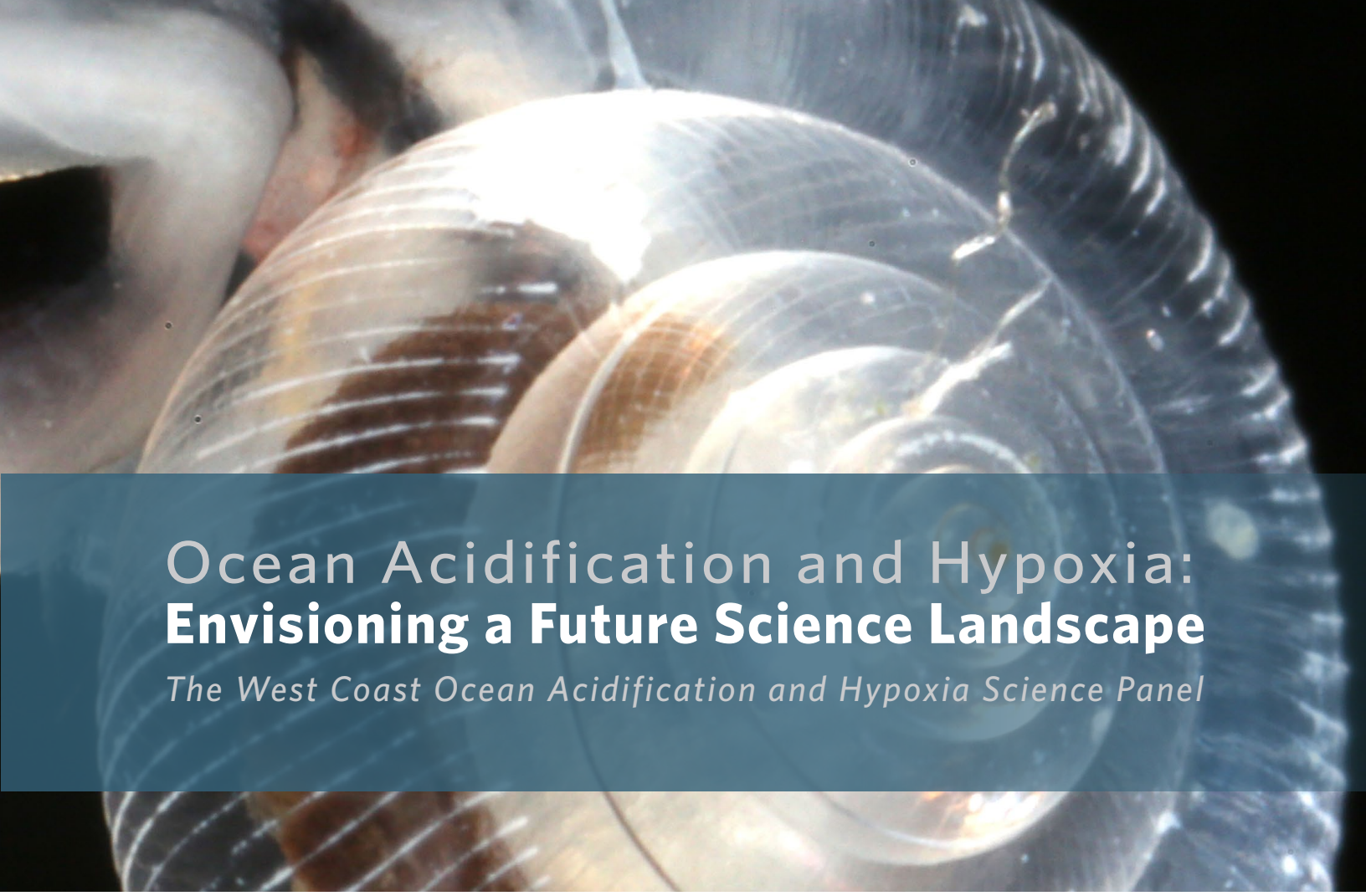

Ocean Acidification and Hypoxia: **Envisioning a Future Science Landscape**

The West Coast Ocean Acidification and Hypoxia Science Panel

Vision

Facing environmental concerns with wide ranging impacts, we work together in strategic and concerted ways toward studying, monitoring, mitigating, and managing these impacts to navigate through uncertainties. The west coast is poised to respond with a scientific community that has the background, range of expertise, and infrastructure to address ocean acidification and increasing hypoxia.

