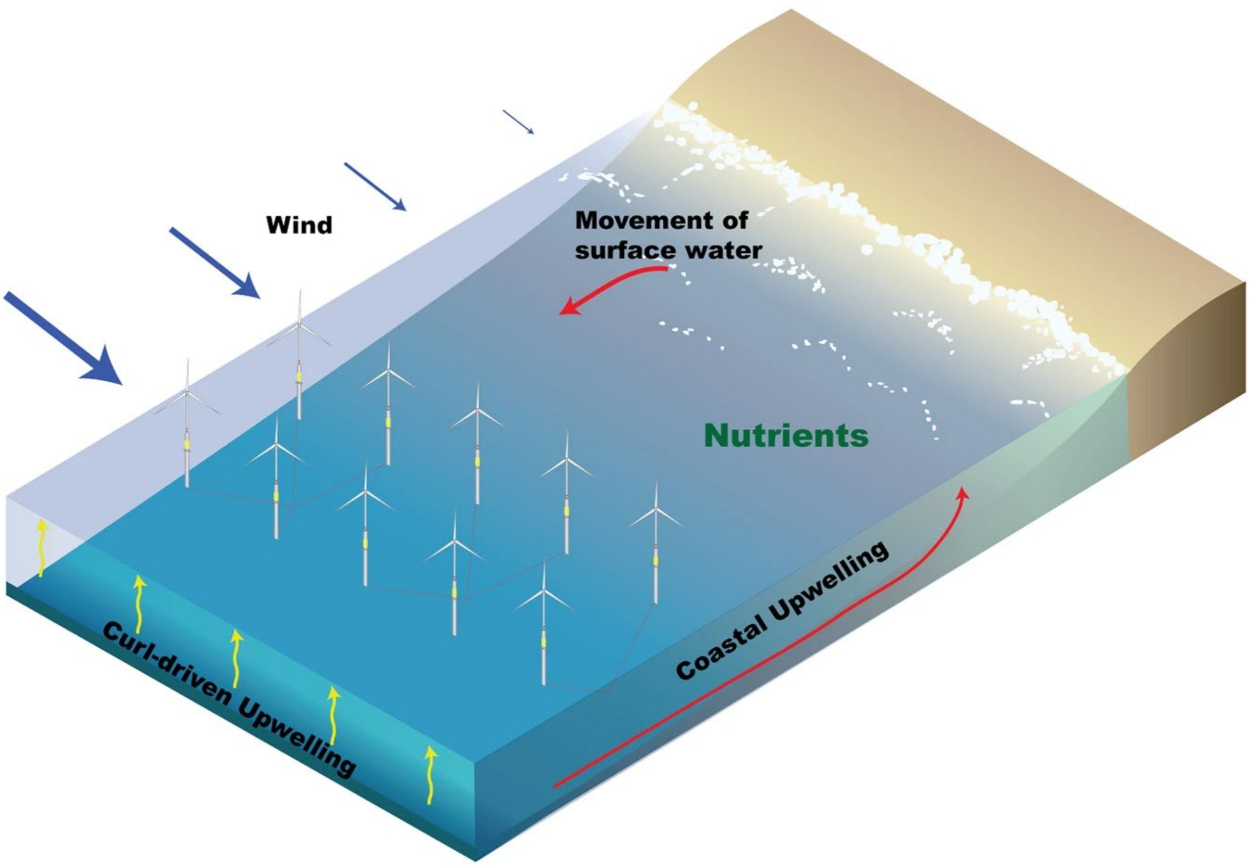
OCS Study
BOEM 2024-049

Observational and Modeling Approaches for Assessing Impacts of Offshore Wind Development on California Current Upwelling

Workshop Summary
March 4, 2024



U.S. Department of the Interior
Bureau of Ocean Energy Management
Pacific Regional Office, Camarillo, CA

BUREAU OF OCEAN ENERGY MANAGEMENT

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March 4, 2024

August 2024

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U.S. Department of the Interior
Bureau of Ocean Energy Management
Pacific Regional Office, Camarillo, CA

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To download a PDF file of this report, go to the U.S. Department of the Interior, Bureau of Ocean Energy Management, Current Environmental & Technical Studies – Pacific Region webpage (https://www.boem.gov/current-environmental-studies-pacific).

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ABOUT THE COVER

Cover graphic is from Raghukumar et al. (2023), figure 1: Schematic of upwelling processes near an eastern ocean boundary. Coastal upwelling occurs in a narrow (10–20 km) coastal band and curl-driven upwelling occurs over a larger offshore area.

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Contents

List of Figures

List of Abbreviations and Acronyms

ADCP	Acoustic Doppler Current Profiler
BEUTI	Biological Effective Upwelling Transport Index
BOEM	Bureau of Ocean Energy Management
CEC	California Energy Commission
CeNCOOS	Central & Northern California Ocean Observing System
COP	Construction and Operations Plan
CUTI	Coastal Upwelling Transport Index
DOE	Department of Energy
DOI	Department of the Interior
EIS	Environmental Impact Statement
EPIC	Electric Program Investment Charge
HRF	High Resolution Forecasting
MBARI	Monterey Bay Aquarium Research Institute
NEMURO	North Pacific Ecosystem Model for Understanding Regional Oceanography
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
ORACLE	Observationally Driven Resource Assessment with CoupLEd models
OSSE	Observing System Simulation Experiment
OSU	Oregon State University
ROMS	Regional Ocean Modeling System
ROSA	Responsible Offshore Science Alliance
RWSC	Regional Wildlife Science Collaborative
SAR	Synthetic Aperture Radar
SCCOOS	Southern California Coastal Ocean Observing System
SDP	Studies Development Program
SIO	Scripps Institution of Oceanography
SWFSC	Southwest Fisheries Science Center
UCSC	University of California Santa Cruz
UCSD	University of California San Diego
WEA	Wind Energy Area
WFIP3	Wind Forecast Improvement Project 3
WFP	Wind Farm Parameterization
WHOI	Woods Hole Oceanographic Institution
WRF	Weather Research & Forecasting

1 Workshop Overview

On March 4, 2024, the Bureau of Ocean Energy Management (BOEM) convened a workshop to discuss observational and modeling approaches to understanding the impacts of offshore wind development off the West Coast on California Current upwelling, and to develop overall recommendations for how to monitor and model the relevant parameters to assess such impacts. The workshop was informed by a previous modeling study that simulates impacts of offshore wind infrastructure in the California wind energy areas on hydrodynamics in the region (Raghukumar et al. 2023). Discussions were also informed by recommendations from a recent National Academies of Sciences report, which highlights the need for more observational studies that target all phases of wind energy development as well as more model validation studies that evaluate simulations of hydrodynamic processes at turbine, wind farm, and regional scales (National Academies 2023). Despite focusing on the Nantucket Shoals region, this previous report's recommendations are relevant for Pacific offshore wind as well. The workshop was attended by 19 in-person participants and 23 virtual participants representing federal and state agencies, academic institutions, national labs, a Tribal support organization, offshore wind developers, industry professionals, and a non-profit organization. Attendees' expertise included physical oceanography (both modeling and field sampling), atmospheric science and modeling, federal permitting, renewable energy generation, engineering, offshore wind development, and data management and delivery. The workshop was facilitated by Kearns & West.

