[DRAFT]

CALIFORNIA OFFSHORE WIND ENVIRONMENTAL MONITORING FRAMEWORK

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ABOUT THIS REPORT

This report was collaboratively developed by the California Marine Sanctuary Foundation (CMSF), with input from over 200 scientific experts, in coordination with the California Ocean Protection Council (OPC) and the California Department of Fish and Wildlife (CDFW). The Framework authors received targeted input from additional contributors and state agencies. This document is a state-wide framework presenting conceptual structures and guidance for developing monitoring plans for taxa and habitats potentially affected by floating offshore wind (OSW). It will serve as a foundational resource for the OSW community in California, enabling informed decision-making to minimize and mitigate negative impacts on marine ecosystems and coastal communities.

This Framework is founded in scientific process and was developed to support the goals of California's AB 525 Strategic Plan. This document is not: a regulatory document, a comprehensive literature review, a prescriptive one-size-fits-all checklist, nor an impact assessment.

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ABOUT CMSF

CMSF has championed science-based solutions to protect ecosystems and strengthen community resilience for over 30 years, bridging the gap between scientific research and sustainable ocean management.

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- Habitats and Ecosystems
- Oceanography
- Marine Mammals and Sea Turtles
- Marine Birds and Bats
- Fish and Invertebrates
- Data and Technology

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CALIFORNIA OCEAN PROTECTION COUNCIL

List of Acronyms

AB 525: Assembly Bill 525 (California state legislation)
ADCP: Acoustic Doppler Current Profiler
AI: Artificial Intelligence
AIS: Automatic Identification System
AUV: Autonomous Underwater Vehicle
BA: Biological Assessment
BACI: before-after-control-impact
BOEM: Bureau of Ocean Energy Management
BSEE: Bureau of Safety and Environmental Enforcement
CalCOFI: California Cooperative Oceanic Fisheries Investigations
Cal Poly: California Polytechnic State University, San Luis Obispo
CCC: California Coastal Commission
CCLME: California Current Large Marine Ecosystem
CCMP: California Coastal Management Program
CD: Consistency Determination
CDFW: California Department of Fish and Wildlife
CEC: California Energy Commission
CeNCOOS: Central and Northern California Ocean Observing System
CEQA: California Environmental Quality Act
CMSF: California Marine Sanctuary Foundation
CSLC: California State Lands Commission
CZMA: Coastal Zone Management Act
DMSP: Data Management and Sharing plan
DVM: Diel Vertical Migration
EA: Environmental Assessment
EFH: Essential Fish Habitat
EMF: Electromagnetic Field
EPAct: Energy policy Act of 2005
ESA: Endangered Species Act
FAD: Fish Aggregating Device
GAP: General Activities Plan
GIS: Geographic Information System
HAB: Harmful Algal Bloom
HLT: Heavy Lift Terminal
HRG: High Resolution Geographic Survey
IOOS: Integrated Ocean Observing System
IPF: Impact Producing Factor
IUCN: International Union for the Conservation of Nature

MBES: Multibeam Echosounder
MOCEAN: Mission Being the Ocean
MMPA: Marine Mammal Protection Act
MPA: Marine Protected Area
MSIR: Marine Site Investigation Report
MQ: Monitoring Question
MWCP: Marine Wildlife Contingency Plan
NEPA: National Environmental Protection Act
NGO: Non-Governmental Organization
NMFS: National Marine Fisheries Service, also known as NOAA Fisheries
NOAA: National Oceanic and Atmospheric Administration
N-PAcT: Northeast Pacific Acoustic Telemetry
OCS: Outer Continental Shelf
OCSLA: Outer Continental Shelf Leasing Act
OPC: Ocean Protection Council
OST: Ocean Science Trust
OSW: Offshore Wind
PAM: Passive Acoustic Monitoring
PDO: Pacific Decadal Oscillation
PEA: Preliminary Environmental Assessment
PEIS: Programmatic Environmental Impact Statement
PISCO: Partnership for Interdisciplinary Studies of Coastal Oceans
QA/QC: Quality Assurance / Quality Control
REEF: Reef Environmental Education Foundation
ROI: Return on Investment
ROSA: Responsible Offshore Science Alliance
ROV: Remote Operated Vessels
RSZ: Rotor Swept Zone
RWSC: Regional Wildlife Science Collaborative
SAP: Site Assessment Plan
SCCOOS: Southern California Coastal Ocean Observing System
SCP: Scientific Collecting Permit
SPI: Environmental Sample Collectors - Sediment Profile Imagery
SWRCB: State Water Quality Resources Control Board
TEK: Traditional Ecological Knowledge
UAS: Uncrewed Aerial Systems
USFWS: United States Fish and Wildlife Service
USGS: U.S. Geological Service
WEA: Wind Energy Area
WG: Working Group

Glossary of Terms

Pre-construction baseline refers to information about a species and/or relevant environmental factors that aid in understanding and characterizing the prior state or condition of an ecosystem or its component before an introduced disturbance. In this document, pre-construction baseline data will serve as a reference for assessing the impacts of floating OSW construction and operations.

De Facto MPAs are areas where activities are restricted by law for reasons other than conservation or natural resource management.

Energetic costs refer to the amount of metabolic energy an organism must expend to perform a specific activity, maintain bodily functions, or adapt to its environment. Each marine species operates on an "energy budget." If an organism spends too much energy on one activity, it has less available for survival and reproduction.

Exposure is defined as the degree to which a species or habitat encounters floating OSW impact-producing factors and stressors.

Impact refers to a change or response resulting from exposure to specific conditions, stimuli, or an impact-producing factor. The observed change is a departure from the prior state, original condition, or baseline situation.

Impact-producing factor (IPF) is defined as any specific element, activity, or physical component of a project that has the potential to cause a measurable change, either beneficial or adverse to the marine environment or its biological receptors.

Intensity - Relative significance of impacts. It describes the magnitude of an impact on the environment. It gauges how substantial the elicited change is.

Marine birds refer to all species that spend substantial time foraging in the waters of the CCLME; coastal species that do not use marine habitats, and species that only transit over the ocean during migration (e.g., songbirds and most shorebirds) were excluded.

Mitigation refers to actions taken to avoid, minimize, rectify, reduce, or compensate for environmental impacts.

Monitoring is a type of systematic data and observation collection aimed at detecting change. OSW monitoring can also be used to assess potential impact risks and test scenarios (ahead of construction/operations), to inform the mitigation of impacts (during operations), and to support adaptive management practices.

Population - a group of the same species or smaller taxa in a common spatial arrangement that interbreed when mature." The term "population" is also sometimes used to mean a smaller geographic subset of a species that is being separately considered for research, management, or mitigation purposes. Also defined as a group of individuals of the same species that live and interbreed within a specific geographic area.

Population-level impact - A change in a demographic rate (such as survival or reproduction) that is sufficient to affect the overall abundance, trends, or persistence of a population.

Probability - The qualitative likelihood that the impact will affect the population, considering the biological, spatial, and temporal overlaps.

Monitoring Questions (MQs) - the specific, targeted inquiries or objectives that should guide effective monitoring data collection and analysis. These questions are designed to focus monitoring efforts on outcomes or issues, ensuring that the data gathered aligns with the goals of the impact monitoring program. These are related to an intersection between IPF and impact.

Reef Effect - tendency of human-made, submerged structures (e.g., OSW foundations) to act as artificial reefs.

Research questions - specific, exploratory, or hypothesis-driven inquiries that guide scientific investigation. Unlike monitoring questions, which are often focused on routine data collection for defined outcomes, research questions aim to address uncertainties, expand the boundaries of knowledge, and explore new concepts or methodologies

Risk refers to the probability and intensity of the impact.

Risk assessment is the systematic, relative evaluation of a taxon or system's potential exposure to the impacts and consequences of such exposure, considering species-typical, contextual, and ecological factors.

Sensitivity - Refers to the degree to which a biological receptor (species, population, or habitat) is likely to exhibit a negative response to a specific stressor or Impact Producing Factor.

Vulnerability of a species refers to the probability of adverse effects from exposure to a stressor, and it may consider species sensitivity (e.g., low reproductive rates) and adaptive capacity (e.g., behavioral avoidance).

How to Use the Environmental Monitoring Framework

Navigating recommendations for the State for monitoring impacts from floating offshore wind in California.

This document is a state-wide framework presenting conceptual structures and guidance for developing monitoring plans for taxa and habitats potentially affected by floating OSW. It will serve as a foundational resource for the OSW community in California, enabling informed decision-making to minimize and mitigate negative impacts on marine ecosystems and coastal communities. This Framework is founded in a scientific process and was developed to support the goals of California's AB 525 Strategic Plan. **This document is not:** a regulatory document, a prescriptive one-size-fits-all checklist, nor an impact assessment.

The Framework is organized into sections for each Working Group: Data and Technology; Habitats, Ecosystems, and Oceanography; Marine Mammals and Sea Turtles; Marine Birds and Bats; and Fish and Invertebrates, which each build off the overarching framework sections.

Start Here

For context for understanding the report, we recommend all readers start at the **Framework Findings**

For a Broad Overview

Executive Summary: A concise, high-level summary of the key takeaways of The Framework's background, methods, results, and recommendations

Framework Recommendations

- **Data:** identify core principles for data collection, management, and sharing to ensure data quality, accessibility, and efficiency
- **Technology:** include suggestions to optimize monitoring technology use and enhance capabilities and availability of technologies
- **Overarching Foundational:** identified by all scientific WGs for pre- during-, and post-construction to inform best practices fundamental to the following WG specific monitoring recommendations
- **Impact-specific:** include an assessment of each sensor/data collector recommended for assessing each impact topic and associated monitoring questions with an exploration of opportunities, limitations, cost/effort, and monitoring initiatives where applicable

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Executive Summary

The California Offshore Wind Environmental Monitoring Framework (The Framework) provides a science-based foundation to guide the development of site-specific monitoring plans for species, habitats, and oceanographic processes that may be affected by floating OSW. The Framework identifies potential environmental impacts from OSW development, proposes relevant monitoring questions (MQs), and reviews available and emerging monitoring tools. It is not intended to be regulatory or prescriptive; instead, it serves as a flexible, statewide resource to support consistent and scientifically sound monitoring approaches that can be adapted to specific project sites.

The California Current Large Marine Ecosystem (CCLME) is a uniquely productive ecosystem driven by wind-powered upwelling that fuels major fisheries and diverse habitats. California's OSW lease areas extend past the continental shelf, requiring floating wind turbines to accommodate deep water. This technology has never been deployed at the scale anticipated in California, and therefore, will be an unprecedented application of OSW in a primary upwelling zone. As a result, the environmental impacts of floating OSW in California are unknown. In the absence of global guidelines for these novel conditions, the Framework presents a scientifically robust solution to address the unique monitoring needs of California's offshore environment.

The Framework was developed through collaboration with scientific experts across multiple disciplines, including oceanography, habitats, marine mammals, sea turtles, seabirds, bats, fish, invertebrates, data, and technology. This approach promotes a coordinated, practical method for monitoring that builds on existing knowledge while addressing important data gaps. Key strategies include expanding long-term datasets, establishing regional pre-construction baselines, and strengthening ocean observing systems to improve spatial and temporal coverage.

Ultimately, integrating physical and biological data is critical for separating potential OSW impacts from the natural variability of the ecosystem. By defining essential MQs, data needs, and methodologies at the outset of California's OSW development, the Framework provides the predictive, ecosystem-level foresight to scale up renewable energy while safeguarding the long-term health and resilience of California's marine environment.

Overarching Foundational Recommendations

Successful OSW management in California will require a coordinated, ecosystem-scale approach that spans the project lifecycle and integrates across taxa, habitats, and human uses. Distinguishing these impacts from natural variability and increasing climate-driven stressors, like marine heatwaves and acidification, will be exceptionally challenging, even with additional data collection. The following recommendations represent foundational, shared priorities across all Scientific working groups (WGs) to help address these challenges before in-water monitoring.

Synthesize, analyze, and leverage existing long-term monitoring datasets to understand natural variability, and inform analytical and statistical power analyses to strategically direct new investments to fill information gaps.

- Enhance and build upon the coordinated, statewide ocean observing networks (CalCOFI, CeNCOOS, SCOOS, ACCESS) that leverage and sustain existing long-term monitoring programs; specifically: integrate advanced, multi-modal sensors onto established monitoring platforms to fill critical spatial and temporal gaps and enable continuous, ecosystem-scale data collection across taxonomic groups and oceanographic variables.
- Expand available data on the seasonal distribution, density and behavior of priority species (e.g., beaked whales, offshore pelagic birds, forage species, endangered and threatened species) using integrated monitoring technologies. Establish regional pre-construction baselines across taxa and oceanographic systems to capture natural variability, spatial use, and key vulnerability periods prior to development. Effective baselines should integrate the longest feasible temporal data and draw from physical, chemical and biological monitoring efforts, datasets, and models to assess how oceanographic drivers influence the abundance and distribution of key species over time. These baselines, along with contemporary impact monitoring, will enable researchers to disentangle OSW-related impacts from natural variability in the CCLME.
- Establish responsive management frameworks by defining clear thresholds, triggers, and action pathways pre-implementation to ensure monitoring results (e.g., species displacement, habitat degradation, upwelling patterns) directly inform timely, transparent, and defensible decisions.
- Collect data in a manner consistent with long-term data integration and use for assessment of impacts, mitigation efficacy, and adaptive management.
- Provide a better understanding of existing stressors to evaluate cumulative and system-level impacts of OSW development.
- Utilize regional spatial analysis to map priority benthic and pelagic habitats and socio-ecological uses, informing OSW design to minimize conflict and mitigate impacts on sensitive environments.