Concerns are growing at multiple levels of government about the effects of ocean acidification and increasing hypoxia events on ecosystems along the coasts of California, Oregon, Washington, and British Columbia. Thoughtful and strategic research and monitoring will be essential to improve understanding of these impacts and to develop effective management and mitigation options. Working with the West Coast Ocean Acidification and Hypoxia Science Panel, the California Ocean Science Trust has developed this vision for the future state of knowledge and role of science in improving our ability to understand and manage ocean acidification and hypoxia on the west coast. This long-term vision can help ensure that near-term choices of how we approach these issues will deliver benefits in the years to come.

This document seeks to assist decision-makers across the public sector in supporting science to address ocean acidification and hypoxia. Taking advantage of the opportunity and assets we share across the California Current, this document describes the research and monitoring, partnerships, and institutional capacity to address ocean acidification and hypoxia on the west coast.

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This report was produced by the California Ocean Science Trust, working in partnership with the West Coast Ocean Acidification and Hypoxia Science Panel. The information provided reflects the best thinking of the Ocean Science Trust based on conversations with external experts and with input from the OAH Panel. The content is not intended to direct policy decisions.

The West Coast Ocean Acidification and Hypoxia Panel, convened by California Ocean Science Trust, is funded by the Ocean Science Trust with funding support from the California Ocean Protection Council and Coastal Impact Assistance Program. Oregon support is being provided by the Oregon Governor's Office, the Oregon Department of Fish and Wildlife, the Oregon Department of Agriculture, the Oregon Department of Environmental Quality, the Oregon Department of Land Conservation and Development, and the OSU Research Office.

The Institute for Natural Resources in Oregon, working in collaboration with California, is supported by the Oregon Governor's Office, the Oregon Department of Fish and Wildlife, the Oregon Department of Agriculture, the Oregon Department of Environmental Quality, the Oregon Department of Land Conservation and Development, and the OSU Research Office.

Recommended citation: Ocean Acidification and Hypoxia: Envisioning a Future Science Landscape. California Ocean Science Trust, Oakland, California, USA. February 2015

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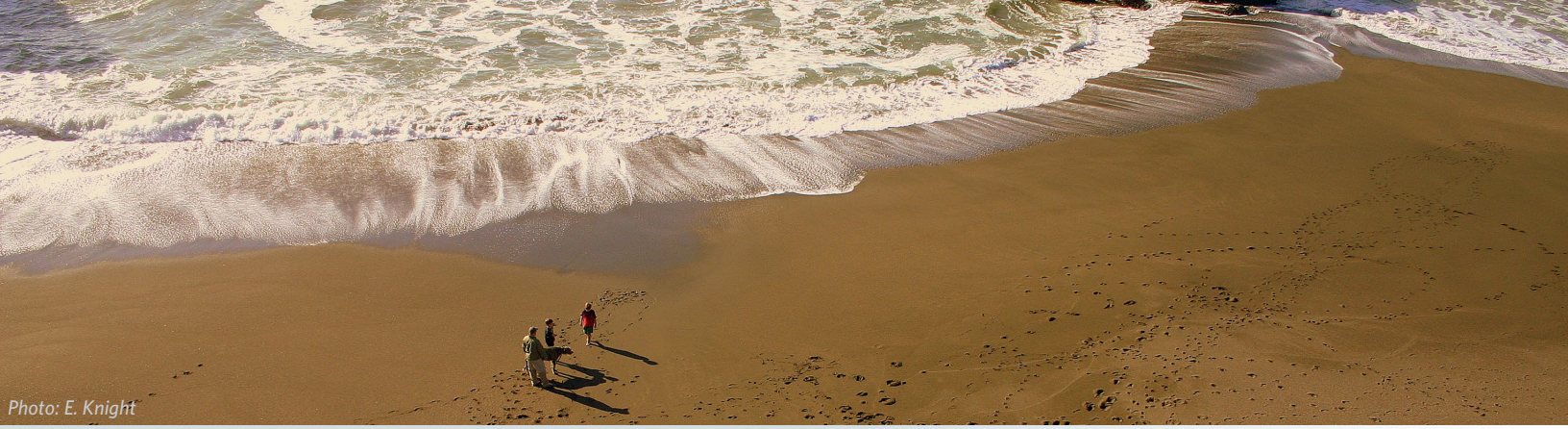