1.1 Objectives

The main objectives of the workshop were identified by the organizers as:

- Bring together people who are tackling similar questions from different angles to communicate needs and knowledge gaps, foster relationship-building, and facilitate information-sharing.
- Discuss possible approaches and best practices for monitoring and modeling offshore wind farm impacts on hydrodynamics and biogeochemistry, and generate potential recommendations.
- Inform an ongoing BOEM-funded modeling study (BOEM 2023) by the National Oceanic and Atmospheric Administration (NOAA) that investigates potential impacts of West Coast offshore wind development on upwelling and biogeochemistry.
- Inform the scientific community of what the regulators' science needs are to support the offshore leasing process.

For additional information, the workshop agenda can be found in Appendix A and the full list of participants can be found in Appendix B.

1.2 Summary

The workshop began with an overview of the previous California Current modeling study (Raghukumar et al. 2023) to set the stage, followed by presentations that shared federal (BOEM) and state (California Energy Commission [CEC]) government perspectives as well as an industry perspective (Equinor Wind) regarding Pacific offshore wind development. The attendees then heard presentations about winds (resource assessment and wind wake modeling) and the ocean observing capabilities of autonomous underwater vehicle glider networks and future monitoring plans. At this point, attendees discussed strategies for observational monitoring of offshore wind impacts and associated challenges. The workshop then transitioned into presentations about model-based approaches to studying wind farm impacts on hydrodynamics, with a discussion following that focused on the knowledge gaps of current modeling studies and the ways in which modeling can inform observational monitoring plans. A more detailed description of each presentation is provided in the next section.

The key takeaways from the selected presentations and related discussion are as follows:

- We need more observational data of the wind field, especially at the sea surface, to better understand how atmospheric stability and the resulting wind wakes will influence hydrodynamics.
- More information is needed at several important spatial scales, namely at the scale of an individual turbine and its floating substructure system; at the scale of the wind farm and its immediately adjacent waters; and at the regional scale (hundreds of kilometers encompassing the wind farms and their wakes).
- A comprehensive approach for monitoring hydrodynamic and biogeochemical parameters at the wind farm scale would involve the use of a combination of gliders, which would provide a spatial footprint, with moorings, which would capture higher frequency variability. The inclusion of other technologies such as Lidar buoys, Wirewalkers/profilers, floats, and ship-based methods would help create a more complete picture of the wind energy areas and surrounding region.
- We need to identify the magnitude of signal change expected from offshore wind development at the spatial scales described above before we can attempt to separate them from both natural variability and climate change impacts.
- Some challenges that came up included: (i) the lack of criteria for what is considered an acceptable/unacceptable impact on the marine environment and associated standardized data needs; (ii) the disconnect between NEPA review scope (usually site specific, with discussion of cumulative impacts of current activities) and stakeholder interests (cumulative impacts of current and future activities); and (iii) the timing of scientific studies relative to regulatory decisions, which ideally would be informed by science but often happen first.
- Future modeling studies need to consider ocean-atmosphere coupling effects across the West Coast region, near-field physics for resolving meter-scale phenomena, cumulative impacts of multiple wind farms, different turbine configurations, and more downstream impacts of changes in California Current upwelling such as on fisheries, economics, and spawning areas.
- Modeling techniques such as the Observing System Simulation Experiment (OSSE) approach and near real-time modeling can help inform the cost-effective deployment of future observational monitoring systems.

2 Workshop Proceedings

2.1 Welcome and Context-setting

Dr. Tom Kilpatrick, BOEM, provided an overview and statistics of BOEM's Environmental Studies Program, which funds studies every year that address BOEM's knowledge gaps. Only ~9% of funded studies in the past 5 years have been related to physical oceanography and the majority have focused on the East Coast. He reiterated the findings of the National Academies hydrodynamics report (National Academies 2023) and their applicability to the Pacific region. He shared his hope that this workshop would foster productive discussion regarding the formulation of a monitoring plan for offshore wind impacts on hydrodynamics.

2.2 Presentation: Study Introduction

2.2.1 Kaus Raghukumar, Integral Consulting: *Projected cross-shore changes in upwelling induced by offshore wind farm development along the California coast*

Dr. Kaus Raghukumar provided an overview of the previous modeling study (Raghukumar et al. 2023). The study used the Regional Ocean Modeling System (ROMS; Shchepetkin and McWilliams 2005) to compute physical upwelling metrics and assess how offshore wind farms impact California Current upwelling. They used the Weather Research & Forecasting (WRF; Skamarock et al. 2019) model for winds, representing wind farm impacts on the wind field with the widely used Fitch et al. (2012) Wind Farm Parameterization (WFP); they found modest changes in total upwelling near hypothetical wind farms off Humboldt and Morro Bay, but substantial changes in the spatial distribution of upwelling.

Recommendations include gathering more data on wind speeds at the sea surface (wind models such as WFP have more validation data at hub height for resource characterization), subsurface current velocity and density structure, and phytoplankton and fisheries response, using various techniques such as Wind Lidar, Wirewalkers, and Acoustic Doppler Current Profilers (ADCP).

Questions:

- What are the potential cumulative impacts on upwelling if offshore wind development is scaled beyond the proposed two offshore wind farms in California?
  - This aspect has not been explored yet.
- Could horizontal mixing remove the effects of enhanced and reduced upwelling on each side of the wind farm?
  - The spatial range spans tens of kilometers, with a reduction in upwelling evident within a 50-kilometer zone. Horizontal and vertical mixing would occur across these spatial scales.