- Require use of spatio-temporal risk assessment (an analytical framework that quantifies how marine life vulnerability changes fluidly across space and time). Because the CCLME is a highly dynamic oceanographic environment, static baseline maps are unlikely to provide a predictive basis for capturing how pelagic birds, bats, and marine mammals will interact with OSW infrastructure over time. By formalizing a dynamic method within the monitoring framework, management can move beyond rigid, permanent restrictions and instead deploy highly responsive, climate-smart adaptive management strategies.
- Incorporate socioeconomic indicators and human-use data into monitoring frameworks to assess coupled impacts of ecosystem change on biodiversity.
- Establish formal, multi-stakeholder coordination structures (e.g., https://rwsc.org/) to unify monitoring priorities and ensure seamless integration across government agencies, tribes, industry, commercial and recreational fisheries, coastal communities and the scientific community.
- Establish sustained, regional funding mechanisms to support long-term monitoring, data integration, and research that extend beyond the scope of individual projects.
- Strengthen experimental design and attribution: monitoring should implement standardized, statistically rigorous frameworks, such as Before-After-Control-Impact (BACI), using control sites and lifecycle-based comparative studies to ensure that established and emerging technologies provide sufficient power to detect scalable changes across taxa throughout all project phases. High priority species, habitats and processes should be the initial focus of monitoring.

Data & Technology Recommendations

Data are the heart of any monitoring program. Technology - including sensors, monitoring platforms, and analytical tools - enables data collection and helps transform data into actionable information. The Data and Technology WG assessed data and information systems, monitoring technologies, and standards across all expert WGs. Recommendations are guided by six foundational principles listed below. These principles are designed to be applicable to data from any source, public or private, and can serve as baseline criteria for evaluating all data collection and analysis activities under the Framework. Technology was evaluated based on suitability for target species, technical limitations, and cost-benefit analyses. Specific technology and data recommendations are in the sections for each species and habitat group. *For more in-depth Data and Technology recommendations see sections 2.5 and 3.7.*

Data Recommendations

To support monitoring effectiveness and efficiency, all OSW data activities should be evaluated for how well they address the following principles:

1. Transparent
2. Well documented & repeatable
3. Standardized to enable access & (re)use
4. Ethical & privacy protecting
5. Networked & interoperable
6. Fit for purpose

- Create a public catalog of OSW-related data collection projects to support coordination around the use of space, shared platforms, and common methods.
- Invest in pooled training data and open-source tools to improve AI models for data analysis, including image review and event detection, to speed up analysis times and reduce monitoring costs.
- Require data publication in existing public data repositories, with robust metadata that can be connected to a public data catalog.
- Prioritize auditable and open-source software for data collection and analysis to ensure transparency and reliability across all state-authorized projects.
- Establish minimum cybersecurity protocols for data collection, processing, and storage to mitigate risks associated with OSW infrastructure[1] and satellite transmissions.
- Maintain essential data infrastructure for the 30-year lifespan of OSW projects by mandating that 5-10% of site monitoring project budgets support data management, sharing, and preservation.
- Account for regulatory policies and guidance when designing data collection to reduce need for redundant assessments to achieve standards necessary for permits and authorizations, as well as engineering.
- Consider alternatives to data collection when monitoring is infeasible or it is cost- or time prohibitive to collect sufficient data for statistical power and reduction of uncertainty.

[1] Throughout this document, the term infrastructure refers to all components of the turbine and platform, mooring and anchoring systems and the electrical transmission network.(e.g. cables).

Technology Recommendations

- Evaluate monitoring techniques through in-situ research to compare well-established methods against emerging methodologies, identifying the most effective sensors/instruments for detecting specific impacts.
- Invest in emerging monitoring technologies and quantitative modeling to improve impact detection, utilizing simulations to optimize monitoring design and minimize structural interference before installation.
- Advance and calibrate emerging technologies, such as AI and eDNA, and prioritize standardization and open-source workflows to ensure data comparability and improved monitoring accuracy.
- Utilize multi-sensor platforms and vessels to scale monitoring across taxa, aligning intensity of effort with seasonal habitat use while improving remote data transfer to reduce logistical costs.
- Establish monitoring plans before infrastructure design and procurement to integrate engineering-based monitoring solutions directly into OSW assets for all data, including from OSW developers.
- Establish a formal review panel to set benchmark-based standards for technology demonstration and acceptance, ensuring objective performance evaluations rather than relative measures.
- Refine technology calibration and validation and develop high-quality training and testing datasets for analytic technologies. Select from the existing data standards (e.g. ISO, EML, DwC) and use the same data standards for the same data.
- Require technologies that apply AI to data collection and processing to disclose how AI is used in order to develop consistent guidance for AI application and assess reliability of outputs.
- Improve capacity to detect effects to OSW development amid natural and linkages between dynamic oceanographic conditions and species distributions and responses, including the collection of basic species distribution and habitats.

Habitats, Ecosystems, and Oceanography: Recommendations

Impacts from OSW infrastructure (habitat degradation, habitat creation, and changes to physical and biological oceanographic processes) will vary across estuarine, nearshore, pelagic, and offshore environments. Key concerns include sediment resuspension, benthic disturbances, environmental pollutants released during construction in Humboldt Bay, Port San Luis, and nearshore areas, and impacts to broad-scale oceanographic processes (such as upwelling). Knowledge gaps remain regarding how habitat creation from OSW infrastructure will affect nearshore, pelagic, and offshore benthic biological processes.

Foundational Recommendations for Habitats, Ecosystems and Oceanography

- **Establish, Maintain and Enhance Long-Term Observation Networks** (e.g. CalCOFI, SCCOOS, CeNCOOS, ACCESS) to support continued collection of physical, biogeochemical, and habitat variability data across spatial (statewide, regional, site-specific) and temporal scales. Add observing assets as needed to fill coverage gaps or to focus on local impacts. Prioritize maintaining existing monitoring programs and refine monitoring to improve detection of OSW related impacts to natural variability.
- **Coordinated Seafloor Mapping and Geophysical and Geotechnical Surveys** Conduct broad-scale benthic and pelagic habitat and ecological mapping to establish essential physical and biological baselines, along with coincident geophysical and geotechnical surveys, ensuring OSW development and site-specific monitoring are informed by accurate seafloor data, inside and outside Wind Energy Areas (WEAs), as well as potential cable routes.
- **Resolve uncertainties with respect to infrastructure impact on upwelling** Explore combinations of modeling and observational studies that could further refine the structure and magnitude of predicted impacts based on refined infrastructure deployment scenarios, as well as if it is feasible for an updated observing system design to detect such changes.

Habitats, Ecosystems, and Oceanography: Impact Topics and Monitoring Questions

Impact Topic	Monitoring Questions
Impacts from infrastructure during construction	• How might sediment plumes and release of contaminants from cable laying impact the nearshore environment (e.g., water quality, conversion of benthic habitats)? • How may benthic habitats be impacted from short-term & long-term disturbances associated with construction?
Impacts from infrastructure during operations	• How much benthic habitat will be converted (i.e., created and degraded) by OSW infrastructure? • How will OSW infrastructure impact colonization & community stabilization (i.e., invasive species) near platforms and cabling? • How will habitat creation from OSW infrastructure facilitate reef effects (i.e., colonization, changes in biodiversity)?
Impacts from port developments	• How will port development (e.g., channel dredging) impact nearshore habitats & soft-bottom communities?
Biological oceanographic impacts	• How will OSW infrastructure impact transport of nutrients, primary production, & zooplankton nearshore and offshore? • How will altered upwelling, hydrodynamics, or nutrient fluxes impact zooplankton and phytoplankton community structure & biomass in WEAs?
Physical oceanographic impacts	• How may OSW infrastructure impact physical oceanographic processes such as upwelling (magnitude and spatial structure of upwelling, physical circulation, and nutrient transport) inside and outside of WEAs? • To what extent do scouring and sediment resuspension from OSW wind infrastructure (specifically anchoring, trenching, and cabling) disrupt local benthic environments?

Marine Mammals and Sea Turtles: Recommendations

Noise, vessel traffic, and infrastructure are the primary IPFs for marine mammals and sea turtles from OSW. Potential impacts to resident species include injury from construction noise and entanglement, whereas nearshore and offshore transient species risk injury from vessel traffic and/or infrastructure entanglement. In estuaries such as Humboldt Bay, port development is most likely to impact marine mammals with alteration of habitat and spatial avoidance associated with vessel traffic and noise. While EMFs may cause spatial avoidance of sea turtles, and infrastructure may lead to entanglement of marine mammals and sea turtles, these potential impacts remain knowledge gaps.

Foundational Recommendations for Marine Mammals and Sea Turtles

- Employ advanced integrated, multi-method monitoring to coordinate acoustic, visual, tagging, and oceanographic approaches to assess species exposure, distribution, habitat use and behavioral responses.
- To account for spatial and temporal variability in species' distributions, target monitoring within high-use habitats, migration corridors, and feeding areas with seasonal patterns and priority species.
- Prioritize long-term acoustic monitoring to establish comprehensive pre-construction baseline soundscapes and maintain passive acoustic monitoring (PAM) throughout all project phases to track noise and species vocalization changes within and beyond WEAs.
- Improve characterization and understanding of species abundance, distribution, timing of sensitive life history periods, and ecology and movement patterns. Must cross-reference distribution data with ecosystem/habitat predictors to improve ability to forecast future and changing distributions. Establishing this pre-construction baseline will be essential for evaluating variability and detecting project-related changes.

Marine Mammals and Sea Turtles: Impact Topics and Monitoring Questions

Impact Topic	Monitoring Questions
Monitoring for acoustic impacts and behavioral modifications	● How will noise from OSW activities alter movement & behavioral patterns of priority species, as well as existing soundscapes? ● How will increased ambient noise impact a species ability to detect & avoid gear (entanglement risk)?
Monitoring for vessel traffic and strike risk	● How will projected increased vessel traffic (during construction, operations & maintenance) heighten risk of vessel strikes for marine mammals and sea turtles?
Monitoring for spatial distribution impacts due to infrastructure and vessel presence	● To what extent will the projected increase in vessel traffic during the construction and operation phases heighten the risk of spatial avoidance and vessel strikes? For nearshore species (i.e., sea otters, harbour seals) acute long-term disturbance to haul out and foraging areas should be monitored to determine energetic and reproductive effects.
Monitoring for entanglement risk	● What are the risks of primary, secondary, or tertiary entanglement of marine species during construction & long-term operations? ● What is the sensory capacity of marine fauna to detect subsea infrastructure and subsequently exhibit avoidance behaviors to avoid entanglement?
Monitoring for non-acoustic environmental impacts (EMF, lighting, artificial reefs)	● How will non-acoustic environmental changes (artificial lighting, artificial reefs, increased turbidity) impact foraging or prey quality? ● How does EMF pose a risk to behavioral patterns, navigation, or physiological health of sea turtles?

Marine Birds and Bats: Recommendations

Infrastructure was identified as the high priority IPF for marine birds because of the potential for collision-related injury and mortality for individuals transiting through the rotor-swept zone (RSZ). Additionally, the impacts of infrastructure on energy cost and resource access via displacement of individuals to reroute around OSW footprints were identified as high priority knowledge gaps. Significant uncertainties remain regarding the rates of occurrence, movement patterns, behavior, and habitat use of bats in the CCLME; therefore, while no high priority IPFs were identified for bats, numerous knowledge gaps were highlighted.

Foundational Recommendations for Marine Birds and Bats

- Invest in large-scale regional, multi-season baseline monitoring efforts to characterize marine bird and bat species distribution, flight behavior, offshore bat activity, and environmental drivers across regions.
- Invest in, advance, and validate scalable collision risk and avoidance detection systems (e.g., radar, acoustic, and sensor-based platforms) with real-time data capabilities.
- Prioritize monitoring in high-risk habitats, including shelf and nearshore waters, OSW footprints, cable corridors, and port/infrastructure areas, with location-specific approaches rather than statewide generalizations.
- Prioritize and target monitoring to resolve key uncertainties for high-risk and data-limited species.
- Enhance colony and at-sea monitoring for key high vulnerability/high risk species to determine and enhance vital rate data like survival, mortality, generation time and birthrate that are necessary for effective impact attribution, population status monitoring and potential mitigation.

Marine Birds and Bats: Impact Topics and Monitoring Questions

Impact Topic	Monitoring Questions
Monitoring for collision risk	• What is the risk of individual mortality from collision with turbine blades? • What are the population-level consequences of collision mortality? • How does collision risk vary with time, space, and weather conditions?
Monitoring for spatial distribution and responses to infrastructure	• How may OSW activity and infrastructure cause seabird and bat avoidance, displacement, and shifts in distribution? • To what extent does OSW activity and infrastructure attract marine bird/bat species and create an ecological trap? • What is the energetic cost to birds or bats from displacement or avoidance?
Monitoring for resource changes	• How does OSW change the abundance and composition of seabird and bat prey species? • How do spatial distribution changes of marine birds and prey due to OSW impact prey availability? • Will nearshore marine birds and bats use OSW infrastructure as islands to roost and forage? • How might OSW infrastructure influence offshore insect activity and alter bat foraging accessibility?

Fish and Invertebrates: Recommendations

Infrastructure is the primary IPF for fish and invertebrates[2], with potential impacts including altered abundance, community composition, habitat use, and recruitment. Crucially, floating OSW development introduces massive, 3-dimensional hard structures into pelagic and soft-bottom expanses that naturally lack such features. These effects are likely to be most extensive for demersal and benthic species, where the addition of novel hard substrate may trigger cascading community shifts, both positive and negative, via the reef effect. For plankton, the highest priority is infrastructure-driven community changes resulting from altered hydrodynamics, including the transport and recruitment of planktonic early life history stages of fishes and invertebrates to the novel offshore physical structures.