Photo: E. Knight

Why Describe a Future Vision: Recognizing the Opportunity

The West Coast Ocean Acidification and Hypoxia Science Panel has brought together coast-wide expertise to address decision-makers' needs about ocean acidification and increasing hypoxia. The Panel is laying the foundation for understanding the processes, potential effects, and potential interventions for addressing ocean acidification and hypoxia. While their work focuses on the most up-to-date science and results in scientific publications and white papers, the Panel also offers insight and creative thinking about how to approach these particular ocean issues based on many years of experience. The Ocean Science Trust worked with the Panelists to capture their best thinking about how to build our knowledge of ocean acidification and hypoxia and best serve decision-makers seeking ways to manage and mitigate impacts. Starting with Panelists and including additional experts they recommended, we posed the following questions:

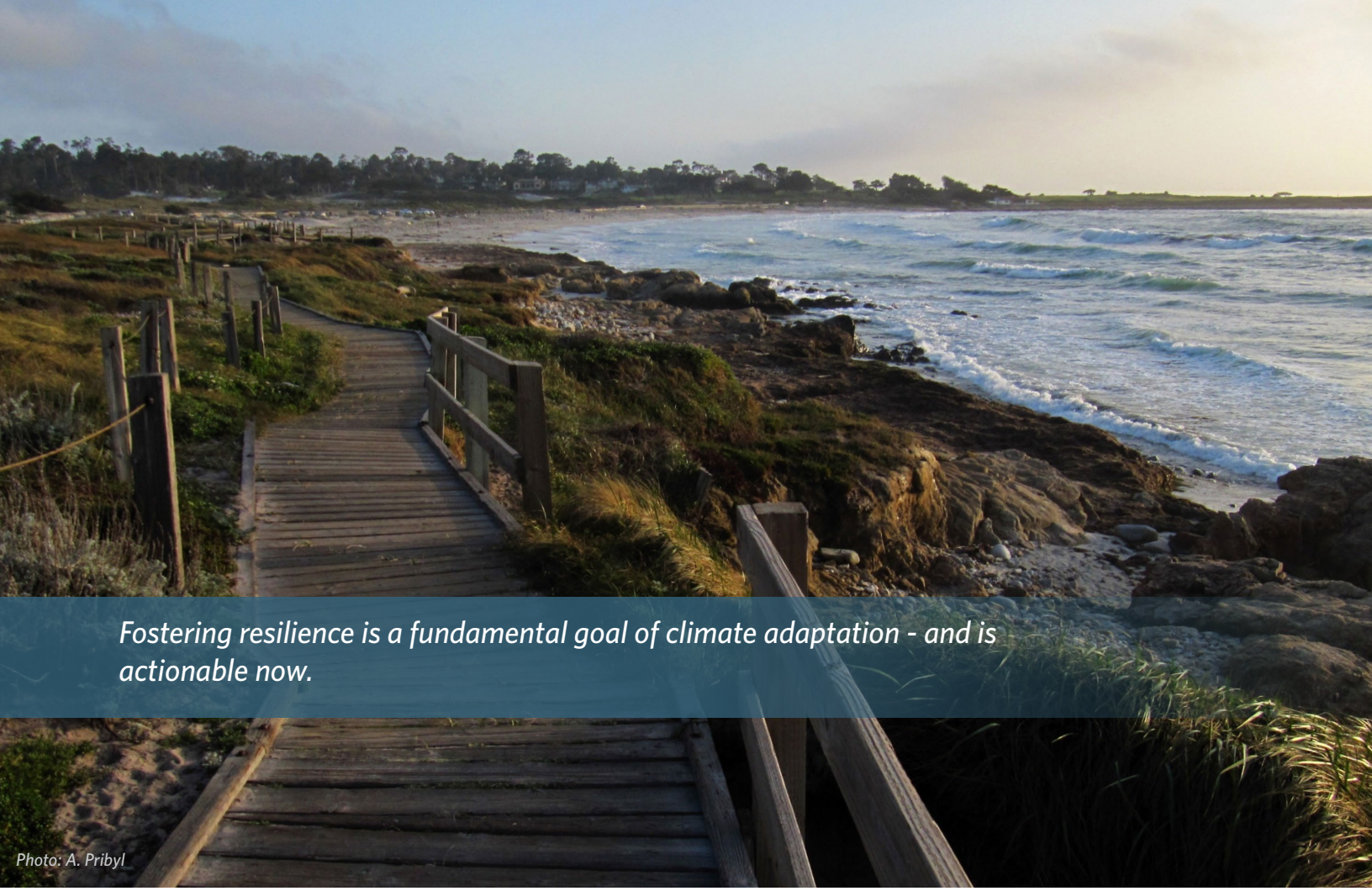
- What will we need to know 5, 10, 20 years from now to effectively address ocean acidification and hypoxia?
- What will we do differently as a result of that knowledge?
- How should scientists, industry members, and stakeholders work together in new ways to address these challenges?