2.3 Presentations: Government and Industry Perspectives

2.3.1 Rick Yarde, BOEM: *Pacific Region Renewable Energy Overview*

Rick Yarde reviewed BOEM's renewable energy leasing process timeline. In California, five offshore wind leases have been granted, with lease sales occurring in December 2022 for $757 million. Public scoping began in December 2023, and leaseholders are currently collecting data for construction and operations plans (COPs), subject to BOEM review and completion of Environmental Impact Statements (EISs). In Oregon, public comment was open on scoping for an Environmental Assessment within the final Wind Energy Areas (WEAs) near Brookings and Coos Bay, with a plan for auction later this year. Mr. Yarde noted public engagement and consideration of environmental impacts that occur under the National Environmental Policy Act (NEPA), and BOEM aims to address concerns over environmental impacts through informed decision-making and study programs.

Questions:

- Why were the aliquots removed in the southernmost portion of the Brookings WEA?
  - BOEM discovered these areas to be important for scientific surveys by the National Marine Fisheries Service (NMFS).
- Explain the outer continental shelf withdrawal areas as shown in the Pacific Coast Outer Continental Shelf (OCS) Regions Map.

    - BOEM's jurisdiction on the OCS extends from 3 to 200 nautical miles off the coast of California, Oregon, and Washington, and the withdrawal regions represent National Marine Sanctuaries.
- Will the turbines rotate to the direction of the wind?
    - Julie Lundquist answered: Yes, they will rotate up to three circulations around the tower on a time scale of 5-10 minutes before unraveling in preparation to rotate again.
- Will the science ever get ahead of the decision-making, i.e., before WEAs are announced?
    - Modeling studies focus on areas that have already been leased.
    - BOEM's process relies on and prioritizes utilizing the most current and best information, enabling informed decisions as more data becomes available.
    - Another attendee noted that the offshore wind studies and science from the Atlantic OCS Region can help inform the Pacific OCS Region, especially regarding mitigation strategies that can be included in the NEPA review process.

2.3.2 Daphne Molin, CEC: *Offshore Wind R&D Overview*

Daphne Molin presented on the research and development initiatives funded by the State of California. Most funding comes from the Electric Program Investment Charge (EPIC) program (5-year investment cycle) to advance clean energy technologies to market. Research and Development (R&D) objectives are to improve reliability, affordability, safety, environmental sustainability, and equity. Ms. Molin reviewed EPIC and provided details on the program's objectives and investments. Recent investments include studies on remote environmental monitoring, anchor and mooring line designs, innovative manufacturability of components, and environmental evaluations. She concluded by presenting upcoming EPIC offshore wind R&D investment and research priority areas.

Questions:

- Is California exploring R&D closer inshore where the state has more authority?
    - California is exploring the impacts of running transmission onshore and is working on integrating this into the proposals.
- Explain the sensor technology on the transmission cables and at what level does it detect entanglement?
    - The objective is for both studies to explore the detection of any anomalies on the lines through tension sensing, aiming to pinpoint key signatures.
- Could studies be conducted on the sensors attached to transmission lines, considering environmental packages or a full suite of the biological-geological-physical sensors?
    - Yes; however, to suggest and fund these studies, they must align with improving ratepayer benefits. A funding priority is to tie studies with ratepayer benefits, aiming to enhance understanding of how data influences generation potential or turbine optimization.

2.3.3 Michelle Fogarty, Equinor Wind US

Dr. Michelle Fogarty outlined Equinor's environmental research and data collection milestones integrated into the BOEM renewable energy leasing process timeline. She explained that the relationship between BOEM and the developer initiates after the lease auction and spans about 40 years. Dr. Fogarty then shared the scales for environmental research collaboration and detailed the drivers of environmental data collection and research for Atlas Wind, which include: permitting and incorporation into the EIS prior to COP approval; power sales agreement and post-COP approval conditions; state conditions; and Equinor elective research initiatives. She concluded her presentation by detailing the challenges of environmental research collaboration, covering goals, actions, and examples associated with 4 aspects of collaboration: consistency, predictability, data governance, and innovation (Figure 1).

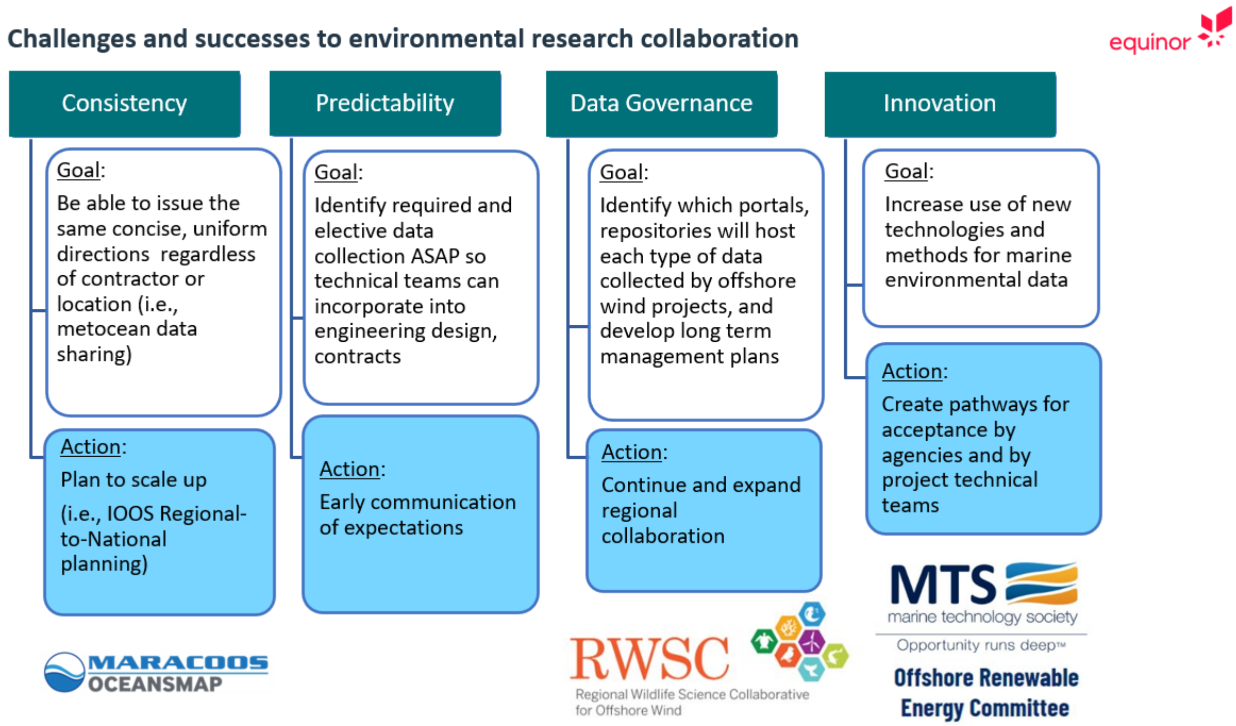

Figure 1. Challenges and successes to environmental research collaboration. Michelle Fogarty, Equinor Wind US.

