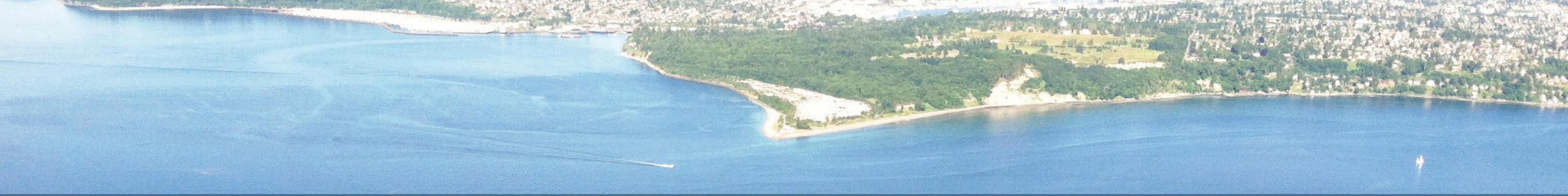

Modeling Tools: Summary of Needs to Enhance Understanding of Ocean Acidification and Hypoxia in Coastal Oceans

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The West Coast Ocean Acidification and Hypoxia Science Panel

Why models?

While ocean acidification and hypoxia (OAH) are increasing worldwide, upwelling-dominated coastal regions, such as those found on the North American West Coast of the U.S.; British Columbia, Canada; and Baja California, Mexico are particularly affected. Episodic OAH conditions are severe enough to affect biotic resources and important economic sectors, such as wild-caught fisheries and aquaculture. Models are a key component of the scientific toolkit to grasp the ramifications of OAH and explore options for appropriate management responses. They do this in four key ways:

1. allow us to forecast what future conditions will look like, based on projections of CO_2 emissions and other global change scenarios;
2. permit us to interpolate sparse data to get a spatially-explicit view of conditions away from monitoring sites;
3. allow us to test out scenarios to predict the efficacy of management actions; and
4. help us better understand and prioritize data gaps, including thorough evaluation of monitoring plans.

Models are important for two major types of OAH-related management applications: pollution management and marine resource management.

Pollution management. The input of anthropogenic carbon dioxide (CO_2) to the ocean is the primary driver of acidification. At the same time, managers need to better understand the effects of local carbon and nutrient pollution on OAH in the coastal ocean, and natural factors that lead to low O_2 and high CO_2.

Water and air pollution controls on point and non-point sources of nutrients and carbon are management actions that can reduce OAH stress at the local level. Since instituting such controls is costly, managers often seek a higher level of certainty about whether these actions will lead to a meaningful local environmental response in terms of OAH stress.

Marine resource management and spatial planning. West Coast states and provinces all engage in forms of spatial planning - for fisheries management, industrial/maritime/aquaculture operations, marine protected areas and more. Models can help support ecosystem-based management of marine resources in several ways, including: 1) evaluating the range of possible or likely ecological and fishery impacts in response to multi-stressor changes; and 2) evaluating the efficacy of ecosystem-based management actions in ameliorating OAH impacts. As with pollution management, spatially-explicit, physical and biogeochemical

About this Document

This document was developed as a technical summary to supplement the suite of products and recommendations that have emerged from the West Coast Ocean Acidification and Hypoxia Science Panel. It adds specificity to the Panel recommendation to develop modeling tools to support decision-making for ocean acidification and hypoxia. The information provided reflects the best scientific thinking of the Panel.

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

West Coast Ocean Acidification & Hypoxia Science Panel

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simulations and forecasts of the coastal ocean can provide the scientific basis for evaluating which types of management actions are likely to be effective, and in which locations. Such models exist – see “Ongoing Efforts” – but investments are required to refine them in order to support OAH-related management decisions.

The West Coast Ocean Acidification and Hypoxia Science Panel recognizes the need to accelerate the development and integration of knowledge required to improve decisions. In Panel discussions, a number of specific recommendations have arisen. These are summarized below, highlighting specific models and effective ways to use them.