Foundational Recommendations for Fish and Invertebrates

- Build on and sustain California's uniquely comprehensive marine fishes and invertebrate monitoring assets — including the 76-year CalCOFI time series and established fisheries-independent and ecological monitoring programs — by designing new OSW monitoring programs to explicitly integrate with, leverage, and conserve these legacy data streams. The dynamics of the California Current Ecosystem require multi-decadal observational records to distinguish natural variability and secular trends from OSW-driven impacts.
- Invest in regionally comprehensive, multi-year pre-construction baseline studies of species composition, abundance, distribution, movement, and seafloor habitat, integrating traditional sampling with emerging tools (e.g., eDNA, acoustics, high-resolution imaging, and AUVs).
- Expand regional oceanographic monitoring (temperature, current velocity, nutrient fluxes, plankton assemblages, and upwelling dynamics) to establish a robust pre-construction baseline of ecosystem processes within and outside OSW areas.
- Develop robust species distribution models that map current fish and invertebrate occurrences against existing natural habitat features and environmental covariates. Enhancing these predictive spatial models is essential to forecast how the unprecedented introduction of novel, 3-dimensional structures into previously open-ocean or featureless soft-bottom environments will shift baseline habitat preferences and drive the attraction, displacement, or redistribution of local populations.

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[2] Plankton are considered in the Fish and Invertebrates Working Group section.

Fish and Invertebrates: Impacts Topics and Monitoring Questions

Impact Topic	Monitoring Questions
Physical habitat alteration and benthic and pelagic ecology impacts	● How does the introduction of novel hard infrastructure alter the occurrence, abundance, demographic structure, and overall composition of local fish and invertebrate assemblages? ● What are the physical and ecological impacts of upper-water-column epibiota sloughing off and accumulating on underlying seafloor habitats and benthic communities? ● How does the addition of novel hard-bottom substrates influence recruitment dynamics and community composition in the adjacent natural soft-bottom environments?
Ecosystem alteration via biogeochemical and physical oceanographic drivers	● How will OSW-driven alterations to physical oceanography (e.g., wind wake, upwelling transport, and circulation) influence primary productivity, plankton distributions, and trophic transfer to forage fishes and benthic communities? ● How might the release of chemical contaminants and biohazards during port development, construction, and operation impact local bioaccumulation and the health of plankton, fish, and invertebrate communities?
Behavioral ecology and spatial connectivity changes	● Will the 3-dimensional OSW infrastructure act as a barrier or a facilitator (corridor) for the dispersal and movement of larvae, juveniles, and adults between populations? ● Will OSW infrastructure cause Fish Aggregating Device (FAD) attraction/avoidance behaviors, and how will this alter localized predator-prey dynamics and trophic interactions? ● How will the presence of OSW infrastructure and altered oceanography impact the diel vertical migration (DVM) and foraging behavior of pelagic fishes and zooplankton? ● How does physical habitat disruption and EMF from buried/surface power cables alter the spatial connectivity and movement of demersal and benthic species?

Impact Topic	Monitoring Questions
Impacts to population dynamics (dispersal, recruitment, and demographics)	● Will WEAs function as *de facto* Marine Protected Areas (MPAs) due to excluded activities, and how will that impact fish abundance, size structure, mortality rates, and reproductive output? ● What is the risk of OSW infrastructure facilitating the recruitment and persistence of non-native/invasive invertebrate species, acting as steppingstones for range expansion? ● How do the assemblages of fish and invertebrates recruiting directly to offshore infrastructure differ from those in natural habitats, and does this artificial recruitment ultimately sink or subsidize natural populations?

1. Introduction

To meet California's bold renewable energy targets, floating offshore wind (OSW) has emerged as a critical component of the state's clean energy future. In June of 2023, the Bureau of Ocean Energy Management (BOEM) executed five OSW leases in federal waters 20 miles offshore from the California coast, two off the coast of Humboldt Bay in northern California and three off the coast of Morro Bay in central California. Assembly Bill 525 (AB 525)[3], signed into law in 2021, is the state legislation for planning OSW development in California (California Energy Commission [CEC], 2024). Establishing the framework for responsible OSW development in California, AB 525 has a central goal of minimizing environmental impacts. Several foundational documents guide the science of OSW impacts on marine life in California, including BOEM's Programmatic Environmental Impact Statement[4] and the National Ocean and Atmospheric Administration (NOAA) Fisheries West Coast Offshore Wind Energy Strategic Science Plan[5], which help set the context of OSW in California's unique ecosystem (BOEM, 2024a; NMFS, 2024).

The California Current Large Marine Ecosystem (CCLME) is a highly productive region along the U.S. West Coast. Wind-driven upwelling brings cold, nutrient-rich water to the surface that supports vast biodiversity, major fisheries, and coastal habitats like kelp forests (Lorenzo et al., 2005; Thompson et al., 2024). The U.S. West Coast has a narrow continental shelf, placing deep waters close to shore. Since the OSW lease areas extend past the continental shelf, these conditions require floating wind turbines instead of the fixed-bottom foundations used in most OSW projects. Floating turbines at this scale are a new technology (NOWRDC, 2023). Their use in a productive upwelling ecosystem is unprecedented, and their potential environmental impacts are not yet fully understood. Existing monitoring guidelines from other regions may not apply to California's specific context, creating a need for a tailored, scientifically robust framework to guide environmental monitoring (NOWRDC, 2023).

This document presents the California Offshore Wind Environmental Monitoring Framework (hereinafter referred to as the Framework). The Framework will provide guidance for developing future monitoring plans for species and habitats potentially affected by floating OSW. It will serve as a foundational resource for the OSW community in California, enabling informed decision-making to minimize and mitigate negative impacts on marine ecosystems and coastal communities. The Framework

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[3] https://www.energy.ca.gov/data-reports/reports/ab-525-reports-offshore-renewable-energy
[4] https://www.boem.gov/renewable-energy/state-activities/california-offshore-wind-programmatic-environmental-impact
[5] https://www.fisheries.noaa.gov/topic/offshore-wind-energy/assessing-impacts-to-marine-life

uses a collaborative scientific process that leverages expert opinion to ensure it reflects the best available science.

1.1. Scope and Goals

The Framework synthesizes existing research on potential environmental impacts from both floating and fixed-bottom OSW development. It identifies key environmental monitoring questions and provides guidance on potential sensors and data collection methods to address them. It assesses the relative ease or difficulty of monitoring/measuring impacts, and distinguishes between well-established techniques and more challenging, emerging methodologies. The Framework also assesses current and emerging monitoring technologies to leverage ongoing monitoring efforts. In collaboration with regulatory agencies, scientific data requirements for California OSW permitting and policies were also identified. The Framework recommends immediate opportunities to fill near-term scientific gaps, particularly for pre-construction and construction phases in existing lease areas.

The Framework is intentionally designed as a broad scientific and methodological template. This generalized nature means that project-specific monitoring plans will be required to address the unique conditions of each OSW Wind Energy Area (WEA; e.g., Humboldt Bay, Morro Bay, and others as they are identified).

To use this document effectively, it is important to understand the scope and boundaries intended. The Framework is not:

1. **A regulatory requirement or checklist.** It does not create new regulations or mandatory standards. It is not intended to interpret or dictate regulatory requirements. Compliance will be determined by permits issued under existing laws (e.g., Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA)), and other federal and state regulatory and permitting requirements.
2. **A prescriptive checklist**. It will not provide a single "one-size-fits-all" monitoring plan. Project-specific monitoring must be tailored to a site's unique ecological and oceanographic conditions.
3. **An impact assessment.** The Framework provides scientific expert opinion of potential impacts based on our best understanding but does not predetermine what those effects will be or set thresholds for acceptable impacts.

Goal of the Framework: Provide a science-based framework for detecting and understanding potential environmental impacts from floating OSW projects in California. This is accomplished through a collaborative, multi-disciplinary, and adaptive approach. The Framework identifies monitoring questions that address environmental impacts, knowledge gaps, and provides guidance on strategically targeted monitoring efforts that will support assessment of project-level and cumulative impacts. By identifying transparent, science-based approaches, the Framework can guide the development of detailed monitoring protocols to ensure that OSW development proceeds in a manner that is both environmentally responsible and scientifically informed.

Key Objectives:

- **Synthesize Existing Knowledge:** Aggregate information from existing studies, observing systems, and ongoing monitoring efforts to identify key environmental impact questions and priority knowledge gaps.
- **Assess Monitoring Technologies:** Evaluate current and emerging methods and technologies for monitoring marine habitats and species.
- **Develop a Systematic Framework:** Provide broad guidance to establish systematic monitoring of OSW impacts, demonstrating through clear examples how to prioritize monitoring efforts.
- **Inform Science-Based Decisions:** Offer scientific input on monitoring priorities, grounded in a scientific expert opinion process and robust literature review.

1.2. Audience

The Framework serves three main audiences:

Communities, including local governments, commercial and recreational fishing, scientific community, and the general public (Communities). The Framework helps these communities understand potential impacts from OSW development and provides them information on how those impacts could be monitored. Examples of use include:

- As an educational resource to understand what impacts should be monitored and explain how scientific information can inform OSW planning;
- For scientists to design studies by applying identified methods and priority questions to structure pre-construction baseline studies and post-construction monitoring; and
- Identify information gaps by using the literature synthesis and recommendations to focus on areas where further research is needed.

Decision-makers and regulators at federal and state agencies and tribal governments (Governments) can use the provided foundational scientific expertise on marine species and habitats that could be impacted by OSW to direct monitoring initiatives. It sets realistic expectations about what impacts can be detected. Examples of use include:

- Evaluating monitoring plans and methods,
- Informing development of monitoring guidance, protocols, and best practices.

OSW energy leaseholders and developers (Developers) as they plan and execute required environmental monitoring throughout a project's lifecycle (siting, construction, operation, maintenance). Examples of use include:

- Guide for designing robust, science-based monitoring plans,
- Identify best practices by adopting recommended methodologies for surveys, technology, and data analysis to ensure quality and consistency.

1.3. Background

California's pursuit of floating OSW is a groundbreaking endeavor that requires scaling this technology from global pilots into a first-of-its-kind commercial reality for the United States. The two federally designated WEAs in California are located off the Central Coast near Morro Bay (BOEM, 2022a) and the North Coast near Humboldt Bay (BOEM, 2022b). Both WEAs occur beyond the steep continental shelf, which drops to depths where traditional fixed-bottom wind turbines are not feasible. The Morro Bay WEA depth ranges from 2,953 to 4,265 feet, and the Humboldt Bay WEA depth ranges from 1,640 to 3,600 feet, which is significantly deeper than the deepest operating OSW project in Norway (721 feet) (Equinor, 2026), presenting unprecedented engineering challenges. Potential effects of these large-scale floating OSW structures in California's unique and diverse marine ecosystems are a major area of uncertainty, which led to this concerted effort to develop a comprehensive environmental monitoring Framework to understand and monitor potential impacts.

1.4. Regulatory Environment

The scope and design of environmental monitoring for OSW development does not occur in isolation. Required monitoring programs are shaped by the permits, consultations, and authorizations that agencies require at every stage of a project. The permitting landscape for OSW development involves multiple federal and state agencies, each with statutory authorities that trigger their own permitting requirements, consultations, and approvals. To meet these requirements, project developers must collect environmental data covering marine species, habitats, and environmental conditions from the sea surface to the ocean floor. Because many of these authorities overlap in scope and timeline, successful project permitting depends on strong interagency coordination and the iterative analysis of data and information.

At the federal level, oversight of OSW environmental permitting is led by BOEM under the Outer Continental Shelf Lands Act (OCSLA), which serves as the lead federal agency responsible for leasing, planning, and environmental review. The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) play consultative roles, providing Endangered Species Act (ESA) consultation and Fish and Wildlife Coordination Act coordination, and NMFS further consults on Magnuson Stevens Fishery Conservation and Management Act (MSA) Essential Fish Habitat (EFH). Both USFWS and NMFS directly authorize activities that require Marine Mammal Protection Act (MMPA) authorizations. USFWS is further responsible for implementation of Migratory Bird Treaty Act and Bald and Golden Eagle Protection Act. The Office of National Marine Sanctuaries may consult if there are nearby National Marine Sanctuaries. There are other permits and consultations, not all associated with wildlife, as part of offshore wind approvals. The Bureau of Safety and Environmental Enforcement (BSEE) oversees operational safety and environmental compliance during construction and operations, working in coordination with BOEM throughout the project lifecycle.

At the state level, the California Coastal Commission (CCC) regulates coastal development, requiring a federal consistency determination and project consistency certifications to ensure OSW projects align with California's Coastal Zone Management Act (CZMA) which provides California's approved Coastal Zone Management Plan enforceable policies. The CCC's authority extends seaward to the three-nautical-mile state water boundary; however, consistency review under CZMA may be requested for activities in federal waters that could have a direct impact on resources in the coastal zone. The California State Lands Commission (CSLC) has jurisdiction over state sovereign lands, including issuing leases for use of submerged lands and the beds of navigable waterways that may be impacted or occupied by transmission infrastructure connecting offshore facilities to the onshore grid. CSLC also permits geophysical surveys of the ocean bottom and marine environment. California Department of Fish and Wildlife provides scientific review and regulatory oversight to protect state-listed species and sensitive habitats, often coordinating closely with federal counterparts on species that span both jurisdictional frameworks.

A permitting authority is the statutory or regulatory framework that grants a federal or state agency the legal authority to review, condition, and approve (or deny) components of a proposed project (Appendix A). These authorities are established by laws such as the National Environmental Policy Act (NEPA), ESA and OCSLA. which are federal authorities, and the California Environmental Quality Act (CEQA) and the Coastal Zone Management Act (CZMA), which are state authorities. While agencies administer and implement permitting and consultation processes, it is the underlying statute that defines the scope of review, decision standards, timelines, and substantive requirements. For California OSW projects, multiple permitting authorities apply concurrently, with different agencies exercising jurisdiction depending on where the impact is located (federal or state waters), the resource affected, and the project phase. Collectively, these authorities establish requirements for environmental data collection and monitoring, including baseline surveys conducted prior to construction to characterize existing conditions and inform impact analyses. Authorizations issued prior to construction also include conditions requiring continued monitoring and reporting during construction, operations, and decommissioning to evaluate project impacts and ensure compliance with permit conditions.