Questions and comments:

- After leases are announced, engineers will start working on platform development. However, given the continuous evolution of sensor technology, what's currently available may differ in the future. How does the process accommodate this anticipated technological growth?
  - This should be an early recommendation for developers to consider adding extra sensors within wind farm operations.
- Is there a push for developing a collaboration program between the East and West Coasts on these environmental studies related to offshore wind energy?
  - There may be a group like this (American Clean Power Association may have more initiative), but the presenter was not certain.
- To ensure consistent information, it's important to engage in dialogue about the requirements of data collection. It may be beneficial to establish a centralized repository of information alongside regional portals.

2.4 Presentations: Wind Wakes

2.4.1 Shannon Davis, DOE: *Winds Energy Synergies with Coastal Upwelling Research*

Dr. Shannon Davis of the Department of Energy (DOE) emphasized DOE's efforts to reduce uncertainty in various ways, including through assessment of the wind resource, its long-term variability and the related environment, advancing atmospheric computational tools, and analyzing deployment risks. West Coast deployment challenges include floating wind turbines, deep water installation, new wind-wave regimes, and greater influences of clouds. The Wind Forecast Improvement Project 3 (WFIP3) addresses some of these challenges off the East Coast through extensive field observations and numerical modeling experiments to determine best practices and considerations for deployments.

Synergies with coastal upwelling research include improving air-sea model methodology, environmental analyses, artificial intelligence and machine learning applications, and forecasting. Dr. Davis described the Observationally Driven Resource Assessment with CoupLEd models (ORACLE) project, which is focused on the West Coast and combines observations, satellite data, machine learning, and high-resolution modeling to carry out analyses that support the floating offshore wind industry. Future work includes a new approach to inferring upwelling strength from surface heat flux and assessing the impact of marine clouds on the offshore wind industry. Dr. Davis concluded by highlighting DOE's collaboration with other agencies and organizations, such as through the ACE-FWICC program (Addressing Challenges in Energy: Floating Wind in a Changing Climate), which looks at impacts of different wind farm build-outs and how this impacts levelized cost of energy.

Questions:

- Explain the potential challenge posed by clouds.
    - Presently there is not a lot of great offshore precipitation data on either coast. DOE seeks to observe how clouds off the West Coast could impact turbulence in the lower atmosphere; it may be a significant factor for wind velocity profiles offshore.
- What are DOE's plans to implement wind farms in ocean-atmospheric modeling experiments (such as ORACLE)?
    - The East Coast is starting to explore the potential of its underdeveloped resources, particularly focusing on offshore wind. The Floating Offshore Wind Shot will look at impacts of wind farm buildouts on both coasts. All relevant datasets are consistently accessible to the public through the wind data hub's model output layer.

2.4.2 Julie Lundquist, University of Colorado Boulder: *Representation of wind farm wakes in models*

Dr. Julie Lundquist described the anatomy of a wind wake, with two key components being enhanced turbulence and momentum deficit. She explained that wind wakes vary with the stability of the atmosphere. If the atmosphere is stably stratified, wind wakes are pronounced, follow topography (demonstrated via animation), and reach the surface of the water; if the atmosphere is unstable, then wind wakes are lofted above topography (animation) and do not reach the surface of the water. Wakes may persist for up to 100 km offshore according to Synthetic Aperture Radar (SAR) data, which detects changes in the microwave emissivity of the surface.

Dr. Lundquist explained that turbines and their wind wakes can be represented in atmospheric models in different ways, depending on the spatial scale of the model. She used mesoscale simulation animations to show that offshore wind farm wakes vary with wind speed, wind direction, and atmospheric stability, and that power generation/loss is linked to these variables as well. To capture the complexities of individual turbine wake effects, large-eddy simulations are required. At the end of her presentation, Dr. Lundquist highlighted open questions and needs:

- Need: more validation of mesoscale wind farm parameterizations
- Question: How do wind wakes from floating wind turbines differ from those from fixed-bottom turbines? (likely smaller and less coherent due to turbine displacements from waves/surge)

- Question: Does the varying nature of wakes offshore disrupt the formation of secondary circulations in the water forced by wakes?
- Question: Can approaches like wake steering used to manipulate wakes onshore to maximize power production also minimize wake impacts on ocean circulations?
- Question: How can we better validate wake model parameterizations?
- Need: more observations to help assess how wind wakes affect the surface ocean

Questions:

- Are there changes in surface heat flux in addition to changes in momentum flux due to the wind wake?
    - Researchers are currently assessing how wakes influence both surface heat fluxes and surface momentum fluxes. Depending on whether or not the simulations include coupling with an ocean model, the way these fluxes interact with the atmosphere changes, and so there is a lot of variability in the answers.

2.5 Presentations: Ocean Observations

2.5.1 Dan Rudnick, SIO: *Annual and interannual variability observed by the California Underwater Glider Network*

Dr. Dan Rudnick of the Scripps Institution of Oceanography (SIO) presented an overview of underwater gliders and the types of sensors carried by these gliders. Variables measured include pressure, temperature, salinity, velocity and acoustic backscatter, chlorophyll fluorescence, dissolved oxygen; and more recently, pH, nitrate, optical backscatter, downwelling irradiance, turbulent dissipation, carbon dioxide concentration, and passive acoustics. The California Underwater Glider Network consists of 5 operational lines that can capture annual cycles and interannual variability of these variables. Targeted phenomena include El Nino-Southern Oscillation, marine heat waves, and salinity signals.

Lines 66.7 and 80.0 bracket the Morro Bay wind energy lease area and are capable of observing large scale changes in the region. However, smaller-scale changes, such as at the scale of the lease area, will not be resolved by these glider lines. Dr. Rudnick proposed that an optimized observing system for the wind lease area could combine gliders for spatial coverage with moorings to also capture higher frequency variability.

Questions:

- Are there sufficient measurements of biogeochemical properties from gliders, such as chlorophyll fluorescence of the ocean, to validate or confirm satellite data and inform other oceanographic calibration efforts?
    - The gliders do measure chlorophyll fluorescence. Calibration of the sensors can be a challenge sometimes, in which case we use satellite observations to enforce consistency between the sensors.