The overall vision for the future provided here reflects ways in which the scientific community can approach ocean acidification and hypoxia in the years to come. Each section outlines a goal and describes how we can get there. This document does not set science or research priorities for moving forward; these will be addressed in documents now being developed by the Panel that synthesize best available scientific information to address the needs of decision-makers and resource managers.

Ocean Acidification and Hypoxia: Large-scale and Complex Ecological, Social and Economic Challenges

The lowering pH of the ocean due to elevated levels of carbon dioxide - ocean acidification - will impact marine ecosystems in the coming years. The hypoxic condition of low dissolved oxygen in water is often coupled with ocean acidification through chemical, biological, and oceanographic processes. Current research of ocean acidification and hypoxia on the west coast makes it clear that the oceans will change, and continue to change at accelerated rates. Science has a critical role in the face of unprecedented, long-term, and ubiquitous environmental change to inform mitigation efforts at local, regional, and national levels to help reduce the impacts.

The scale of these environmental issues is much larger than the scale of human approaches to management. We need to strategically prepare for managing on a long-term basis as we will continue to face ocean acidification and increasing hypoxia in the decades ahead. The oceans' capacity to store CO_2 means that water upwelled along the coast will continue to bear the signature of its last contact with the atmosphere. Today's atmospheric levels will be reflected in upwelled water 3-5 decades from now. Investing in science can build upon what we know and identify what is still unknown. A deeper understanding of the processes and drivers of ocean acidification is necessary to inform and improve management and mitigation efforts.



Fostering resilience is a fundamental goal of climate adaptation - and is actionable now.

Photo: A. Pribyl

Opportunity for a Strategic Approach

Addressing ocean acidification and hypoxia gives us an opportunity to jump start ocean science in new and transformative ways. This issue highlights some of the limitations of our current system, while improving our approach to ocean acidification and hypoxia can improve our ability to learn about and manage other new and escalating environmental threats.

Ocean acidification and increasing hypoxic events are environmental threats that have global reach, long timelines and impacts, both known and as yet unanticipated. We need to think differently about how to incentivize and implement research on these complex issues. From academic, federal, and state science communities, we have intellectual and physical resources in place, as well as a suite of strategies in which we can invest further and prioritize. But given the magnitude of these challenges, we first must recognize the need to work together in ways that mobilize thought-leaders and experts to expand our breadth of options in managing for large-scale and long-term environmental impacts.

The West Coast is Poised to Respond

The interdisciplinary and innovative work of the Panel demonstrates why a west-coast-wide, bi-national approach is critical to understanding ocean acidification and hypoxia, and what this scale of approach provides to agencies in policy and management nationwide. The west coast region is well positioned to develop a comprehensive approach as existing infrastructure and long-term studies are already increasing our knowledge, as well as fostering greater expertise, capacity and collaborative science partnerships. Inclusive of diverse habitats and influences (upwelling, rivers and estuaries, urban coastlines), the west coast sets a broad stage for gaining an understanding of long-term environmental threats that can enrich management efforts on other coasts.