A clear example of how federal and state permitting authorities operate together is provided by NEPA and CEQA processes, which are the primary federal and state environmental review statutes. NEPA requires federal agencies to evaluate the environmental impacts of major federal actions and consider alternatives before making a decision, while CEQA requires comparable environmental review for projects that require discretionary approval by California state or local agencies. For OSW projects, NEPA review may occur for federal actions such as lease issuance or plan approvals, while CEQA review may apply to related activities within state jurisdiction, such as port upgrades, transmission infrastructure, or other onshore facilities; recent legislation such as California Senate Bill 286 encourages state agencies to coordinate CEQA review with federal NEPA processes where feasible, supporting a more integrated environmental review for OSW development.

With respect to wildlife and habitats, federal and state permitting processes will result in mitigation and monitoring requirements that address potential impacts and meet statutory standards, such as negligible impacts to marine mammals and no jeopardy for endangered species. Studies and surveys undertaken to inform impact assessment and mitigation should, as possible, apply data formats and reporting standards that meet the needs of statutes, regulations, and guidance/policy of authorizing and consulting agencies to minimize the needs for redundant data collection efforts that can result in higher impacts than necessary.

1.5. How the Framework Was Developed

The Framework synthesized scientific research with subject matter expert opinion to identify the potential impacts of floating OSW on California ocean ecosystems. The objective was to transform scientific findings into monitoring recommendations that are practical and flexible, while remaining applicable to California's existing regulatory framework. The Framework systematically progressed from identifying broad risks and potential impacts of OSW development to specifying the species, habitats, technologies, and questions necessary to inform monitoring recommendations for OSW development.

The Framework was a collaborative process between CMSF and the Coordination Team, scientific experts, and contributor groups. The Coordination Team (consisting of CMSF, Cal Poly San Luis Obispo, OPC, and CDFW) was responsible for providing the overarching strategic direction and ensuring the Framework's scope, content, and focus remained aligned with its core purpose. CMSF, with support from scientific experts and the Coordination Team, developed and led the scientific approach for collecting and synthesizing results. A total of six Working Groups (WG) were led by CMSF in conjunction with the respective scientific chairs to execute the expert input. The WGs were organized by ecological and technical expertise. The ecological WGs included: Marine Mammals and Sea Turtles, Fish and Invertebrates, Marine Birds and Bats, Habitats and Ecosystems, and Oceanography. A Data and Technology Integration WG worked across all taxa and habitats. Ecological WGs were further divided into subgroups based on ecological and/or functional groups to ensure differences in focal habitats or specific life histories were captured.

Potential impact producing factors (IPFs; e.g., infrastructure and vessel traffic) and impacts (e.g., habitat degradation and injury/mortality) were identified for each WG through a literature review and further refined through expert input to generate a matrix of IPFs, impacts, and evaluation criteria. After WGs evaluated each IPF and relevant impact, the results were ranked (high, medium, low priority, knowledge gap) using a key based on the intensity and probability of occurrence at a population level. Concurrently, a decision tree prioritized species (high, medium, low priority) based on their exposure, sensitivity, and ecological or management significance. The results of both were combined to generate a data set of knowledge gaps and high priority potential IPF-impacts and their relevant species and habitats and to produce monitoring questions (MQs). **To ensure targeted future monitoring, only the IPFs, impacts, knowledge gaps, and species or functional groups ranked as *high priority* were used to inform the MQs and respective recommendations.** This sequential workflow is outlined in Figure 1, and a comprehensive explanation of the methodology is detailed in Appendix B.

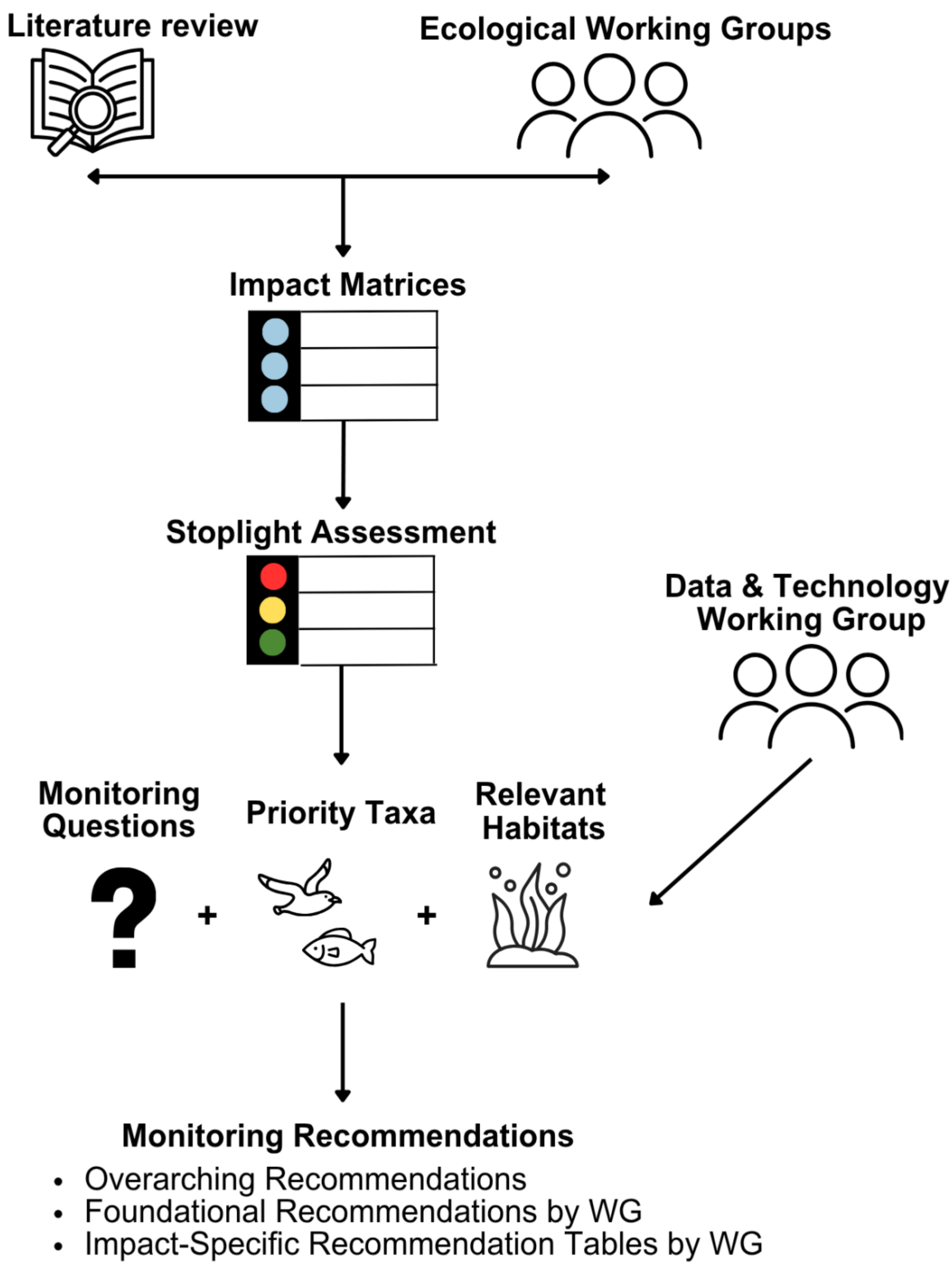

Figure 1. Methods illustrating how different Framework components build upon each other to produce a prioritized list of monitoring recommendations.

1.6 Traditional Knowledges and Tribal Science

This Framework is based on non-indigenous science, which is not the only type of knowledge that should inform the monitoring of OSW impacts on California's coastal and marine environment. California Native American tribes hold essential Knowledges and perspectives, including Traditional Knowledges and tribal science, that must be considered as California works to develop a comprehensive environmental monitoring program for OSW. This is especially important as tribes have consistently expressed concerns about the potential impacts of OSW development on species, habitats, and cultural resources – all of which are often interwoven in tribal culture in a way that cannot meaningfully be understood through non-indigenous science.

At the outset of this effort, OPC in coordination with CMSF invited tribal scientists and holders of Traditional Knowledges to contribute expertise across the focal areas of this framework. Due to significant constraints on tribal capacity, tribes were unable to participate in the development of the Framework. OPC recognizes and affirms that tribal perspectives and priorities are an essential complement to the largely non-indigenous approaches presented in this Framework, and is committed to ensuring early, often, and meaningful tribal engagement in OSW environmental monitoring to center tribal concerns and priorities, inform mitigation of potential impacts, and heal from historic wrongs. That will include ongoing formal consultation on this Framework and its implementation.

3.Data

2. Data

Data, information, and knowledge are the heart of any monitoring program. They allow us to assess baseline conditions, monitor changes, plan for adaptation and mitigation, and test the effects of our actions. Documentation, preservation, access, and reusability are essential to any data program. Offshore data efforts pose additional data collection challenges because of the logistical difficulties and cost of conducting monitoring so far from land, as well as the limitations of satellite imagery and sensors for taking ocean measurements. This section describes a set of core principles, based on established best practices for data, as well as a list of specific recommendations for OSW monitoring data for California.

Successful data programs require many institutions and individuals to coordinate and having shared language around data enables successful collaboration. Key terms are defined below using common national and global definitions as much as possible. An important overarching concept is “data governance” which encompasses the purpose and goals for collecting and using data, policies such as contract terms and data licenses, and frameworks for technical implementation. Data management executes and informs data governance, supporting the shared goals and agreements with data standards, repeatable methods, documentation, and data infrastructure. (See Sebastian-Coleman, 2018; DAMA-DMBOK[6]).

With appropriate data governance and application of the data principles described below, data collected for OSW monitoring can be connected across data producers, technologies, and spatial and temporal scales. Consistent data processes make data easier to analyze and reuse which also maximizes the data’s value. When data can easily be linked across projects and monitoring programs, more data is available for cumulative and regional assessments, forecasting the development of adaptation and mitigation measures, and planning for future OSW development. Well-structured and documented data are also essential for analytic applications.

2.1 Key Terms

Data

Data refers to values, measurements, and observations that describe quality, quantity, or other aspects. Data may be classified as “raw data” from a sensor, experiment, or other measurement tool that has not been calibrated, reviewed for quality (aka Quality Assurance / Quality Control, (QA/QC)), or organized into a structure like a data table or schema. Once data has been significantly aggregated or processed from its original

[6] https://dama.org/learning-resources/dama-data-management-body-of-knowledge-dmbok/

format, the result may be referred to as a “data product,” such as underwater video with annotations of species names or a GIS layer showing seasonal animal movements.

Data are often considered the foundation of a “knowledge hierarchy” where analysis and communication transform data to become information, knowledge, and wisdom (Rowley, 2007). While this Framework uses the word data broadly to cover many different scientific and monitoring outputs, it is important to consider this meaning of data within a larger context of understanding the ocean, especially when co-designing and collaborating with tribal and Indigenous partners (Jennings et al, 2023). Not all components of a monitoring system may fit the above definition of data but may still provide vital and valuable insights and knowledge.

Metadata

Metadata are data that describe data. Metadata are an essential part of documentation at both the file level (e.g. column headings and units in a data table) and the project level (e.g. data creator, geographic location, year) that enable someone to know enough about the data to be able to discover, access, retrieve, manage, and reuse it (Riley, 2017).

Data Standard

A technical specification that details the structure, organization, documentation, and format of data. Using data standards allows for the consistent collection of data, and aids in data aggregation, sharing, and reuse, as well as the interoperability of data across different systems, sources, and users. See the IOOS data standards[7], data.gov[8], National Library of Medicine[9], and US Fish & Wildlife Service[10].

Data Repository

A persistent, findable, searchable entity that provides infrastructure for long-term storage and access to data. It should provide for data publication by data holders, as well as access for using/reusing data. Datasets in a repository are described with standardized metadata that provide essential information about the data and enable efficient search and reuse. Repositories should also employ unique identifiers, use redundant storage systems, and have clear guidelines for the types of data and data

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[7] https://ioos.noaa.gov/data/data-standards/

[8] https://resources.data.gov/standards/concepts/

[9] https://www.nnlm.gov/resources/data/data-glossary/data-standards

[10] https://www.fws.gov/data-standards/what-is-a-standard

products accepted. Individual repositories may or may not be federated with other repositories. See the Encyclopedia of Big Data[11].

Analytics

This term includes activities and tools related to processing, reviewing, and synthesizing data, such as AI-assisted video review, ecosystem models, and automated data processing workflows.

Systems

All the platforms, sensors, and analytics together and the connections among them. System activities include data transmission and storage, data standards, power, and technology procurement policies.

2.2 Data Categories

The WGs describe detailed and specific data types needed for each monitoring priority, such as bird flight height. In order to talk more generally about data and technology needs for OSW monitoring, the specific data types described by the WGs are aggregated into the following list of data categories for this section:

- Presence, distribution, and habitat use patterns including seasonality
- Abundance and population dynamics
- Demography and life history/life stages
- Behavior and behavioral response (short- and long-term)
- Oceanographic (e.g., currents, waves, wind, bathymetry, temperature, salinity)
- Productivity/upwelling
- Physiological health and growth
- Biodiversity/biomass/species richness
- Habitat composition/recovery
- Water quality
- Sediment composition, movement, and toxicity
- Trophic relationships
- Injury/Mortality

These data categories also roughly map onto regional and international data type taxonomies, such as those for the Integrated Ocean Observing System (IOOS) and Global Ocean Observing System (GOOS) Essential Ocean Variables (EOVs, Martín Míguez et al, 2026), although more work will be needed to align California's data

[11] https://link.springer.com/rwe/10.1007/978-3-319-32001-4_59-1

dictionaries and standards with global frameworks like these for the greatest potential for data interoperability and reuse.