2.5.2 Jack Barth, OSU: *Ocean Observations: Southern Oregon and Northern California*

Dr. Jack Barth of Oregon State University (OSU) discussed the oceanographic setting of the Oregon coast and the existing southern Oregon and northern California glider lines (La Push, Washington Shelf, Newport, and Trinidad Head gliders). He highlighted glider capabilities and their ability to collect data while enduring harsh weather conditions without being tethered to the ocean floor. The Trinidad Head glider currently intersects the Humboldt wind lease area, and future ideas include developing 1-2 new glider lines that would map Oregon's Coos Bay and Brookings wind energy areas. Other future ideas include implementing additional sensors for acoustic monitoring of tagged species, as well as equipping gliders with passive acoustic hydrophones to record marine mammal activity and sounds associated with offshore wind energy development.

Questions:

- Why has the 100-year wave height increased from 10 to 15 meters?
    - Studies have shown that a change in storm tracks in the North Pacific allows more wind to blow and build waves as waves propagate across the basin to shore.

2.5.3 George Watters, NOAA SWFSC: *Monitoring the effects of wind-energy development off the coast of California*

Dr. George Watters of NOAA's Southwest Fisheries Science Center (SWFSC) introduced the new organization of the Center's Ecosystem Science Division (ESD), which has a wind-focused branch that aims to establish a long-term glider-based monitoring program. This program will span the ecosystem to observe variables that change quickly and are of interest to stakeholders, will grow in stages, and will link to longer existing time series datasets. This program will also meet the need for glider transects that capture upstream-downstream and onshore-offshore contrasts in wind speed in and around the wind lease areas. The draft of the first version of the monitoring plan will be completed summer 2024, and will consist of a ramp-up approach to building out glider lines in the California wind lease areas. They plan to start with a couple glider lines in Humboldt this year and begin collecting a wide range of ecosystem observations. This initiative will grow in stages over time and integrate with existing data sets.

Questions & Comments:

- Will this kind of reorganization be mirrored at the other fisheries science centers?
    - Other fisheries science centers have ecosystem science divisions, but it is unclear if/how they plan to integrate wind research into those other divisions.
    - In the Northeast Fisheries Center, there is an offshore wind branch staffed by people with different scopes working with other programs.
- There is a need for the Morro Bay program to develop relationships with other entities, such as universities and communities, including the Suquamish Tribe.
    - Suggestion to consider the scheduled offshore wind drinks group as a potential opportunity to establish relationships, meet contacts, and foster collaborations.
- What is the plan to include nitrate and pH sensors on the gliders?
    - It is possible to include these sensors. We have to collaborate with Dan Rudnick on this, he is the one pioneering sensors on gliders.
- In terms of the questions of how many gliders, and for how long they are deployed: how far along are you in the planning process of the monitoring program?
    - We have just started to scratch the surface. Understanding the Trinidad Head line is something we want to lead to, and we want to make lines as long as it makes sense to. We have not yet decided how many gliders and for how long.

2.5.4 Henry Ruhl, MBARI/CeNCOOS; Synchro: *Overview of a Regional Observation System and its Capabilities*

Dr. Henry Ruhl of the Monterey Bay Aquarium Research Institute (MBARI) introduced the Central and Northern California Ocean Observing System (CeNCOOS), which is certified by NOAA to be an integrator of data and observations. They focus on the entire data lifecycle, deploying gliders, radar systems, and monitoring stations along the coast to collect data on various phenomena. CeNCOOS collaborates with Synchro, a co-design lab and test bed focused on Monterey Bay, to synchronize and evolve technology for industry, ocean science, and conservation. Synchro is leading an offshore wind pilot study that evaluates technology for offshore wind industry baseline and impact assessment, with two years of fieldwork beginning in March 2024. This pilot study would apply tools to investigate potential impacts of offshore wind development to upwelling along the California coast.

Questions & Comments:

- Is there a sustained wind measurement campaign or long-term wind area measurement plan?
    - Yes, there are some studies conducted that use Lidar to detect wind speeds (Pacific Northwest National Laboratory's Lidar Buoy Program). Beyond that, the presenter is not aware of an organized effort to conduct atmospheric viewing for these efforts.
- Jack Barth: This seems like an "all-hands-on-deck" situation, where we should all come together to figure out how best to monitor offshore wind development.
    - Yes, this is an open and evolving project and we are trying to identify ways to remove barriers to access and participation.

2.6 Discussion: Observation Synthesis

Following presentations on the Study Introduction, Government and Industry Perspectives, Wind Wakes, and Ocean Observations, attendees engaged in a group discussion focused on observational monitoring strategies. Questions that prompted the discussion addressed the types of technology and sampling resolution required to monitor offshore wind impacts, how this strategy could include investigating wind farm-scale and turbine-scale impacts, and how this strategy could also capture expected changes due to natural variability in the region. Other questions included whether existing observing infrastructure is sufficient for future needs, and whether observing needs would vary during the different stages of wind farm construction.

The following section provides a brief synthesis of key discussion threads, organized by theme. Both in-person and virtual attendees participated in this discussion.

2.6.1 Technology and sampling methods required to monitor offshore wind impacts on upwelling

- Autonomous underwater vehicles/gliders/Saildrone: Consistent and repeated gliders are needed with increased sampling around wind farms than is currently available. Gliders are ideally complemented by other platforms.
- Buoys: Deploy buoy arrays near and upwind of wind farms for surface wind observations, integrating data with the Global Telecommunication System to improve ocean and atmospheric models and enhance weather predictions.
- Lidar: Many developers are utilizing Lidar buoys, which measure the vertical wind profile, for site characterization. To enhance anomaly detection, consider outfitting buoys with Lidar up to turbine hub height, but be aware that sharing this data may require exclusive arrangements with developers due to its proprietary nature. Integrating Lidar and other non-public data into specific tools is recommended, along with advocating for a West Coast buoy system and Lidar program. DOE noted they have a program where buoys can be leased.

- Wirewalkers/crawlers: Explore the potential of incorporating technology onto offshore wind infrastructure (platforms/cables): install Wirewalkers powered by wave energy or crawlers onto existing cables.
- Argo floats: Argo Float program aims at monitoring and collecting data on the temperature and salinity of the world's oceans via a fleet of drifting robotic instruments; these data are freely and openly available. This systemic approach may inform long-term design strategies for ocean monitoring and research.
  - Determine the desired sampling resolution, adapt coastal floats for repeated profiling, and employ smart sampling strategies with multiple floats at different times to do repeated vertical structure analysis. Could modify/adapt sampling regime depending on conditions.
- Ship-based:
  - Consider incorporating biogeochemical sensors on commercial ships/wind farm maintenance ships. https://imos.org.au/facilities/shipsofopportunity/biogeochemicalsensors
  - Gather insights from planned atmosphere/ocean boundary layer measurements of the DOE WFIP3 field work off Massachusetts. They intend to moor a barge (temporarily) and take measurements from there as well as island-based measurements including scanning systems measuring winds over water. Challenges include designing cost-effective mooring programs that could measure wind wakes as their spatial extents change and whose directions cover all 360 degrees.
  - Consider whether sampling via nets is necessary – requires ship time and is expensive, but provides detailed information. Shadowgraph images may be a more cost-effective option.
- Installing sensors onto offshore wind infrastructure: Many people want to add sensors to infrastructure, but it is challenging for the developer to consider installation, maintenance, data communication, etc. The level of interest depends on the wind developer; lease stipulations encourage coordination among developers, highlighting the need for thoughtful infrastructure development.