Build a forum to advance coastal ocean modeling

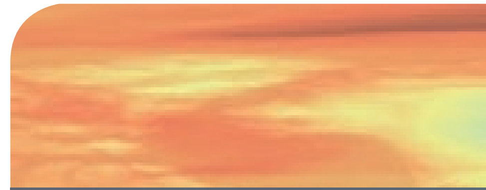
The biogeochemical drivers of OAH are complex. The diverse groups, entities, and funded programs throughout the region engaged in observing and modeling these changes will benefit from an integrated approach. An organized community of modelers, observational researchers, and managers can: 1) provide a vehicle for dialog on management goals and scenarios; 2) encourage discussion on the use of model outputs to illustrate outcomes of management action; 3) facilitate discussion about the level of validation needed to use models to support management decisions; 4) coordinate modeling products among different technical specialists; and 5) continuously improve models through model-data comparison and assimilation.

Existing modeling efforts and the status of underlying data to support models vary considerably by region along the West Coast. One of the first actions of such a forum should be to summarize key regional and local management needs and the status of existing data and models that would support those needs.

Develop a suite of coupled ocean-margin physical and biogeochemical models

Physical models describe the movement of ocean water masses in space and time, along with their inherent properties of temperature, salinity and density. Biogeochemical models describe the mass balance transport and transformation of carbon, oxygen, pH, nutrients and other biogeochemical properties in water. When linked to ecosystem models that integrate physical, biogeochemical and ecological properties to predict effects on marine life populations and whole ecosystems, coupled physical-biogeochemical models can provide projections of future ocean chemistry and facilitate an understanding of interaction with ocean food webs.

Models can be grouped as 1) those used to study processes under both idealized and realistic conditions; and 2) those capable of hindcasting, nowcasting or forecasting realistic ocean conditions. Simulation models used for #2 require observed forcing fields (e.g., winds, river runoff) and assimilation of data in real-time to improve forecasts, as is done routinely for weather forecasts. Simulation models require a much greater long-term investment of resources, both to provide ongoing forecasts and to improve these forecasts. A nested set of physical and, to a lesser extent, biogeochemical models exists for the West Coast, covering scales from the Pacific Basin to regional (hundreds of kilometers), and in some places, even local (tens of kilometers) scales. To date, most progress has been made with physical models of the mid to outer shelf and beyond, including extensive validation with existing and ongoing data sets. Validation against in-situ observations has grown but evaluation of their predictive performance remains a pressing need. Due to the coarse resolution of regional scale models, important gaps remain in our ability to understand and predict OAH dynamics in coastal waters that extend across the inner-shelf (from ~50 meters water depth) into the surf-zone, estuaries and bays. As a result, federal and state waters that are the focus of important management concern and actions remain beyond the reach of many models. Biogeochemical models that are coupled to physical models exist, mostly at the regional scale and not focused on the ocean margin. There is a pressing need to validate the biogeochemical models with existing and ongoing data sets, and to include biogeochemistry in coastal models. Currently, all Integrated Ocean Observing System (IOOS) regions along the Pacific Coast have a suite of physical forecasting models. Capacity for downscaling these models, extending them closer to shore and coupling them with biogeochemical models is variable and limited in most instances. Investments in



ONGOING EFFORTS

The West Coast OAH Science Panel developed these recommendations for needed modeling efforts while recognizing that the oceanographic modeling community is actively engaged in advancing many of these priorities. A workshop held in December of 2013 brought together many members of the West Coast modeling community (including eight members of the Panel) to scope opportunities for the development of models to inform management efforts. A number of research groups across the West Coast are in various stages of developing and applying models that will begin to meet these recommendations.

the development of high-resolution, coupled physical and biogeochemical models that can remedy these gaps are essential. Such models would enable capacity to forecast short-term changes in OAH at temporal scales that can support adaptive management decisions. Such models are also ideal for evaluation of management decisions.

Develop ecosystem models

As defined here, ecosystem models integrate physical, biogeochemical and ecological properties to predict effects on marine life populations and whole ecosystems. These models can be statistical or computational. Modeling to predict the effects of OAH on ecosystems in general, and on commercially important species in particular, is still in its infancy. An essential component of such models is parameterizing the impacts of OAH on organismal performance and feedback loops that occur between species, an effort which requires considerable experimental and observational data to properly validate. Federally supported, spatially explicit, regional-scale numerical models are under development for the West Coast, such as the Atlantis model. However, the biogeochemical algorithms that support this model currently do not include OAH, and the scientific basis to parameterize the prey-predator interactions needs work. Moreover, these models are focused on commercially-important species; many keystone species that are critical to marine food webs are not represented.