2.3 Core Data Principles

The six principles below should be applied to any new data collection effort. They can be applied through policy, technical implementation, state guidance to non-state partners, funding requirements, and other approaches, potentially in combination. For example, New York State's Energy Research and Development Authority uses its power purchasing contracts to implement a data sharing policy and cites a regional guidance memo to tell data collectors where to publish data. Ideally, these principles would also be applied to existing data, which may benefit from additional effort to make the data more useful and usable. These principles reflect the discussions of the Data and Technology WG, recommendations from Mid-Atlantic OSW monitoring programs (see Regional Wildlife Science Collaborative (RWSC) and Responsible Offshore Science Alliance (ROSA), 2022), scientific and open data principles (FAIR & CARE, Open Data Charter[12]), the UN Ocean Decade Data Strategy, sustainability reporting principles (Taskforce on Nature-Related Financial Disclosures, Icebreaker One's NOVA Principles[13]), and recommendations from other OSW reports such as Courtney & Sen (2023) and McCoy et al. (in review).

1. Transparent
2. Well documented & repeatable
3. Standardized to enable access & (re)use
4. Ethical & privacy protecting
5. Networked & interoperable
6. Fit for purpose

1.Transparent

It is important that monitoring be conducted in a manner that is transparent to the public and all interested parties. Transparency involves public notification when a project is under development and launched, providing timely public reports, discouraging delay in sharing data and outcomes, providing mechanisms to manage and share data, and engaging the public, developers, regulators, tribes, and others as appropriate to ensure data collection methods are vetted, data management and use is equitable, cultural resource information is protected, and greatest value can be derived from data.

[12] https://opendatacharter.org/
[13] https://ib1.org/nova/

Sufficient information on completed studies should be publicly available so that others could reasonably repeat the study and verify the outcomes. There will be some data that should not be made widely public or may be delayed in release, such as commercially or culturally sensitive data, and there also may be some proprietary models or technologies applied to projects; however, sufficient information to allow for peer-review and vetting of data is important to achieve transparency and repeatability of studies.

2.Well-documented and repeatable

Good documentation supports transparency, credibility, and reproducibility. Data collectors should use existing best practices and guidelines and document their study designs, data collection methods, and analyses. Good documentation also supports consistency across project partners and saves data collectors time because they can reuse methods, code, templates, and other tools from similar efforts. Documentation should include quality control and assurance procedures and data handoffs. Documentation should also describe limitations of the data and any use restrictions, including licenses and data sensitivities. Documentation can be published along with code, such as by posting a PDF of a methods description document on Zenodo that links to code on GitHub.

One common tool to support documentation and consistency within and across projects is a Data Management and Sharing plan (DMSP). Groups such as the RWSC and ROSA have created open templates on DMPTool.org that are tailored to offshore energy research.

While some new research methods and frameworks may need to be created for CA OSW monitoring, many frameworks already exist and could be applied with minimal modification. Sources for these include:

- Ocean Best Practices database[14]
- Geophysical data (BOEM, 2024b)
- Passive acoustic monitoring (Van Parijs et al., 2021)
- Fisheries data, (CCC 2026; ROSA 2022)

For data types are one of the Global Ocean Observing System (GOOS) Essential Ocean Variables (EOV), there is extensive information available to help data collectors

[14] https://www.oceanbestpractices.org/

document methods and processes so that data are standardized to be published in [15] the Ocean Data and Information System (ODIS)[16].

Reusing existing practices and methods can support repeatability and allows researchers to cite existing documentation, rather than start from scratch. Standardizing methods also supports standardized data (Principle #3).

3.Standardized

One of the most significant transformations in science over the last 10 years is the shift to FAIR data practices, which prioritize the Findability, Accessibility, Interoperability, and Reusability of data (see Wilkinson et al, 2016). FAIR data practices increase data value by enabling data discovery and use beyond any individual study. Using common data standards is an essential part of making data FAIR. Data standards define required metadata fields and include consistent formats for data elements such as units of measurement, timestamps, and location. Major ocean data repositories, such as the Ocean Biodiversity Information System (OBIS) and Global Biodiversity Information Facility (GBIF), require specific data standards for data publication in order to enable the broadest possible reuse. For example, information describing Global Ocean (GOOS) Essential Ocean Variable (EOV) data (i.e. metadata) are visible in the Ocean Data and Information System (ODIS)[17] regardless of where the actual data is stored.

The U.S. Integrated Ocean Observing System (IOOS) provides detailed data specifications and standards to enable data interoperability across states, regions, and data partners (Biddle et al., 2025). As a Regional Alliance of GOOS, IOOS uses globally agreed standards including those of the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO) 19115 Topic Category. The OBIS-ENV-Data approach works together with globally agreed and updated taxonomy from the World Register of Marine Species (WoRMS) which can be packaged with an Ecological Metadata Language (EML) metadata records for long-term preservation using the Darwin Core Archive data standard (DwC-A)[18]. Tag data is typically routed through the Animal Telemetry Network (ATN) Data Assembly Center, similarly using the ATN Registration, Data Permissions, and Metadata Procedures.

Because California will, at minimum, be looking to integrate data across state agencies, developing a list of recommended data standards and repositories for data publication will help enable data integration. Existing regional monitoring programs like the Ocean

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[15] https://goosocean.org/what-we-do/framework/essential-ocean-variables/

[16] https://odis.org/

[17] https://odis.org/

[18] https://manual.obis.org/darwin_core.html

Observing Systems and CalCOFI have extensive experience integrating data from multiple partners and can provide guidance and tools from their workflows.

4.Ethical & privacy protecting

Some data cannot or should not be shared without some restrictions or modifications. For example:

- Acoustic data may reveal US Navy activities with national security implications
- Archaeological data could make culturally important sites vulnerable to looting
- Site assessment surveys or commercial fishing records may contain proprietary business information

Personally identifying information is unlikely to be a major component of OSW monitoring but the potential exists to capture it unintentionally through community monitoring efforts, such as via cell phone pictures. Data collectors should make clear in their project descriptions and documentation, such as in a DMSP, how they will handle any data with sensitivities. This could include publishing to repositories that support embargoes or permission-based access, obfuscating or aggregating data, or delaying data that cannot be shared in near-real-time.

Ethical issues include giving proper credit to data collectors and respecting use restrictions, which can be done through the use and enforcement of licenses, such as those from Creative Commons and MIT. Monitoring projects and programs must appropriately label tribal and Indigenous contributions of data, information, and knowledge, such as with Local Contexts' tribal Knowledge Labels. Where disadvantaged or underserved communities are being asked to participate in data collection and analysis, adequate resources (e.g. hardware, cloud storage, staff, training) should be budgeted for and provided to these groups to support their full participation (UNESCO, 2023). Data collectors should also consider opportunities to co-design data products that would meet MQs and the needs of the communities with whom they are collaborating.

5. Networked & Interoperable

Under this principle, networked refers both to data infrastructure and the human processes that connect data. Interoperability is the I in FAIR data principles and allows data to be easily used and reused by any user, from any data source, and beyond the original purpose of data collection. Network coordination creates the paths for data to flow, and interoperability makes data flows possible.

Because ocean data gain value and impact when connected to other data and shared with a wide range of communities and users, it is important for data collectors to think about and plan for data interoperability from the outset. One important component of this is standardized descriptive metadata (see metadata definition in the glossary). Projects should use common metadata standards to describe project goals and data to be collected and share that information as early in a project as possible as a way to create shared awareness of work happening in the area and reduce potential duplication of effort.

Metadata and data should be hosted on public data repositories in order to be discovered and connected to other data. A data repository is infrastructure that provides long-term data storage and makes data searchable and available for reuse. Individual laptops or closed institutional cloud accounts are not data repositories. More than 3,000 data repositories already exist, from generalist repositories like Zenodo or Figshare, to repositories focused on very specific domains and data types[19]. Regional Ocean Observing Systems, including CeNCOOS and SCCOOS, publish data to government data repositories like the National Center for Environmental Information (NCEI). Many data repositories support progressive data publication, where descriptive metadata forms a stub for the full data record, which will be filled in when the project is complete. Robust repositories offer machine-readable data and machine-to-machine connectivity, creating a seamless experience for people searching, viewing, and accessing data. Some repositories also offer options for embargoing or selectively sharing data, when not all data or data products can be public immediately or have sensitivities that require access restrictions (e.g. the exact location of cultural artifacts).

Using robust public data repositories supports the creation of specialized portals and catalogs, which draw on those repositories. For example, the OPC's data portal is hosted by DataONE, a networked data platform that relies on the use of common data standards at partner repositories to make data discoverable across sources. The RWSC and ROSA both maintain lists of recommended repositories for different ocean data types, which helps coordinate data publication across partners and data providers and ensure repositories can connect to regional portals and platforms, like the Northeast Regional Ocean Data Portal and the West Coast Data Portal.

California can also play an important role in coordinating research priorities and projects across individual OSW sites. The potential to collect DRIP (data rich, information poor; Wilding et al. 2017) data is substantial with disjointed efforts. Without consistent guidance, it is less likely that compliance monitoring or federally funded research will connect to the critical ongoing regional monitoring programs of the California current

[19] https://www.re3data.org/

ecosystem, such as CalCOFI and the regional Ocean Observing Systems. A networked approach also supports effective technology deployment, such as coordinating sensor arrays across as ships and other platforms operated by the UC system to maximize the utility of the data they collect.

The state also has opportunities to leverage platforms that are funded or otherwise supported by the state, such as ships and other platforms operated by the UC system. Coordinating sensor arrays on these platforms and maximizing the utility of data collected by them for multiple purposes will increase the impact of monitoring investments.

6. Fit for purpose

Any data project should have a clear sense of how the data it generates will be used and the audience for the data and data products. Mapping the data life cycle from planning to use and communication can be done in a DMSP. Even if the project is one component of a much larger effort, such as a regional climate model, the data outputs of a data project should be delivered ready-to-use to the people who need them. While open-ended research is an important part of expanding our understanding of the ocean, monitoring resources are limited and need to be targeted to where they can have the greatest impact. Power analyses to understand how the expected amount and type of data necessary for statistically robust studies would improve or contribute to other studies, models, and existing monitoring programs may help prioritize data projects, and clarify the use cases and needed data products. If data are connected to adaptive management frameworks, where certain values trigger action, data projects need to outline how the data will be delivered to managers in an actionable format, as well as the review processes and auditability of the data trail. In some cases, data may need third-party or peer review to support trust and validate methods.

While this principle focuses on fitness of a project for a singular purpose or use case, all of these principles combined are designed to maximize reusability across any one use or purpose. For example, making data "AI-ready" requires standardization, good documentation, and ethical and privacy-protecting measures. The initial audience for monitoring data should be more refined than “anyone” but ultimately most monitoring data should be available to everyone.

2.4 Alternatives to New Data Collection

It is important to acknowledge that priorities for data collection cannot include all questions of interest, and uncertainty will remain as OSW projects move forward.

If changing baseline, variability, remoteness, expense, weather, or other factors suggest a study would not achieve sufficient data collection to reduce uncertainty beyond current levels or allow for robust analysis, the question or potential impact should be considered via other means, such as predictive models that account for data limitations to the extent possible, studies of proxy species or habitats, or reasonable mitigation measures to reduce risk.

Alternative investments may also be appropriate for addressing questions that are not cost-effective to address with monitoring. In addition to direct avoidance and minimization mitigation measures, offset measures may be a good alternative to monitoring in some cases. For example, assessing collision rates of rare bird species may not be feasible given the rarity of interactions relative to the amount of monitoring possible. An offset, such as nesting habitat conservation measures, may be a more effective use of limited funds for addressing potential mortality. Another example could be collaboration with fishers and regulators to support whale avoidance and entanglement reduction as opposed to substantial expenditures for extensive cable and mooring monitoring.

2.5 Data Recommendations

Apply all monitoring recommendations using these core principles for data collection, management, and sharing:

1. Transparent
2. Well documented & repeatable
3. Standardized to enable access & (re)use
4. Ethical & privacy protecting
5. Networked & interoperable
6. Fit for purpose

Because data quality and accessibility define monitoring efficacy, adhering to these principles support that data can be applied efficiently across all priority topics.

- Update and maintain a catalog of relevant data and monitoring programs, using the recommendations in the WG tables as a starting point (Sections 5.3, 6.3, 7.3, 8.3). These data are currently fragmented across multiple portals, platforms, and repositories.
- Prior to a federal leasing cycle, prioritize calibration and validation of new methods to expand cost-effective monitoring to offshore areas. For example, comparing eDNA sampling with trawl and visual surveys, assessing cue rates of marine mammals for acoustic density assessments, and creating open training libraries for image recognition.