2.6.2 Monitoring wind fields is key

- Several participants stressed the importance of monitoring the wind field in and around offshore wind farms, since altered winds are responsible for changes in upwelling (Raghukumar et al. 2023) and oceanic vertical mixing.
- Mike Jacox asked whether wind farms would be represented in operational weather models (e.g., High-Resolution Rapid Refresh), which are used to produce the wind fields that drive California Current regional models. If they are not, then wind farm-induced impacts might not be captured in ocean models that are forced by these wind products.
- Some of the possible wind sensors are listed above (buoys, Lidar).

2.6.3 Sampling resolution required to monitor offshore wind impacts on upwelling

- Determine if the current frequency of data collection is good enough to detect changes, and what the key variables to monitor during these processes are (temperature, salinity, chlorophyll, etc.). High-Resolution Forecasting (HRF) measurements may aid in detecting change as well.
- Consider discrete events that need to be monitored: there are concerns about marine aggregation under platforms – there can be misalignment between sampling schedules and biological events,

such as fish migration or bloom events that would require more frequent sampling, but for a shorter period of time.

- Data assimilation systems and OSSEs can be utilized to help determine sampling requirements.

2.6.4 Monitoring offshore wind impacts in the context of natural variability

- What is the magnitude of the signal we are looking for? And how big is it with respect to natural variability? We need to have good modeling studies to help us understand the scale of the wind farm effect before deciding what to deploy to observe it.

2.6.5 General challenges

- We cannot design an observing system without knowing what types of variables we need to monitor; there is currently no criteria for what is considered an acceptable impact on the marine environment. We need to come together to develop a set of standardized data needs that can be shared with lessees: what types of observations, at what scale, at what level of precision. There is a sense of urgency for the West Coast since construction is 5–10 years out. We need to collect baseline data in advance to know the normal background state and to be able to attribute impacts of structures vs. climate variability/change to the system.
- It is difficult to determine the reference frame for assessing impacts of offshore wind in the lease area.
- As offshore wind development progresses, we need to be able to disentangle changes that are happening with or without offshore wind, like climate change.
- Before constructing a wind farm, an EIS is required to state potential impacts and address stakeholder concerns. An EIS is normally carried out at the site level (unless programmatic) and includes discussion of cumulative impacts of current activities, but stakeholders are interested in the cumulative impacts of multiple sites that will be constructed in the future. The Programmatic EIS for NY Bight is underway (more regional approach), and it is attempting to standardize impacts. Cumulative impacts are tricky as it depends on what is already built and what can be analyzed (not forward-looking).
- There is a disconnect between NEPA review scope (usually site-specific, with discussion of cumulative impacts including current activities) and stakeholder interests (cumulative impacts of current and future activities.
- Site impact assessments are not addressing wake effects, only focusing on the site itself – wake effects could extend beyond the site and may not be easily captured in the planned studies.
    - There have been some efforts to take the regional approach to assessing impacts: current efforts on the East Coast, such as ROSA (Responsible Offshore Science Alliance) and RWSC (Regional Wildlife Science Collaborative), aim to view the region holistically, including oceanographic impacts on different species.

2.7 Presentations: Modeling

2.7.1 Mike Jacox, NOAA SWFSC: *Offshore Wind Farm Impacts on Pacific Upwelling, Nutrients, and Productivity*

Dr. Mike Jacox presented on the ongoing BOEM-funded, NOAA Fisheries/Integral Consulting-led study (BOEM 2023), which aims to evaluate the potential impacts of California (and potentially Oregon) offshore wind development on upwelling and biogeochemistry through model simulations, and compare these simulated biogeochemical impacts to those projected to take place due to climate change. This study improves on the previous California Current upwelling modeling study conducted by Integral Consulting (Raghukumar et al. 2023) by explicitly modeling biogeochemistry (adding the North Pacific Ecosystem Model for Understanding Regional Oceanography [NEMURO] biogeochemical model) and focusing on a larger domain at 1/30 degree resolution. This study also incorporates updated wind farm build-out scenarios including larger turbines than the previous study (15 MW vs. 10 MW). Dr. Jacox emphasized that it would be worth exploring how wind farm impacts compare to climate change impacts (without wind farms) on California Current hydrodynamics and biogeochemistry.

Questions & Comments:

- Support was shared for framing the model in the context of climate change.
- Can the Mendocino WEA be included in the model?
  - No, that area is not far along enough in the process to date.
- Can you put the simulated vertical velocity changes due to climate change (from Pozo Buil et al. 2021) in the context of the simulated CUTI (Coastal Upwelling Transport Index) changes due to wind farms from Raghukumar et al. (2023)?
  - The wind farm vertical velocity changes are comparable to those from climate change if we integrate upwelling from the coast to the center of the wind wake (which gives maximum signal). However, you get less net impact from wind farms when you look closer to shore or when you integrate farther offshore (due to the compensating increase in upwelling offshore of the wind farm).

2.7.2 Chris Edwards, UCSC: *UCSC Modeling Systems*

Dr. Chris Edwards of the University of California Santa Cruz (UCSC) discussed various UCSC modeling systems, their approaches, and capabilities. He focused on data assimilation systems, which are powerful models that provide near-real-time estimates of physical and biogeochemical states at 1/10-degree resolution. These systems require observations, however, and the ocean is under-sampled. When evaluating different types of observations, glider observations have the largest impact on a per datum basis on upwelling and alongshore transport metrics (Moore et al. 2011, 2017). Dr. Edwards recommends generating more atmospheric and ocean observations from both gliders and moorings to improve the performance of these data assimilative systems.