I. Identifying Pragmatic, Strategic Research Trajectories

The following research trajectories describe general directions for targeting scientific investments to improve understanding and advance our ability to mitigate for and adapt to the potential large-scale and long-term environmental threats posed by ocean acidification and increasing hypoxia.

a. Implement Efficient Management-relevant Monitoring Programs

Monitoring will be critical to understand ecological and socioeconomic changes due to changing ocean conditions, and to evaluate the effectiveness of management strategies. Investing in building and maintaining long-term data sets will create an invaluable bank of information through which we can better understand impacts and trends on long time scales.

Goal

Continued and strategic monitoring is deepening our understanding of the drivers and impacts of ocean acidification and hypoxia, evaluating the effectiveness of management, and providing salient knowledge to inform new strategies.

Rationale and Details

Monitoring programs provide the time-series necessary to detect changing chemical, biological, and ecological responses to ocean acidification and hypoxia. To understand dynamics in coastal systems and the role of nearshore processes, measurements of select parameters at strategic locations will provide necessary information about the variation of ocean conditions through time and space.

With limitations to time and resources, there is a need to target efforts to understand the impacts on sentinel species that represent essential ecosystem functions (role in the ecosystem), and species of particular economic, social and cultural value. Understanding the capacity of marine populations to evolve or adapt to changing ocean conditions informs how to identify hot spots of genetic potential that might be well adapted for a more acidic or hypoxic environment. Protecting or supporting these genotypes can improve the resilience of marine systems to endure long-term exposure to stressors.

b. Link Monitoring Data with Research to Inform Real-world Context

Studies that reflect environmental complexity are needed to build upon our understanding of ocean acidification and hypoxia. A more holistic approach to studying change in the ocean can better inform our ability to predict impacts to marine ecosystems.

Goal

Creative and innovative research across multiple disciplines has established a new body of scientific knowledge and is continuing to build our understanding of the drivers and impacts of ocean acidification and hypoxia.

Rationale and Details

To promote a growing understanding of multi-species and multi-stressor effects that interact in the marine environment, it is necessary to test multiple variables, time scales, spatial scales, and environmental stressors.

New methodologies are needed to untangle effects of different stressors, using proxies and tracers to help understand how organisms' responses observed in the lab extrapolate to the natural environment. Shifting from the laboratory to large-scale, natural experiments in mesocosms can provide more realistic organism responses to ocean acidification and hypoxia. Laboratory and field experiments that match the temporal and spatial scales at which environmental stressors occur can inform how vulnerable species actually are, and provide insight for the most efficient scales for management. Knowing more about how organisms respond to multiple environmental changes can help to identify when the impacts of stress are moderated or exacerbated.

Using real data from the lab and field can improve the ability and capacity of models to anticipate how ocean acidification and hypoxia will transfer through food webs and impact ecosystems. Modeling is an important and valuable tool to inform decision-making but the quality of models is dependent upon the integrity of data input.

Photo: K. Joe

c. Leverage Resources for Technology and Instrumentation

Coordinating new networks and supporting existing infrastructure to measure ocean conditions can serve multiple uses across sectors, and are essential for understanding changes in the marine environment.

Goal

Networked infrastructure and technology exist along the West Coast and are working concurrently to collect data, promote access to shared resources, and exchange data between multiple users.

Rationale and Details

Coordinating a network of instruments deployed at strategic locations can provide linked physical, chemical, biological, and socioeconomic data streams. Adding chemical and biological sensors to buoys already maintained by the ocean observing network can reduce installation costs while improving the capacity of existing ocean observations. Partners can support data collection by offering a lending library of sensors available to researchers that make the instruments accessible in a cost-effective manner.

The standardization of chemical and biological measurements enhances the credibility and exchange of data. Data portals can increase transparency by improving access to data sets that are essential to models and for use in new approaches.

There are also opportunities for instrument and technological innovations that foster the development of cost-effective and reliable instruments required to accurately measure parameters of ocean acidification and hypoxia.