- Descriptive information about OSW-related data collection projects should be made public as close to project initiation as possible. Project descriptions should be shared in a public catalog, or portal such as Tethys[20], to support coordination around the use of space, shared platforms, and common methods.
- Data should be published in existing disciplinary repositories and made as public as possible and only as private as necessary. Data should be structured and formatted with the intent to share from the very beginning, with the data standards required by the target repository flowing into the study design and collection workflows.
    - If data collection is funded by the state or required for state compliance, public data sharing expectations should be clear in permit requirements, grants, and/or contracts.
    - Create a list of recommended repositories for each relevant data type which can be cited by reference in contracts, grants, and permits.
    - For the small number of data types without an existing, commonly used repository (e.g. video), subject matter and technology experts should collaborate with global standards partners (such as the Research Data Alliance, Intergovernmental Oceanographic Commission, or Marine Imaging Society) to ensure that data are as FAIR as possible.
- California should consider creating model data policies for state agencies and project funders that address:
    - Industry review processes for data sharing and what types of proprietary data from industry will not be shared
    - Terms of limited embargoes for data review and journal publication
    - Data and data product licensing
    - Tribal data sovereignty in the context of CARE principals (Collective Benefit, Authority to Control, Responsibility, and Ethics developed by the Global Indigenous Data Alliance), supporting tribal ownership and control of their own data.
- Investing in pooled training data for automation could reduce future monitoring costs and improve event detection. Open-source computer vision models, annotation software, and other data process tools exist now but are limited by a lack of data. California could invest in secure data pooling for imaging data to scale up AI tools for the field.
- Software for collection, quality control and assurance, managing, organizing, and analyzing data should be auditable and ideally open source.
- The state should review existing cybersecurity and information security protocols for state agencies and determine any minimum recommendations that need to be made for data collection and storage projects. This is a particular issue for data that are

[20] https://caoffshorewind.databasin.org/

collected and/or transferred directly on and via infrastructure, such as satellite transmissions from sensors on turbines.

- Successful data management, sharing, and storage requires long-term investments and dedicated staff. The state should maintain essential data infrastructure throughout the 30–40-year term of an offshore energy project and beyond. While the baseline cost of data storage is falling, data stewards are needed to ensure data moves from collection to information and knowledge into the data products needed to reach target audiences.
    - Data projects funded or authorized by the state should include explicit data management and sharing activities in their budget, for at least 10% of the total project costs.
    - The state could consider creating a data sharing institution that provides long-term data services and cost-recovery via subscription or other revenue generating activities.
- Account for regulatory policies and guidance when designing data collection to reduce need for redundant assessments to achieve standards necessary for permits and authorizations, as well as engineering.
- Consider alternatives to data collection when monitoring is infeasible, or it is cost- or time prohibitive to collect sufficient data for statistical power and reduction of uncertainty.

4. Technology

3. Technology

Technology is constantly changing and improving. The ability to monitor environmental effects of OSW is related to the capabilities, availability, and cost of technologies that serve as tools to collect data. Oceanographic monitoring has been ongoing for many purposes over decades, driving the development of a variety of platforms and sensors. Terrestrial data collection, such as for learning about onshore wind effects on birds and bats, has also driven technology development for monitoring. Technology can be pre-existing, adapted, or bespoke for questions related to OSW adverse and beneficial effects on wildlife and habitats.

Platforms and sensors are defined in the key terms below. In some cases, platforms and sensors may not be “technologies,” for example, when animals serve as the platform for tags or human observers serve as sensors on a vessel. Commercialization of technologies has been an important part of improving the ability to collect data in offshore environments, and offshore industry demand for these technologies has been a key driver of commercialization.

California and the US West Coast have unique environmental features that require different technology than the US East Coast. Also, unlike projects to date on the US East Coast, California OSW will be floating infrastructure, which has different infrastructure and environmental risks than fixed. Thus, technologies developed for US East Coast projects continue to need adaptation to address deeper water, different infrastructure, different currents and ocean conditions, and other differences from the US East Coast. Transitioning from mostly crewed to new uncrewed platforms and autonomous sensors has also been underway worldwide and continues to be an important part of technology development for OSW monitoring.

This section of the Framework also covers analytic technologies for data analysis, management, and use. Analytic technologies include fixed algorithms and the adaptive computer science models referred to as Artificial Intelligence (AI) such as Machine Learning and Computer Vision.

3.1 Key Terms

Platforms

These are structures that carry sensors. Example platforms include animals (carrying tags or bands) as well as ships, drones, submersibles, buoys, satellites, and turbine infrastructure. The IOOS maintains a standardized list of platforms at http://mmisw.org/ont/ioos/platform.

Sensors

Sensors collect data and are typically carried by platforms. Sensors can include human observers, cameras, acoustic receivers, and animal tags. Humans and animals are not "technologies," but technologies can be used by humans or deployed on animals. Technology development has resulted in opportunities for more augmented and remote studies.

Analytic Technologies

Analytic technologies include hardware, software, and mathematical and computer science techniques that are used for data acquisition, storage, sharing, transmission, management, QA/QC, formatting, or analysis. An example is algorithms for classification of animal species from PAM data.

3.2 Technology Categories

Technology can be broken down into sensors/data collection equipment (hereafter referred to simply as "sensors") and platforms. Sensors collect specific data or samples, such as PAM systems, radar, and cameras. Platforms are where sensors are housed or deployed, such as vessels, buoys, and autonomous underwater vehicles (AUVs). Below is a high-level breakdown of types of sensors and platforms. An overview of which sensors can be used to collect different data categories is presented in Appendix G. To review which platforms these sensors can be deployed on, see Appendix H.

Sensors:

- Passive acoustic monitors (e.g. hydrophones, ultrasonic recorders)
- Active acoustic monitors (e.g. sonar, echosounders)
- Tags (e.g. bird bands, satellite tags, GPS tags, suction-cup temperature depth recorders, radio tags, passive integrated transponders, Motus tags)
- Environmental sample collectors (e.g. water samplers, eDNA samplers, box grabs, sediment corers, conductivity/temperature/depth sensors)
- Vibration sensors
- Light/heat sensors, optical backscatter and turbidity.
- Radar[21]
- Metocean condition sensors (e.g. LiDAR, FLiDAR, Acoustic Doppler Current Profiler [ADCP])
- Nets, traps, and other items for organism collection (e.g. plankton tows, fish tows or pots, mist nets, seines)

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[21] https://ioos.noaa.gov/project/hf-radar/

- Imaging systems (e.g. digital cameras, infrared cameras, thermal imagers, night vision devices, sediment profile imagers, side scan sonar, video, satellite imaging systems)
- Biological/physiological samplers/monitors (e.g. biopsy samplers, blood samplers, whale blow samplers)

Platforms:

- Mobile
  - Crewed water-based vessels (e.g. ships, zodiacs, remote operated vehicles [ROVs])
  - Autonomous water-based vessels (e.g., AUVs/Autonomous Surface Vessels/Gliders,)
  - Crewed aerial vessel (e.g. plane, helicopter)
  - Autonomous aerial vessel (e.g. drone)
  - Animals (e.g. animals can carry tags, bands)
  - Satellites
- Fixed
  - Buoys (moored with surface float)
  - Offshore wind infrastructure (e.g. blades, nacelles, turbines, cables, moorings)
  - Subsea moored platforms (e.g. moored housings for fish video)
  - Cabled infrastructures and sensing systems (temperature, ocean sound, ocean bottom pressures are all EOVs that can be measured via fiber optic cables and are being developed in GOOS linked efforts)
  - Other infrastructure (e.g. other dedicated monitoring platforms, aquaculture facilities)

Analytic Technologies:

- Software (e.g. general purpose, custom, computer programs, coding)
- Hardware (e.g. edge machines in the field, office systems, data storage drives)
- Algorithms (e.g. target identification, sorting and searching - processes to be followed)
- Artificial intelligence, including computer vision and machine learning (e.g. process automation, prediction, summarization - data trained and validated systems without rules defined in advance)

There are a variety of reviews of existing and emerging technologies available (e.g., Forsblom et al. 2024; Szesciorka et al. 2025; Wind Energy-Environmental Research and Engagement Network 2025; supplementary materials accompanying Dorrian et al. 2025 and Courbis et al. 2024). These databases and descriptions are mainly static but provide detailed descriptions of a variety of makes and models of sensors, platforms, and analytic technologies and some of the methods and data associated with their use. It is difficult to rely on static descriptions of technologies and technology readiness levels to assess proposed future research methods, but these materials provide researchers developing projects with starting points for evaluating available and emerging options for addressing research questions and identifying contemporary opportunities and limitations in data collection. It is not necessary to repeat such a review here.

There are several relevant national and international organizations and networks that are regularly convening experts to set and revise standards and practices using such technologies, all of which have strong participation from California. Examples include:

- Animal Borne Ocean Sensors (AniBOS) https://anibos.com
- OceanGliders: https://www.oceangliders.org
- Global HF Radar Network: http://global-hfradar.org
- Ocean Biomolecular Observing Network (OBON): https://obon-ocean.org
- OceanSITES: https://ocean-sites.org/
- Deep Ocean Observing Strategy (DOOS): https://www.deepoceanobserving.org
- U.S. Ocean Sound Monitoring and Condition Reporting: https://www.soundscapemonitoring.us

3.3 Technology Uses

Technologies will be used for both mitigation and monitoring. In some cases, monitoring will be necessary to implement mitigation or to determine effectiveness of mitigation. Different technologies and methods will be needed for real-time and archival monitoring, as well as short-term and long-term data needs to address priority questions. Studies to assess change will most likely require before/after study designs and control sites. Monitoring also has a legal component, demonstrating compliance with permit and authorization requirements. To achieve sufficient monitoring effort for these uses, relevant technologies will need to be accessible, available, relatively inexpensive, scalable, durable, and reasonably easy to employ.

An important use of technologies will be to expand monitoring to better integrate observational and environmental conditions information to inform understanding of relationships among environmental variables and the biological parameters of taxa and habitats. Multi-sensor systems and concurrent, collaborative study designs that take advantage of improved autonomous platforms will allow for large-scale and long-term monitoring.

The presence of platforms of opportunity for monitoring, such as infrastructure and vessels for OSW, will create new avenues for data collection and can be considered early in planning to improve integration with OSW site assessment, installation, and operations. Long-term, autonomous platforms deployment can provide information on rare events, like use patterns of endangered species for which robust data are difficult to obtain.

There are also efforts to explore broad collaborative science, leveraging OSW as an ecological monitoring tool (Kohut et al. 2025). Efforts such as Mission is the OCEAN (MOCEAN) are advancing technology and data-driven frameworks to leverage OSW infrastructure for nature-inclusive design, which will need evaluation and adaptation through monitoring efforts. MOCEAN is developing a technical report that includes discussion of data needs and structures for validating technologies in the context of ecological benefits.

3.4 Technology Strengths, Limitations, and Gaps

Strengths, limitations, and gaps related to technology vary depending on the monitoring question, the environmental conditions, and the taxa or habitat under consideration. Technology gaps for bird and marine mammal OSW monitoring were reviewed in Courbis et al. (2024), along with a description of limitations and constraints of existing sensor, platform, and analytic technologies. Many of the gaps identified in evaluating technology for bird and marine mammal monitoring are applicable to other taxa and habitats. Examples of limitations of many systems include the following:

- Battery life/Access to power
- Data storage and remote data transfer limitations
- Lack of data to parameterize algorithms and trainAI for identifying, localizing, and classifying animals and filtering clutter
- Field-of-view and resolution constraints to enable observation across a wide range of object sizes and concentrations
- Depth/pressure operating constraints
- Sensors are poor at detection of small-bodied (imaging) and high-frequency (acoustic) animals at longer ranges, although recent progress is progressing rapidly
- Lack of protocols to integrate datasets at different spatiotemporal scales (body size spectra information is vital for this)
- Invasive and short-term nature of tags, physiological/biological sampling, and tag deployment
- Lack of stable platforms (physical movement of floating platforms) for systems that need stabilization (e.g. systems like radar or cameras can require gyro-stabilized mounts)

- Lack of commercial scale production of some types of tags and monitoring technologies that have historically lacked commercial drivers (e.g., some types of marine mammal tags have generally been built by individuals for bespoke project work and are difficult to source commercially)
- Lack of equipment weatherization and robustness to harsh marine environments
- Lack of availability of integrated systems with multiple sensors in platforms (i.e. platforms allowing standardized multi-sensor attachment and use are not available at commercial scales sufficient for demand anticipated by offshore wind studies)
- Lack of calibration or training datasets in some cases
- Lack of small, autonomous systems that do not require much maintenance and can be deployed and used by vessels and activities of normal windfarm operations[22].

For sensors that could be deployed on infrastructure, there are limitations related to timing of monitoring planning relative to engineering, procurement, and financial milestones for OSW projects. Ideally, engineering solutions to monitoring needs could, in some cases, be built into infrastructure. Some examples of this include distributed acoustic sensing in cables, pre-determined space on turbine platforms to attach specific long-term, autonomous sensor packages, or vibration sensors in blades or on moorings that can detect wildlife or debris interactions (in addition to other equipment integrity issues being monitored for infrastructure performance). In any case, when data collection may be best accomplished through integration of technologies with infrastructure, early planning and design should account for technology and be aligned with timing associated with procurement and manufacturing and project financial and engineering milestones.

There are considerable strengths in using autonomous, commercial platforms with multi-sensor systems that can collect data across multiple environmental parameters and connect ecosystem information with animal use patterns and habitat health. There

[22] As with tags and integrated systems noted above, some small, autonomous systems exist, but more types are needed and they are needed at commercial scale with manufacturers' support (such as troubleshooting and replacement parts), cost reductions that come from sufficient supply and experienced technicians, and availability for procurement without extensive wait time or uncertainty. They also need to be vetted and acceptable to regulatory agencies for purposes of supporting data collection and monitoring for permitting and compliance. More technology is being developed and tested each day, but industry will need repeatable, standardized, cost-efficient, easily attainable, and agency-acceptable options at scale, with competition among manufacturers and vendors to maintain quality and reasonable cost. See Courbis et al. (2024) for further discussion of gaps in technology identified in workshops that considered bird and marine mammal monitoring for offshore wind studies.

are programs underway to develop such technologies. For example, there are a variety of studies funded by the National Offshore Wind Research and Development Consortium (NOWRDC) to develop autonomous platforms with new capabilities to monitor environmental conditions and effects of OSW (NOWRDC 2026).

General limitations and opportunities for sensors are shown in Appendix I, and for platforms in Appendix J.