Questions:

- Is array data being used?
  - We are assimilating glider data, but not mooring data.
- Gliders are one of the few observational tools that provide a vertical structure of the water column. Researchers, particularly at UCSC, are interested in comparing this vertical structure data obtained from gliders with surface-based observations to understand how well surface observations match the vertical structure of the ocean. What are current thoughts on exploring the implications of these comparisons?
  - The Navy is employing the Navy Coupled Ocean Data Assimilation (NCODA) system to establish statistical relationships between vertical profiles and satellite data. We are aware of these possibilities but are focusing on direct observations. The idea of “pseudo-observations” is being explored to address data gaps such as in carbonate chemistry research due to limited observational data.

2.7.3 Thomas Peacock, MIT & atdepth MRV: *Human Interventions in the Ocean: Bridging the Near-Field Gap*

Dr. Thomas Peacock of Massachusetts Institute of Technology (MIT) emphasized the need to investigate key baseline hydrodynamic processes at the wind turbine scale (referenced the National Academies report). He discussed the importance of using near-field modeling to better understand the hydrodynamic impact of a wind turbine — ocean currents moving past a submerged structure like a monopile or floating substructure results in highly localized turbulent mixing in the wake that cannot be resolved by regional ocean models. However, near-field modeling is very expensive and challenging. Dr. Peacock highlighted atdepth MRV's approach of using novel, open-source GPU-based modeling packages that can speed up computation and lower costs for modeling offshore wind turbine and wind farm-scale hydrodynamics. One example of this is the Oceananigans non-hydrostatic ocean model (developed by the Climate Modeling Alliance [CliMA]), and OceanBioME (biogeochemistry package). atdepth MRV has applied near-field modeling to look at impacts of deep seabed mining, specifically the related plume signals and gravity currents. This could have applications to cable-laying scenarios for offshore wind development. atdepth MRV aims to better quantify/assess human intervention in the ocean and is building a multi-scale ocean simulation platform to provide scalable quantification of those interventions.

Questions:

- Has there been progress beyond considering the concept of monopiles to something like the three-cylinder platforms off the coast of Oregon?
    - We would like to work with real geometries and scenarios and see what near-field modeling can do that has not been done yet. We are interested in exploring other geometries in the future.
- Have cumulative impacts of multiple wind farms been considered?
    - This idea would involve running simulations at a certain resolution within an area that spans multiple kilometers. It is possible to simulate a wind farm scenario with several structures included and would require a certain level of resolution to accurately capture the associated dynamics and impacts.
- For the nested approach, are you planning to use terrain-following coordinates?
    - We are not using terrain-following coordinates, but rather a partial cell-filling approach to manage complex bathymetry.
- Can you comment on whether ocean-atmosphere coupling at such high resolution would be necessary to understand monopile impacts?
    - I would defer to the Oceananigans team; atmospheric-ocean coupling is currently at the regional level, and does not yet exist at the near-field scale. .

2.7.4 Hyodae Seo, WHOI: *"Coupled" Effects of Offshore Wind Farms*

Dr. Hyodae Seo of the Woods Hole Oceanographic Institution (WHOI) discussed a coupled ocean-atmosphere modeling approach to understanding the impacts of offshore wind farms. This means that any changes in ocean conditions caused by wind wakes can in turn influence the atmosphere/wind field. His work is focused on the Atlantic offshore wind farms (Massachusetts and Rhode Island lease areas) and uses the 1.5-km resolution SCOAR WRF-ROMS-WW3-CICE regional coupled modeling system to resolve wind wakes and their impacts.

Dr. Seo finds that there is an increase in SST of about 0.3°C in the area of the wind farms resulting from this coupled ocean-atmosphere interaction. There is an upward heat flux anomaly of ~5 W m^2 (i.e., the heat flux anomaly does not drive the SST anomaly). While this increase in SST was found not to impact the wind field at hub height, it does impact the wind stress and heat flux, which in turn alters the atmospheric boundary layer structure. This leads to questions regarding additional unknowns to represent the ocean effect in wake parameterization and the design of observing strategies to monitor the ocean response and air-sea flux near wakes.

Questions:

- Can ocean-atmosphere coupling amplify the wind turbine effects in certain situations?
  - Certain aspects like boundary layer height may amplify, but there is uncertainty; we are currently investigating this.
- Why was the data simulated for June, July, and August?
  - It is easier to detect impacts in summertime. Wintertime is a highly chaotic system with very strong winds and currents, and requires a longer simulation to see any impacts. You still see SST warming even in wintertime. Additionally, the strongest wake effects occur in summertime in this region (Rosencrans et al. 2024).
- Is the generation of the SST anomaly more mechanical?
  - Typically, generation processes involve stresses, ocean stratification, and heat fluxes exiting the ocean, which usually result in cooling, particularly during winter due to differences in mixing.

2.8 Discussion: Modeling and Overall Synthesis

Following the four modeling presentations, attendees engaged in a group discussion focused on model-based techniques of assessing potential offshore wind impacts, as well as an overall synthesis of the topics covered that day. Questions that prompted the discussion addressed the knowledge gaps that remain in our understanding of potential impacts of offshore wind development on California Current upwelling and ecosystem and how future modeling studies can inform observational monitoring plans.

The following section provides a brief synthesis of key discussion threads, organized by theme. Both in-person and virtual attendees participated in this discussion.

2.8.1 Knowledge gaps of current modeling studies

- Need to consider how floating wind farms should be parameterized differently from fixed-bottom wind farms.
- Need to model ocean-atmospheric coupling effects across the West Coast region.
- Need to capture near-field physics to resolve turbine-scale (meter-scale) changes (e.g., new GPU-based modeling tools, which can run in near real time to enable adaptive management and inform decision making).
- Need to model multiple structures together to further understand the cumulative impacts of current and future projects.
- Need to determine the appropriate model spatial resolution for various scales, especially to understand the effect of the wind farms at the mesoscale. If you run the model at a different resolution, you may get a different answer (see Tomaszewski and Lundquist 2020).
- There is currently a lack of consideration for factors such as buoyancy-driven flows and turbidity, which are important for assessing sediment disturbance during system installation: need to incorporate sediment disturbance modeling.
- Consider the offshore wind impacts on the California Current System as it relates to fisheries, economics, migration pathways, and spawning areas.

- Models only capture previous wind energy area determinations, not future. Ideally we could use BOEM wind energy areas in 2040 to help look at cumulative impacts and the big picture.
- Consider using wind turbine configurations other than maximum buildout.
    - Systematic modeling studies on wind turbine wakes may provide insights into various scenarios and their sensitivity to changes in the number of turbines. Expand the size or density of wind farms in models to help determine the number of turbines needed for sustainable climate impacts, for characterizing atmospheric wakes, and for assessing the viability of wind farms.