II. Informing and Improving Management Actions

Addressing ocean acidification and hypoxia will require adopting well-understood tools and techniques designed for environmental challenges that involve uncertainty. It is also an opportunity to change our management approaches in ways that can serve as an innovative model for other ocean management issues. Based on new research and sharing usable knowledge, we can build cross-institutional partnerships to expand our understanding. Looking through the lens of ocean acidification and hypoxia, we can see how our ability to work together to develop and implement effective management will enrich our experience, and improve our ability to deal with a wide variety of ocean challenges.

a. Promote Iterative Learning for Evaluating Effectiveness and Adaptive Management

As we investigate mitigation or adaptation strategies for ocean acidification and hypoxia, being able to assess the risks and effectiveness of managing approaches

Adaptive Management Can Help to Evaluate Currently Used Strategies and Explore Potential Approaches

Adaptive management can help to evaluate currently used and explore potential approaches. For example, marine protected areas have been established and monitored along the west coast, providing a testing ground to observe the impacts of ocean acidification and hypoxia in the absence of other system drivers. Research is needed to evaluate whether photosynthetic organisms have the potential to absorb the impacts of rising CO_2 at levels and in time-frames long enough to benefit neighboring ecosystems. To assess whether ocean chemistry mitigation (geoengineering) is possible, we need to evaluate whether accelerating natural processes that neutralize acidity on geological time scales can match current rates of change.

provides the flexibility to evaluate different techniques and make strategic choices in response to new and deepening scientific understanding.

Goal

Iterative learning is informing management programs and projects by providing new knowledge on mitigating impacts, assessing risks, and testing creative adaptive management options.

Rationale and Details

For long-term, dynamic environmental stressors with global impacts, success of management strategies need not depend on a complete solution or fix, but a relative shift in trajectory. Working together through partnerships to tightly link the collection of monitoring data, implementation of management, evaluation of effectiveness, and incorporation of new information in a continual cycle provides the opportunity to fine-tune our management approach.

For a variety of potential management tools, success needs to be clearly defined to balance goals, costs, effectiveness, tradeoffs, and risk. Testing possible management approaches on small-scales is necessary to understand the suite of options available and to identify which management actions are more appropriate for implementation. Risk assessments to identify vulnerable ecosystems and human communities can inform future management priorities to anticipate impacts. Recognizing barriers (e.g., cost or technology) or failures can support the development of a thorough adaptive management "playbook" and serve as a growing memory bank of options. As time passes and barriers are overcome, these previously unsuccessful management tools can be re-investigated.

b. Expand Partnership Portfolios

Relationships need to be built and maintained across sectors to provide the capacity and momentum to address decision-makers' science needs. Existing partnerships can be reinforced and deepened, while new partners can bring unique and creative perspectives to science.

Goal

Diverse partners, including multiple academic disciplines, industry and private enterprise, are engaged with science, actively motivating, accelerating, and enhancing our understanding of the impacts and management of ocean acidification and hypoxia.

Rationale and Details

The complex challenge of ocean acidification and increasing hypoxia is an opportunity to engage problem-solvers both in and outside of academia to expand our knowledge and enrich our efforts to respond to environmental issues. Within the academic community there are untapped resources of thinkers cultivating innovative ideas and approaches, such as theorists, ethicists, lawyers, and planners. Outside of academia, technological innovators and entrepreneurs can develop and market new tools and instruments. Social scientists and economists can inform how changes in marine resources or uses might affect human communities. Further, integrating biological and socioeconomic data can then advance our understanding of impacts to the marine environment and inform societal responses.

c. Develop New Connections at the Science-Management Interface

There are many unknowns around how to manage the ocean under changing conditions. Currently, management is positioned to be reactive since salient and solid data are needed before information about a threat is actionable. The key to a timely response is two-way interactions between decision-makers and scientists to both learn from and inform management. Together, we can identify what and where are vulnerabilities that affect management goals, how to anticipate and manage for current and future needs, and to tease apart what we know, what we will know, and what is impossible to know.

Goal

Two-way interactions between scientists and decision-makers facilitate a direct response to science needs and the agility to incorporate new knowledge to inform management.