3.5 Efficacy and Acceptance

Assessing new technology, modified technology, and new uses of existing technology for efficacy and accuracy in OSW monitoring can be difficult, and there are no standard procedures in OSW environmental monitoring with respect to evaluating and approving technologies for use. In addition to regulatory considerations and approvals by agencies, public trust and confidence are important. If data are collected with technologies that are not accepted by some of the regulatory agencies or significant sectors of stakeholders, there will be hesitation in the long run to use these technologies and the data they collect may not be used to its full potential.

Thus, performance standards and procedures for vetting new and modified technologies would be helpful to reducing uncertainty about technologies and ensuring quality data collection. *A framework for validation that includes a third-party review, possibly a standing board or panel for review, could improve technology uptake and encourage and de-risk innovation (see IOOS 2026a[23], 2026b[24]).*

Testing and vetting of technology are part of development. For example, Xu et al. (2025) tested and validated distributed acoustic sensing technology for assessing structural health of OSW turbines (e.g. Xu et al., 2025). Such technology could potentially also be purposed to collect acoustic data useful to wildlife monitoring, but there are no standards or vetting process accepted by relevant regulators to undertake such vetting. Studies have shown the ability of distributed acoustic sensing to detect baleen whale calls (Wilcock et al., 2023). If there were a process and a board or panel to review technology, there could be a clear path to evaluate whether such a technology could reach the necessary thresholds of efficacy necessary for OSW monitoring programs.

Minimum performance standards for particular monitoring studies should consider the questions under study. For example, detection of birds or whales as a presence/absence question would not require systems that can accurately triangulate

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[23] https://cdn.ioos.noaa.gov/media/2017/12/ott_process_description.pdf
[24] https://ioos.noaa.gov/project/ocean-technology-transition/

on animal location or may not require capability to identify to species. An acoustic detector for bats and one for fish would have different frequencies of best operation and need to operate in different media (air versus water). Context will affect appropriate performance standards. Cost is also important given limited resources. *Benchmarks for standards rather than relative ranking of technologies against each other is important to avoid driving up costs.*

Further, use of AI is new and could be highly useful for some aspects of monitoring; however, there are no significant standards around AI use. Because of the rapidly growing use of AI, it is important to consider standardization of approaches to training datasets and methods, quality control and assurance, assessing error rates, model auditability and transparency, cybersecurity, and other new issues raised by the use of AI. See also NOAA AI Policy[25].

Another aspect of efficacy is redundant systems. Technology design and monitoring methods should account for potential failures and assess which aspects of systems are weak points where redundancy or other remedies are then built into systems or methods.

3.6 Procurement, Availability, Commercialization

The scale and scope of OSW monitoring will require technologies to be available at commercial scale to maintain consistency and support for systems. Commercial investment in innovation and manufacture of systems requires certainty that there is a viable market and commitments to procurement.

Technologies developed as part of academic or agency research can potentially be scaled. An example of a system for technology innovation and transfer is the NOAA technology transfer program[26]. This system was designed to move technologies developed by NOAA into the commercial market. *A clear system for scaling up and commercializing technology for monitoring could de-risk development and encourage more innovation.*

Monitoring before, during, and after wind infrastructure installation will likely include partnership with developers, regulators, NGOs, and academic institutions. There can be many models for technology acquisition, including building, leasing, or buying. Choices

[25] https://www.noaa.gov/nao-216-128-artificial-intelligence-in-noaa

[26] https://techpartnerships.noaa.gov/techtransfer/#:~:text=The%20NOAA%20Technology%20Transfer%20Program,overall%20goals%20of%20NOAA's%20mission.

in technology will be question specific and, by necessity, must consider value in terms of data obtained relative to cost and convenience, as well as compliance.

3.7 Technology Recommendations

The ability to monitor environmental impacts from OSW hinges on the capabilities and availability of technology tools. To optimize monitoring technology use, experts suggest:

- Use multi-sensor systems and concurrent, collaborative study designs that take advantage of improved autonomous platforms for large-scale and long-term monitoring.
- Use emerging technologies to integrate observational and environmental conditions information to inform understanding of relationships among environmental variables and the biological parameters of taxa and habitats.
- Coordinate monitoring planning for installation and operations early, ideally prior to design and procurement of infrastructure in alignment with financial, engineering, procurement, and permitting milestones. Engineering solutions to monitoring needs could, in some cases, be built into infrastructure.
- Develop standards and processes for technology demonstration and acceptance – possibly a panel or board for review[27].
- Create a clear pathway to transitioning demonstration technologies to commercialization – include pathways to efficiency and cost reduction.
- Develop or adapt an existing system for easily scaling up technology for offshore wind monitoring.
- Undertake efforts to improve calibration and validation of technology and develop training and testing datasets for analytic technologies.
- Leverage platforms of opportunity (e.g. fishing vessels, ongoing research)
- Invest in technologies and innovation – some will fail but that is an important part of innovation.
- Prioritize funding and development of technology that can collect the greatest breadth of data across questions.
- Reduce need for physical access to sensors on infrastructure by improving remote access to power and capabilities for remote data transfer.

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[27] Standards should be benchmark-based rather than relative. Setting standards that are clear and meet the needs of scientific rigor and regulation for different monitoring questions and eventual mitigation expectations will allow design of technology that ultimately improves outcomes rather than striving to be equivalent to current technologies and will reduce confusion and rejection of technologies during regulatory phases of wind development. Technologies do not need to be perfect; they need to meet standards that allow for reasonable scientific assessment and mitigation to occur.

- Standardize interfaces with infrastructure, including possible dedicated space for monitoring technologies.
- Develop deployment configurations and equipment to reduce interference from structures (e.g., blind spots in radar).
- Assess how AI could assist with data collection, validation, quality control and assurance, management, sharing, and analyses and what is the most useful investment.
- Develop standards for use of AI.

4. Framework Findings

4.1. The Challenge of Monitoring for Impacts in the CCLME

Monitoring OSW development in the CCLME is fundamentally different from other places where floating OSW has occurred including the Atlantic or North Sea. While those regions feature relatively stable, shallow shelf environments, California's lease areas sit within one of the most biologically productive yet oceanographically variable boundary currents on Earth. The CCLME is driven by seasonal upwelling, where northerly winds push surface waters offshore, drawing cold, nutrient rich water from the deep to the surface. This process fuels a bottom up system, with plankton, forage fishes and invertebrates (e.g., Pacific sardine, Northern anchovy, and krill) supplying energy to higher trophic level species such as white sharks, blue whales and seabirds (Bizzarro et al., 2023; Thompson et al., 2019). The CCLME is highly variable but produces persistent biological hotspots such as the Monterey Bay Canyon or the Channel Islands, where predators congregate to feed. In addition, the CCLME supports the largest daily migration of biomass on Earth (Hernández-León, 2023), as zooplankton and mesopelagic fish move from the deep twilight zone to the surface at night to feed, sequestering carbon in the process. Variations related to the El Niño and La Niña can link the surface ocean and to deep-sea community changes (e.g. Smith et al., 2013).

Currently the CCLME is undergoing rapid climate-driven transitions, many of which remain poorly understood. Monitoring within such a highly dynamic and variable ecosystem thus presents a significant challenge: isolating the specific impacts of OSW from the background signals of climate change. Climate change acts as a potential threat multiplier in the CCLME, introducing environmental volatility that obscures the ability to isolate and predict impacts of OSW-induced changes. This variability is driven by several stressors: ocean acidification, which is occurring at twice the global rate and destabilizing the forage base (like shell-forming organisms such as pteropods) (Osborne et al., 2020) for higher- trophic species; expanding hypoxic dead zones, which vertically compresses available habitat for high priority rockfish and groundfish (Barth et al., 2024; Gomes et al., 2024; McClure et al., 2023); and more frequent marine heatwaves, such as "The Blob," which drive rapid regime shifts that render past datasets unreliable for predicting future ecosystem states (Jacox et al., 2022). Current management models are ill-equipped to address the cumulative impacts of OSW projects and existing ocean stressors to the CCLME. Consequently, introduction of OSW infrastructure into these already compressed and chemically shifting habitats creates an unprecedented scenario where cumulative stressors may reach a breaking point that traditional management models are ill-equipped to address.

4.2. Cumulative Impacts, Limitations, and Uncertainties

The ultimate intensity of environmental impacts will hinge on the degree to which OSW farms alter foundational physical and biological oceanographic processes within the CCLME. Research at the time of writing only considers planned California lease areas; how potential impacts interact and their cumulative effects from a full OSW build-out were not considered in this process. Some effects can be extrapolated from existing offshore infrastructure (e.g., reef effects from oil rigs), and while cumulative impacts of large-scale floating OSW in the CCLME are novel and remain uncertain, OSW development in other locations (e.g., the North Sea) has been extensive, and cumulative ecosystem effects appear to be minimal. The scale of effect may be contingent on turbine array density (i.e., the number of turbines in an array) and the number of arrays deployed, with the intensity of effects increasing as more WEAs are developed. That said, WG consensus indicates that most direct environmental effects from initial OSW development are likely to be minimal at the population level and are also likely to be challenging to detect relative to natural variability of the CCLME, highlighting the importance of targeted monitoring.

Considering Climate Change and Natural Variability

Distinguishing OSW-specific impacts from natural and anthropogenic variability to behavior, distribution, demographic changes, and other effects with multiple drivers will be extremely challenging. As species distributions shift due to changing ocean conditions (e.g., marine heatwaves and acidification), it will be increasingly difficult to determine whether these shifts are caused by OSW or broader stressors. Projected climate effects are consistently a more consequential threat to marine life than OSW development itself. Observing system simulation experiments (OSSEs) and power analyses can be used to assess the impact and feasibility of specific tools to address this challenge.

4.3 Overarching Foundational Recommendations

The following recommendations represent priorities identified by all scientific WGs. They address pre-, during, and post-construction monitoring and inform best practices. These recommendations, with those presented in the Data and Technology sections, lay the foundation for monitoring that all impact-specific recommendations (see sections 5.3, 6.3, 7.3, 8.3) must build upon and adhere to.

Continue to Build Out a Coordinated Ocean Observing System: Prioritizing existing monitoring programs and further develop an integrated, statewide observing network that combines acoustic monitoring, visual surveys, tagging, oceanographic sampling, and emerging technologies to enable continuous, ecosystem-scale observation. Optimize observation platforms by aligning data collection targets across studies and taxa and deploying sensor arrays and monitoring tools that can capture multiple variables at once.

Mandate Baseline Data Collection on Priority Proxy Species to Isolate OSW Impacts from Natural Environmental Variability: Prioritize the immediate collection of baseline data regarding the distribution, abundance, and habitat use of select "priority species" to serve as ecological proxies for broader taxonomic groups. Without robust, high-resolution baseline data on these key indicator species, it will be statistically impossible to differentiate between natural ecosystem variability and potential anthropogenic impacts of OSW development.

Integrate Physical and Biological Monitoring: Co-monitor physical oceanographic drivers alongside biological variables (e.g., prey and predator dynamics) to better understand OSW impacts and distinguish them from natural CCLME variability and climate change.

Strengthen Experimental Design and Validation: Utilize control sites unaffected by OSW to improve impact attribution. Perform comparative studies between established and emerging platforms (e.g., traditional surveys vs. autonomous sensing) to establish monitoring methods that are validated, scalable, and taxon-appropriate.

Support and Develop Regional, Multi-Year Pre-Construction Baselines: Invest in ongoing and new targeted year-round and multi-year monitoring to capture seasonal patterns and interannual variability in distribution, migration, and spatial use for priority taxa where such data is feasible to collect prior to OSW development. Focus efforts in high-use areas (e.g. migratory corridors and foraging hotspots) with potential to overlap with OSW to improve baseline understanding of variability and inform impact assessment.

Design Lifecycle-Based, Statistically Robust Monitoring: Build on and enhance long term observation networks across CA to support monitoring that spans all phases of OSW development project phases. Apply standardized, statistically robust study designs (e.g., BACI or equivalent) and ensure sufficient spatial and temporal coverage to detect change, while accounting for natural variability and leveraging coordinated, multi-program datasets.

Support Impact Assessment that Could Inform Management: Collect data in a manner consistent with long-term data integration and use for assessment of impacts, mitigation efficacy, and adaptive management.

Support Spatial Risk Assessment and Data Integration: Conduct regional spatial analyses to evaluate overlap between WEAs priority species, habitats, and ecological use areas. Leverage existing platforms to integrate and visualize relevant datasets, supporting improved understanding of potential interactions and inform sighting, mitigation and decision-making processes.

Evaluate Cumulative and System-Level Impacts: Assess OSW development within the context of cumulative stressors, ecosystem dynamics, and interconnected socio-ecological systems. This systems-level approach is vital for distinguishing OSW-specific effects from broader environmental changes, supporting management strategies that address the total impact on ocean health rather than just isolated variables.

Leverage Existing Data and Target Data Gaps: New efforts should build upon the robust monitoring foundation in the CCLME by synthesizing existing datasets to understand typical variability. Prioritizing continuity of long-term programs improves data integrity, while gap and power analyses across priority taxa and habitats can strategically direct future investments toward the most critical information deficiencies, ensuring that limited resources effectively strengthen understanding of the ecosystem.

Establish Coordinated Governance and Stakeholder Engagement: Develop formal multi-stakeholder structures to align monitoring priorities and review findings to support and promote integration between agencies, tribes, the OSW industry, ocean users, and scientific community.

Secure Long-Term, Regional Funding: Develop sustained, regional funding mechanisms (e.g., pooled developer contributions) to support data integration and management, long-term monitoring, and research, beyond individual projects.

Establish a Dedicated Nearshore Monitoring Strategy for Humboldt Bay: Given its unique intersection of exceptional ecological and cultural value and concentrated industrial development, a targeted, Humboldt Bay-specific study should be prioritized to inform monitoring to capture the cumulative impacts of extensive construction dredging, alterations to channel morphology, and permanent habitat conversion.