2.8.2 Modeling can inform observational monitoring plans

- Data assimilation in models is essential for filling observational gaps; but without continuous monitoring, the system's ability to detect changes is limited, relying solely on the data it receives.
- Combining observational data with modeling techniques can enhance prediction and understanding of the system's statistical behavior. Current efforts involve using models to predict float deployment locations in coastal environments and advancing model statistics through observation simulation software.
- How much does knowledge of near-field dynamics influence large scale predictions? Think strategically about where it is less/more important and easier/harder to parameterize – similarly, ask whether we need to get observational data in specific locations in wind farm, or if data points elsewhere are sufficient (when working with limited resources/funding).
- Incorporate the OSSE approach: an OSSE uses models to test different designs of the new observing system before instruments are actually built/deployed, and to compare the performance of the new instruments against the current observing platforms. The results of the OSSE can help guide the design and determine cost-effectiveness of new instruments/systems. OSSE requires metrics for evaluation, which can often be subjective; process studies could help identify the best metrics to use. Suggest incorporating this approach alongside simulation studies.
    - Use modeling techniques to determine the efficiencies of gliders and to determine if additional routes are needed to assess wake effects.
    - Adjust models to simulate how real observing platforms would gather data from the surrounding environment.

2.9 Closing Remarks

Dr. Tom Kilpatrick, BOEM, thanked attendees for engaging in a productive discussion and thanked those who provided informative presentations. A workshop summary report will be posted on the BOEM website.

2.10 Next Steps

Outcomes of this workshop will be presented at upcoming conferences (including, but not limited to, the Ocean Observing in California Joint Meeting hosted by SCCOOS [Southern California Coastal Ocean Observing System], CeNCOOS, and CalCOFI [California Cooperative Oceanic Fisheries Investigations] in May 2024) and will inform future discussions regarding the monitoring and modeling of potential hydrodynamic impacts of offshore wind development in all regions.

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Appendix A: Workshop Agenda

Time	Agenda Item	Lead
Monday, March 4		
8:45-9:00 am	**Welcome and Opening Remarks**	Jenna Tourjé-Maldonado, *Kearns & West Facilitator* Tom Kilpatrick, *BOEM*
9:00-9:25 am	**Study Introduction** Projected cross-shore changes in upwelling induced by offshore wind farm developing along the California Coast	Kaus Raghukumar, *Integral Consulting*
9:25-10:15 am	**Government and Industry Perspectives** Pacific Region Renewable Energy Overview Offshore Wind R&D Overview Equinor Renewables Americas	Rick Yarde, *BOEM Pacific* Daphne Molin, *CEC* Michelle Fogarty, *Equinor Wind US*
10:15-10:30 am	*Break*	
10:30- 11:10 am	**Wind Wakes** Wind Energy Synergies with Coastal Upwelling Research Representation of Wind Farm Wakes in Models	Shannon Davis, *DOE* Julie Lundquist, *CU Boulder*
11:10-11:50 pm	**Ocean Observations I** Annual and interannual variability observed by the CA Underwater Glider Network Existing northern CA and OR glider lines	Dan Rudnick, *SIO/UCSD* Jack Barth, *OSU*
11:50-12:50 pm	*Lunch*	
12:50-1:35 pm	**Ocean Observations II** Monitoring the Effects of Wind-Energy Development Off the Coast of CA Overview of a Regional Observation System and its Capabilities	George Watters, *NOAA SWFSC* Henry Ruhl, *MBARI/CeNCOOS; Synchro*
1:35-2:30 pm	**Observation Synthesis Discussion**	All
2:30-2:40 pm	*Break*	
2:40-4:00 pm	**Modeling** Offshore Wind Farm Impacts on Pacific Upwelling, Nutrients, and Productivity UCSC Modeling Systems Human Interventions in the Ocean: Bridging the Near-Field Gap "Coupled" Effects of Offshore Wind Farms	Mike Jacox, *NOAA SWFSC* Chris Edwards, *UCSC* Thomas Peacock, *atdepth* Hyodae Seo, *WHOI*
4:00-4:45 pm	**Modeling and Overall Synthesis Discussion**	All
4:45-5:00 pm	**Closing Remarks**	Jenna Tourjé-Maldonado, KW

Appendix B: Workshop Participants

In-person Participants	Virtual Participants
Juan Cabrera, *Kearns & West*	Jack Barth, *Oregon State University*
Grace Chang, *Integral Consulting Inc.*	Larry Berg, *Pacific Northwest National Laboratory*
Chris Edwards, *University of California Santa Cruz*	Gregory Britten, *WHOI*
Jerome Fiechter, *University of California Santa Cruz*	Mark Danielson, *California Energy Commission*
Jessica Garwood, *Oregon State University*	Shannon Davis, *DOE Wind Energy Technologies Office*
Kenneth Hughes, *Oregon State University*	Rikki Eriksen, *California Marine Sanctuary Foundation*
Mike Jacox, *NOAA SWFSC*	Colette Fletcher-Hope, *DOE Wind Energy Technologies Office*
Tom Kilpatrick, *BOEM*	Michelle Fogarty, *Equinor Wind US*
Alice Kojima, *BOEM Pacific*	Alex Harper, *CeNCOOS*
Julie K. Lundquist, *University of Colorado Boulder*	Raghu Krishnamurthy, *Pacific Northwest National Laboratory*
Daphne Molin, *California Energy Commission*	Naomi Lewandowski, *DOE Wind Energy Technologies Office*
Tommy Moore, *Northwest Indian Fisheries Commission*	Zhen Li, *BOEM*
Kaus Raghukumar, *Integral Consulting Inc.*	Matt Mazloff, *University of California San Diego*
Henry Ruhl, *MBARI/CeNCOOS; Synchro*	Robert Mazurek, *California Marine Sanctuary Foundation*
Hyodae Seo, *WHOI*	Megan Medina, *SCCOOS*
Jenna Tourjé-Maldonado, *Kearns & West*	Carlos Muñoz-Royo, *atdepth MRV*
Bianca Valdez, *Kearns & West*	Chris Orphanides, *NOAA Fisheries*
Stephanie Webb, *BOEM*	Joy Page, *DOE Wind Energy Technologies Office*
Rick Yarde, *BOEM Pacific*	Thomas Peacock, *MIT & atdepth MRV*
	Christian Reiss, *NOAA SWFSC*
	Dan Rudnick, *Scripps Institution of Oceanography*
	Yi-Hui Wang, *California Ocean Protection Council*
	George Watters, *NOAA SWFSC*

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DOI protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
BOEM's mission is to manage development of U.S. Outer Continental Shelf energy, mineral, and geological resources in an environmentally and economically responsible way.