Rationale and Details

Fostering two-way interactions is important to bring relevance to science and to respond to new scientific information. Building a strategic network and supporting long-term relationships between multiple users of science can construct self-sustaining pathways to integrate science and management. Bringing together scientists and managers around a common need through science-to-management cooperatives, conferences, working groups, panels, and committees can galvanize the best thinking and an organized response to motivate policy or legislation.

d. Empower a Climate-literate Public

Supporting public engagement on environmental threats proactively brings these relevant issues to the forefront. There are opportunities to share scientific information with an engaged citizenry, mobilizing a broad constituency to empower action on issues such as ocean acidification and hypoxia.

Goal

Scientists support an informed and engaged public on environmental issues, mobilizing diverse constituencies with rigorous scientific knowledge.

Rationale and Details

Issues that affect the ocean have far-reaching impacts for communities not only along the coast, but inland and globally. Providing clear links for why we should care highlights the relevancy and urgency of ocean issues. Promoting education and accessible scientific information can build public understanding of scientific processes. As ocean conditions change beyond what we have experienced previously, scientific insight will be needed to predict future conditions. Transparency in the scientific process and engaging the public in these complex issues can build trust, strengthening our ability to work together to discover and support solutions. Being accessible and discussing relevant issues with broad audiences can promote dialogue and bridge understanding with an increasing population of science-literate and invested people. This informed and motivated audience can engage with the scientific process and mobilize local efforts as citizen scientists.

III. Building Institutional Capacity

An important consideration in how we manage ocean acidification and hypoxia is whether we have the institutional capacity to do the work described in this document. A vision for how science operates in the face of complex, long-term, and large-range stressors needs to include a vision for how these systems work together to facilitate research and develop effective management strategies.

a. Academic, Federal, and State Scientists Advance New Approaches to Scholarship

A concerted approach to understanding the impacts of ocean acidification and hypoxia is necessary to address these large-scale issues. Greater cooperation and interdisciplinary collaboration between academic institutions, federal, and state scientists can generate new, more useful knowledge, and serve as examples of innovative approaches to problem-focused questions.

Goal

Academic, federal, and state scientists are supporting opportunities for interdisciplinary, problem-focused collaboration, actively training the next generation of academics and practitioners, and advancing new ways to approach scholarship.

Rationale and Details

Research centers that focus on ocean acidification and hypoxia can build capacity to problem-solve by attracting the best minds and resources toward

this issue and concentrate scientific understanding. Supporting the collaborative work of academic institutions, government agencies, and industry can bring experts together across sectors and promote direct links between science and management decisions. Boundary organizations can also connect scientists to decision-makers, cultivating relationships between academia and agencies to inform timely action.

Within universities, interdisciplinary programs can foster a culture of new thinking infused by multiple areas of expertise. While continuing to pursue basic science in each discipline is essential in furthering our understanding, having an interdisciplinary program allows departments to also engage across their specialties. Departments can reflect interdisciplinary research priorities by recognizing and rewarding publications or collaborations that bring in new perspectives and expertise.

Academic institutions and government scientists can mentor students to promote a generation of practitioners who can collaboratively address real-world problems. Encouraging opportunities to interface with decision-makers can ground student projects in the direct application of their research. Co-mentoring, by having one academic mentor and one mentor that operates in industry or at a federal or state agency, offers students the necessary guidance to better understand and address relevant science needs. Training scientists to understand the language of law, economics, or social science can produce experts able to speak across disciplinary boundaries.

For scientists interested in operating within a policy landscape, fellowships can enable academics to transplant into an agency or policy arena to both learn and inform management processes. This experience can provide a two-way exchange wherein scientists can better understand the process of decision-making, while policy makers learn the current state of scientific knowledge and what is known or unknown.

Universities, agencies, and industry working together can offer educational resources that have global reach since knowledge is not confined to political boundaries. Internet courses and online webinars can concentrate various academic expertise around a research theme, and provide access to resources and information to rapidly disseminate new knowledge. Bringing academics, stakeholders, and policy makers together through workshops and informational meetings can form working groups to discuss emerging issues. Regular exchanges of information can inform and shape approaches in science, industry, or policy, while building relationships and a venue to identify new partnership opportunities.