Three types of investment can most efficiently and effectively advance ecosystem models: 1) basic research, including integrated physical, biogeochemical, and ecological monitoring studies on effects of OAH on marine organisms under realistic exposure conditions and ecological contexts; 2) statistical and/or numerical sub-models that can be coupled to physical-biogeochemical models to predict effects on key species or assemblages; and 3) improvements in the physical and biogeochemical sub-models that support existing ecosystem models.

Build on existing data and modeling infrastructure

Short-term actions can capitalize on existing data and infrastructure, and provide essential information to develop models that can ultimately be used to guide management actions.

- **Use observational data to validate existing models.** Conduct validation to quantify uncertainty and identify key gaps in data and modeling infrastructure. Quantification of uncertainties will inform discussion on the precision required to answer management questions in the near-term and help to focus resources on critical model refinements. Most regional and some local scale physical models have been reasonably validated, but validation needs to be extended to the inner shelf (< 50 meters water depth). In addition, data are available for validation of biogeochemical models in some regions.
- **Refine atmospheric and terrestrial loading models.** Atmospheric and terrestrial loading models are needed to quantify the magnitude and timing of nutrient and carbon inputs into the coastal ocean, as well as sources and pathways. Monitoring and models exist for atmospheric and terrestrial loading, but for most regions along the West Coast they do not currently provide the resolution needed to inform local management action. For those locations where local inputs are deemed important, additional data will be needed for validation.
- **Use existing models to begin bounding answers to management questions.** Existing models can be used to start addressing management questions. In some cases, multiple models or model approaches exist and a comparison of outcomes from different approaches would provide multiple lines of evidence that constrain uncertainty in the answer. This model comparison will be most useful if conducted in a focused geographical regions (e.g., Santa Monica

Bay, Gulf of the Farallones, Columbia River Plume, Strait of Juan de Fuca), and based on shared observational records and specific statistical measures that could be used to test various models. If structured as collaborative comparisons, these analyses are anticipated to effectively lead to integrative approaches to developing the next generation of models; this work represents a natural extension of the modeling forum proposed above.

Collect data to further support model development and refinement

Three major types of data are needed to advance modeling:

1. **Observations of oceanic state for model validation.** Numerical models predict physical and biogeochemical variables that represent oceanic states in time and space (e.g., current speed and direction, salinity, temperature, dissolved oxygen, pH, pCO_2). Observational data that document these patterns (e.g., CTD casts, moorings and gliders) are critical for model validation and uncertainty analysis. While observations of deep waters that are the source of waters upwelled onto the continental shelf are an important need, the inner shelf is the key data gap for model validation.
2. **Biogeochemical process rates.** Models are simplified representations of complex biophysical interactions, expressed through model equations and their parameters. The biogeochemical process rates used in present models are based on globally derived estimates, mostly from open-ocean settings; models would be more appropriately parameterized using process rates specific to the nearshore ocean and local ecology.
3. **Trophic interactions.** Data are needed on trophic interactions including lower-level taxa that are most susceptible to OAH (e.g., planktonic calcifiers such as shellfish larvae and pteropods), and of organisms that have commercial value (e.g., crab, salmon).

...ongoing monitoring efforts are essential to continue in parallel with operational modeling activities.

In addition to these specific data needs for model development and validation, targeted, ongoing monitoring efforts are essential to continue in parallel with operational modeling activities. Such data streams will allow further model refinement, detection of events or places where the model is under-performing, and detection of possible shifts in how the system functions that may not have been captured in models based on past conditions.

Finally, a central repository for observational data and model output needs to be created that would provide open access and encourage research community participation. The organization of such a repository could be part of the modeling forum proposed above.

This report was produced by the West Coast Ocean Acidification and Hypoxia Science Panel (the Panel), working in partnership with the California Ocean Science Trust. The Panel was convened by the Ocean Science Trust at the request of the California Ocean Protection Council in 2013, working in collaboration with ocean management counterparts in Oregon, Washington, and British Columbia. Ocean Science Trust and the Oregon Institute for Natural Resources served as the link between the Panel and government decision-makers.

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