulnerable to SLR using GIS-based mapping software. The vulnerability maps will overlay a wealth of data onto the 3D maps to estimate precisely how, when and where SLR is predicted to impact coastal areas. These high-resolution maps will allow the user to zoom into specific areas to understand precisely how the topography and other physical characteristics of the landscape will make an area more or less vulnerable to SLR.

***Project:* Documenting coastal vulnerability to El Nino-fueled storm surge**

To understand how SLR may impact Southern California's most vulnerable coastal lagoons, SCCWRP is collecting and analyzing data on how El Nino-fueled storm surges in winter 2015-16 affect coastal geomorphology and hydrology. The study involves setting up camera stations and water-level loggers at 10 lagoon sites; an additional two dozen sites stretching from Central California to San Diego are being monitored by other project partners, including a group of citizen scientists. Data will be used to calibrate SLR response models being developed by the U.S. Geological Survey and others.

Priorities for Future Research

SCCWRP's ongoing research on sea level rise will help inform future priorities. For example, SCCWRP is potentially interested in examining how nutrients and carbon from land-based sources are affecting the biogeochemical processes of coastal wetlands. SCCWRP also will continue to explore how vulnerable physical habitats are being altered by seal level rise and storm surge.

***Future focus area:* Linking SLR to habitat vulnerability**
SCCWRP is interested in fostering and strengthening strategic partnerships to create habitat vulnerability maps for all of coastal California, which will ensure that SLR modelers can factor in how biological communities will react to the various stressors within them. For example, SCCWRP is uniquely positioned to characterize the relationship between water depth and biological response – a key relationship to understand as sea levels encroach on sensitive ecological areas. SCCWRP also is well-positioned to offer up insights into the management decision-making process and to partner on GIS modeling efforts.

Δ Weather Patterns

Accomplishments

SCCWRP's ecohydrology research program, which relates physical habitat changes to biological responses, has created a scientific foundation for exploring the role that global climate change plays in altering ecosystems. More information about the development of these physical-biological relationships can be found in the Bioassessment and Ecohydrology research themes.

Ongoing Research

To maintain the biological relevance of reference conditions for a variety of condition assessments of aquatic systems, SCCWRP is reevaluating potential shifting baseline conditions and determining the degree to which condition assessments may be impacted. SCCWRP also is investigating the minimum-flow needs of aquatic biota to pave the way for new water recycling and reuse programs and possible development of minimum-flow requirements for California streams. More information about SCCWRP's work to understand minimum-flow requirements can be found in the Ecohydrology research theme.

Priorities for Future Research

SCCWRP intends to prioritize refining flood-control strategies in light of changing weather patterns, including re-optimization work on BMPs, LIDs (low-impact developments) and channel design. SCCWRP also intends to develop guidelines and parameters for how to appropriately balance beneficial uses for limited water resources. More information on how SCCWRP will integrate changing weather patterns into its research can be found in the Ecohydrology research theme.

Δ Water Temperature

Accomplishments

SCCWRP has only recently begun working in this area.

Ongoing Research

SCCWRP is conducting historical community assessments across the Southern California Bight to understand how climate variability has impacted biological communities over time. Also, as SCCWRP works to maintain biologically relevant thresholds and indices, temperature increases are being studied as a potentially key stressor that may require modifications to the reference conditions used to establish baselines for environmental scoring tools – or perhaps even require entirely new approaches for interpreting environmental monitoring data.

***Project:* Investigating the impacts of rising water temperatures on the Benthic Response Index**

To gain insights into how changing weather patterns may impact biological communities in the future, SCCWRP is analyzing benthic macroinvertebrate data from Bight historical monitoring to understand how the biota may have changed in response to rising water temperatures. Understanding these changes will allow SCCWRP to understand whether the Benthic Response Index – a scoring tool used for the state's Sediment Quality Objectives program – is unintentionally sensitive to temperature-induced biota changes, i.e., the tool is picking up on small, temperature-induced changes to biota composition instead of the changes in pollution levels and other variables it is designed to detect. If the index is found to be sensitive to temperature-induced changes, the Benthic Response Index may need to be recalibrated so it no longer conflates temperature-induced biota changes with the types of impacts the index is intended to measure.

***Project:* Using El Nino and La Nina years to estimate future biota impacts**

SCCWRP is using the same Bight historical data sets being used to assess temperature-mediated sensitivity of the Benthic Response Index to examine how Southern California's dramatic La Nina and El Nino climate patterns affect Bight benthic macroinvertebrate communities. El Nino and La Nina, which tend to trigger far-ranging impacts on biota, portend the types of climate extremes that are expected to become increasingly commonplace and intense in response to global climate change. Hence, El Nino and La Nina can be harbingers of the types of effects that global climate change is likely to bring to Southern California.

Additionally, as SCCWRP builds its coupled physical-biogeochemical model to understand the relative contributions of local land-based nutrient inputs on ocean acidification, the role of the strengthening thermocline is being modeled to understand its contributions to hypoxia and primary productivity. The intensifying thermocline could have multiple important implications for the Southern California Bight: It may be counteracting and dampening the intensity of West

Coast ocean upwelling events, it may be enhancing the trapping of wastewater effluent discharges underneath it, and/or it may be contributing to more deep-layer hypoxia. More information about this modeling work can be found in the Eutrophication research theme.

Priorities for Future Research

As part of the Southern California Bight Regional Monitoring Program, SCCWRP intends to track the movement and proliferation of pathogens, algal blooms and other nuisance organisms in offshore waters (see Eutrophication research theme). SCCWRP also is interested in continuing to mine Bight historical monitoring data and to integrate metagenomics into future Bight monitoring.

Future focus area: **Integrating metagenomics and microbial components into Bight regional monitoring**

SCCWRP is interested in assessing how temperature changes and other factors influence the composition of biological communities by integrating a metagenomics component into the Southern California Bight Regional Monitoring Program. Through metagenomics, DNA samples from the whole aquatic environment can be collected to offer key insights into the composition of the communities living there.

Future focus area: **Analyzing historical Bight fish trawl data for climate change-induced stress**

While fish are likely to be less sensitive than benthic macroinvertebrates to water temperature-induced impacts, SCCWRP is nevertheless interested in analyzing historical Bight fish trawl data as well to gain a more comprehensive understanding of how rising Bight temperatures already may have altered fish populations. This work would build on SCCWRP's examination of historical Bight benthic macroinvertebrate data in an effort to identify temperature-induced impacts to biota.

Literature Cited

Lackey, L.G., E.D. Stein. 2013. Evaluation of design-based sampling options for monitoring stream and wetland extent and distribution in California. *Wetlands* 33:717-725.

Martz, T., K. McLaughlin, S.B. Weisberg. 2015. Best Practices for autonomous measurement of seawater pH with the Honeywell Durafet pH sensor. Technical Report 861. California Current Acidification Network (C-CAN).

McLaughlin, K., S.B. Weisberg, A.G. Dickson, G.E. Hofmann, J.A. Newton , D. Aseltine-Neilson, A. Barton, S. Cudd, R.A. Feely, I.W. Jefferds, E.B. Jewett, T. King, C.J. Langdon, S. McAfee, D. Pleschner-Steele, B. Steele. 2015. Core principles of the California Current Acidification Network: Linking chemistry, physics, and ecological effects. *Oceanography* 28(2):160–169.

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. 2016. The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions. California Ocean Science Trust. Oakland, CA.