New partnerships and collaborations provide the foundation for building new scientific knowledge.

Photo: Steve Lonhart / NOAA NBNMS

d. Foster Creative and Long-range Funding Portfolios

A critical question is whether or not the current funding models are able to support the types of research needed to understand and manage environmental issues like ocean acidification and hypoxia. Funding agencies can direct resources toward important areas of focus, incentivize science integration, and incorporate an eye for long-term management.

Goal

Funding agencies use a multifaceted approach, directing resources to support both long-term monitoring and creative innovation.

Rationale and Details

Strategic funding can build a more robust science framework for solving problems by investing toward long-term goals, supporting collaborations that build bridges across programs, and incentivizing innovation.

The timeframes to observe the trends and impacts of ocean acidification and hypoxia are highly variable. Recognizing that funding opportunities have limited durations that do not match these timeframes, sustaining programs can build upon our understanding by encompassing a full scope of short- and long-term observations. Developing long-term and long-range funding structures can seed research programs and allow sustainability over long timeframes. We have well-tested tools and techniques to track and respond to the impacts of ocean acidification and hypoxia. Investing in the collection of monitoring data, maintaining existing sensors, and supporting ecosystem-based approaches are important long-term and long-range components to understand these issues on relevant time scales.

Continuing to support basic, exploratory science expands our understanding of the natural environment and provides a scientific foundation from which to draw solutions. With sustained funding, researchers can rely on a backbone of support that empowers them to test innovative ideas and build more lasting, fruitful collaborations. Funding criteria can recognize the value of collaborative and interdisciplinary research programs that fall outside typical funding opportunities by setting priorities in grants to enable these kinds of projects.

Targeting areas where the primary barrier for advancement is cost through competitive prizes aimed at technological innovation can accelerate the development of instruments and provide an industry link. To allow for agile responses to emerging needs, funding entities, including philanthropic ones, can respond quickly to support projects in new areas, filling an important niche before other funding agencies are able to direct support. These funds can augment or jump-start interest in particular issues, generating the necessary momentum to deepen scientific understanding and provide greater security for public investment.

Photo: H. Carter

Mobilizing Science Toward Innovative and Collaborative Solutions

The impacts of ocean acidification occur below the surface of the ocean and are less visible to us on a daily basis, while the oceans' capacity to store CO_2 cushions us from the immediacy of our impact on the oceans. Understanding that this means we might not observe or recognize dramatic impacts just yet, this lag time affords the opportunity to strategically act. Knowing more about this environmental threat can bolster our approach to managing the impacts on ocean ecosystems, coastal communities, and economies.

The West Coast has a unique community of scientists working on ocean acidification and hypoxia that provides a model of collaboration and concerted effort. At the vanguard of these emerging issues, scientists along the West Coast are poised to respond, dedicating students and infrastructure in ways that support interdisciplinary collaboration. The foundation of scientific knowledge they are building is critical to confronting these challenges.

To move forward in addressing ocean acidification and hypoxia, the focus falls on ways to invest wisely for the long-term. In the face of environmental concerns with wide ranging impacts and uncertainty, we need to work together in strategic and concerted ways toward studying, monitoring, mitigating, and managing these impacts to navigate through uncertainties. This document outlines ways to support research directions that will promote science that is more relevant to management and policy. The West Coast can respond with a scientific community that has the knowledge and infrastructure to address ocean acidification and increasing hypoxia.

Having a long-term vision of how science operates to address ocean acidification and hypoxia can shape near-term decisions. Monitoring programs are essential. There is also a need to support long-term and collaborative endeavors, as well as basic research to expand our understanding of the processes and drivers of ocean acidification and hypoxia. Through such research directions, we can paint a fuller picture of the challenges ahead, helping decision-makers generate a suite of more efficient, impactful management strategies. The Panel provides the expertise to identify and prioritize next steps for research on the West Coast.

The West Coast has mobilized a diverse community to respond to ocean acidification and hypoxia. Together, coast-wide, we are poised to respond with creativity and concerted effort.


Photo: MBARI


Photo: NOAA

Photo: NOAA