4.5 Working Group Findings

Sections 5-8 present the results and discussion of the stoplight assessments and species prioritization exercises by each ecological WG. IPFs and associated impacts ranked as high priority[28] and knowledge gaps[29] are presented alongside the relevant high priority species and associated habitats.

Each section concludes with WG-specific foundational recommendations designed to address pre-monitoring needs and inform monitoring best practices. Impact-specific recommendations are presented as a series of targeted MQs in detailed tables that address the priority impacts identified by the WG and an assessment of the applicable sensors/data collectors and their relative monitoring capabilities. Where applicable, examples of West Coast monitoring programs and projects that employ these sensors were included to show their current application. For a review of existing California ocean monitoring programs see Appendix E.

[28] High priority IPFs and associated impacts were ranked as moderate or major intensity and almost certain, likely, or possible probability (Table 3).
[29] Knowledge gaps were ranked unknown in either intensity or probability (Table 3).

5. Habitats, Ecosystems, and Oceanography

5.1 Habitats, Ecosystems, and Oceanography Results

5.2 Habitats, Ecosystems, and Oceanography Discussion

5.3 Habitats, Ecosystems, and Oceanography Recommendations

5. Habitats, Ecosystems, and Oceanography

5.1. Habitats, Ecosystems, and Oceanography Results

The Habitats, Ecosystems and Oceanography WGs were divided into three subgroups:

- Nearshore benthic and pelagic habitats were defined as coastal habitats between zero and three nautical miles from the mean high-water line and included soft- and hard-bottom substrate, biogenic habitats, and the water column.
- Offshore benthic was defined as soft- and hard-bottom substrate, including biogenic habitats, extending beyond three nautical miles from the coast.
- Offshore pelagic was defined as open pelagic waters extending beyond three nautical miles.

Priority habitats (Table 1), relevant habitat-defining species (Table 2) and priority physical oceanographic processes (Table 3) were identified for monitoring by WG chairs for each subgroup.

Table 1. *Priority habitats by subgroup*

Priority Habitats
Nearshore Benthic and Pelagic: Estuaries, Saltmarshes, Eelgrass beds, Mudflats, Rocky intertidal, Kelp Forests, Sandy Beach **Offshore Benthic**: Hardbottom, Deep reefs, Seamounts, Canyon walls, Asphalt volcanoes, Rocky outcrops/banks, Subtidal softbottom, Pockmark fields **Offshore Pelagic**: Pelagic zone

Table 2. *Relevant habitat-forming species by subgroup*

Relevant Habitat-Forming Species
Nearshore Benthic and Pelagic: Pickleweed *(Salicornia pacifica)***,** Salt Grass *(Distichlis spicata)***,** *Alkali Heath (Frankenia salina)***,** Cordgrass *(Spartina foliosa)***,** Common Eelgrass (*Zostera marina)***,** Giant Kelp (*Macrocystis pyrifera)***,** Bull Kelp (*Nereocystis luetkeana),* Olympic Oyster (*Ostrea Lurida)* **Offshore Benthic:** Structure-forming sponges**,** Deep-sea corals**,** Deep-sea sponges Soft corals and sea whips (Gorgonians), Sea anemones *(Metridium farcimen)*, Sea lilies and feather stars (Crinoidea), Sea pens (Pennatuloidea) **Offshore Pelagic**: Pelagic zone species

Table 3. *Priority physical oceanographic processes*

Priority Physical Oceanographic Processes
Estuarine circulation Coastal upwelling Curl-driven upwelling Longshore transport Mesoscale eddies and filaments Fronts Offshore Ekman transport

Nearshore Benthic and Pelagic Habitats

Infrastructure and environmental pollutants were identified as the priority IPFs for the nearshore benthic and pelagic subgroups (Table 4). Infrastructure-related impacts focus on habitat degradation during construction and alteration of biological oceanographic processes across construction and operational phases. Several habitats should be monitored for habitat degradation.

Table 4. *IPFs and associated impacts by development phase, and attributed priority habitats for nearshore benthic and pelagic habitats*

IPF	Impact	Development Phase	Priority Habitats
Infrastructure	Habitat Degradation	Construction	Estuaries Salt marshes Eelgrass beds Mudflats Kelp Forests Rocky intertidal Sandy beach Pelagic zone
Infrastructure	Biological Oceanographic Processes	Construction, Operation	Pelagic zone Subtidal softbottom
Environmental Pollutants	Habitat Degradation	Construction	Estuaries Salt marshes Eelgrass beds Mudflats Kelp Forests Sandy beach Pelagic zone Subtidal softbottom

Nearshore Benthic and Pelagic Knowledge Gaps

The impact of infrastructure on habitat during operation was identified as a knowledge gap for nearshore benthic and pelagic subgroups (Table 5).

Table 5. *Knowledge gaps associated with IPFs and associated impacts by development phase and priority habitats for nearshore benthic and pelagic habitats*

Knowledge Gap	Habitats
The impact of infrastructure on habitat creation during operation.	Estuaries Salt marshes Eelgrass beds Mudflats Kelp forests Rocky intertidal Sandy beach Pelagic zone

Offshore Benthic Habitats

Infrastructure was noted as the high priority IPF for the offshore benthic subgroup with potential impacts to habitat degradation during construction and operation phases, habitat creation during the operation phase, and altered physical oceanographic processes during the operation phase (Table 6).

Table 6. *IPFs and associated impacts by development phase, and attributed priority habitats for offshore benthic habitats*

IPF	Impact	Development Phase	Priority Habitats
Infrastructure	Habitat Degradation	Construction, Operation	Subtidal soft bottom Deep reefs Rocky outcrops Seamounts Canyon walls Pockmark fields Asphalt volcanoes Hydrothermal vents
Infrastructure	Habitat Creation	Operation	Subtidal softbottom Pockmark fields Pelagic zone

IPF	Impact	Development Phase	Priority Habitats
Infrastructure	Physical Oceanographic Processes	Operation	Pelagic zone

Offshore Benthic Knowledge Gaps

The impact of infrastructure on biological oceanographic processes was noted as a knowledge gap in deep reefs (Table 7).

Table 7. *Knowledge gaps associated with IPFs and associated impacts by development phase and priority habitats for offshore benthic habitats*

Knowledge Gaps	Priority Habitats
The impact of infrastructure on biological oceanographic processes during construction and operation.	Deep reefs

Offshore Pelagic Habitats

Infrastructure was identified as the high priority IPF for biological and physical oceanographic processes (Table 8).

Table 8. *High priority IPFs and associated impacts by development phase, and attributed priority habitats for offshore pelagic habitats*

IPF	Impact: Development Phase	Priority Habitats
Infrastructure	Biological Oceanographic Processes: Operation	Pelagic zone
Infrastructure	Physical Oceanographic Processes: Operation	Pelagic zone

Offshore Pelagic High Priority Knowledge Gaps

The impact of infrastructure was noted as a knowledge gap (Table 9).

Table 9. *Knowledge gaps associated IPFs and associated impacts by development phase and priority habitats for offshore pelagic habitats*

High Priority Knowledge Gap	Priority Habitats
The impact of infrastructure on habitat creation during construction and operation.	Pelagic zone

5.2. Habitats, Ecosystems, and Oceanography Discussion

Offshore wind infrastructure is expected to impact nearshore and offshore habitats and oceanographic processes through benthic disturbances, resuspension and distribution of sediment, and altered physical oceanographic processes (BERR, 2008; Hemery & Henkel, 2015). Uncertainty on intensity and extent of impacts represents an important knowledge gap.

Impacts from Infrastructure

Expert subgroups across habitats, ecosystems, and oceanography identified OSW infrastructure as a priority IPF. This infrastructure drives environmental change through two primary pathways: physical habitat transformation and hydrodynamic disruption. The physical presence of infrastructure introduces an inherent ecological trade-off across distinct project phases: construction and operational. During the operational phase, these impacts persist long-term as the introduced structures create novel, permanent hard-bottom habitats in previously soft-bottom-dominated areas (BERR, 2008; SEER, 2022). These new surfaces act as artificial reefs that rapidly attract fouling communities, alter regional biodiversity, and introduce organic enrichment to the surrounding seabed via biological waste fallout.

Impacts from Environmental Pollutants

The physical installation of cables, anchors, and foundations causes localized seafloor disturbance and sediment resuspension, releasing environmental pollutants (e.g., heavy metals, persistent organic pollutants) and altering baseline physical and biological processes (Farr et al., 2021; McLean et al., 2022). This stage poses an acute threat via the release of sequestered pollutants, particularly during port dredging and cable burial (Bridges et al., 2008; Taormina et al., 2018). Once disturbed, these contaminants partition into the water column and can be transported significant distances (BERR, 2008). The risk of toxin resuspension is highest in industrialized areas or historic disposal sites, where it can degrade water quality, deplete dissolved oxygen, harm filter feeders, and trigger harmful algal blooms (HABs) (BERR, 2008; Jabusch et al., 2008).

High Priority Habitats and Physical Oceanographic Processes

Priority habitats and physical oceanographic processes key to monitoring OSW impacts are presented below.

Estuaries, Salt Marshes, Eelgrass Beds, and Mudflats

Estuaries are vital land-sea interfaces that provide water filtration and nursery grounds for Pacific salmon and groundfish (NOAA Fisheries, 2022a). These low-energy environments are exceptionally sensitive to mechanical disturbances from OSW cable landfall and port expansion (BERR, 2008). Construction-related resuspended sediment plumes can smother salt marsh vegetation, physically inhibiting photosynthesis and reducing both plant coverage and invertebrate abundance (Ward & Beheshti, 2023). Dredging may liberate legacy toxins or dormant cysts from the sediment, decreasing water quality and impacting shellfish safety (Ward & Beheshti, 2023). Alterations in estuary hydrology due to dredging deeper channels for ship access may also increase erosive forces on the marsh plain foreshore and tidal channels, leading to marsh plain loss (Van Dyke & Wasson, 2005).

Rocky Intertidal and Kelp Forests

The rocky intertidal and nearshore kelp forests represent important hard-substrate habitats defined by complex architecture that provides essential refugia for juvenile fish and colonization surfaces for diverse invertebrate and algal communities (NOAA Fisheries, 2022b). Cable landfall poses a threat of direct habitat destruction, particularly when mechanical excavators are utilized for installation (Taormina et al., 2018). Sediment resuspension from construction endangers kelp canopies, designated as Habitats of Particular Concern for groundfish, by reducing light availability below the thresholds required for sporophyte growth (NOAA Fisheries, 2021; Tait, 2019). Furthermore, increased sedimentation can stifle kelp reproductive capacity by smothering microscopic reproductive stages and physically preventing germination of spores (Springer et al., 2007).

Sandy Beaches

Sandy beaches serve as vital habitat for diverse invertebrate communities and provide essential nesting and foraging grounds for shorebirds, particularly the federally listed Western Snowy Plover (Nielsen et al., 2013). Installation of cables across sandy beaches can generate turbid sediment plumes during the trenching and burial process; if they are not buried, habitat conversion can occur by introduction of hard surfaces into previously soft-bottom areas (Taormina et al., 2018).

Rocky Reefs and Outcrops

Rocky reefs provide essential physical relief that supports diverse marine ecosystems across the California shelf (NOAA Fisheries, 2022b). In aphotic waters, these areas are dominated by structure-forming invertebrates such as deep-sea corals and sponges, which enhance habitat complexity and provide biogenic refugia for approximately 30% of California’s commercially landed fish species (Selgrath et al., 2026). Beyond serving as Essential Fish Habitat (EFH), deep sea sponges perform key ecosystem functions, including nutrient cycling, water filtration, and benthic-pelagic coupling (Thompson & Fuller, 2020).

Installation of OSW infrastructure poses risks to these sensitive habitats through direct crushing or sediment resuspension. Structure-forming invertebrates (e.g. deep sea sponges) found on canyon walls, seamounts, and rocky reefs are exceptionally vulnerable to such disturbances due to their sessile nature and extremely slow growth rates (Selgrath et al., 2026). Furthermore, as filter feeders, these organisms are highly susceptible to increased sedimentation, which can smother existing colonies, inhibit larval settlement, and reduce overall survival (Hourigan et al., 2017; Laidig et al., 2021).

Submarine Canyons, Seamounts, Asphalt Volcanoes and Hydrothermal Vents

Benthic discontinuities (i.e., abrupt changes in seafloor depth and morphology) like submarine canyons, seamounts, asphalt volcanoes, and hydrothermal vents are prioritized due to their exceptional level of fish and invertebrate biodiversity, habitat heterogeneity, and slow recovery rates (M. R. Clark et al., 2010; De Leo et al., 2010; Santora et al., 2018). Submarine canyons act as vital conduits for organic matter, fueling productive deep-sea ecosystems and essential benthic-pelagic coupling (De Leo et al., 2010; Robertson et al., 2020; Santora et al., 2018). Similarly, seamounts create biological hotspots by forcing nutrient-rich waters toward the surface, supporting dense deep reef communities (NOAA Fisheries, 2022b). Off California, even rare features like asphalt volcanoes have been documented as critical habitat for economically significant fish assemblages (Love et al., 2022).

Specialized features like hydrothermal vents support unique chemoautotrophic communities; physical installation can destroy vent structures, remove rare habitats, and generate sediment plumes that threaten endemic species with localized extinction (Van Dover, 2014). Given the abundance of slow-growing, structure-forming invertebrates in these areas, risks of long-term ecological damage from physical disturbance or smothering warrant their classification as high-priority habitats (Althaus et al., 2009; Clark et al., 2012).

Soft Bottom Habitats: Subtidal Softbottom and Pockmark Fields

The majority of the California seafloor is covered in soft bottom sediment (mud and fine sand) (Cochrane, 2024; Cochrane et al., 2023). Benthic infaunal communities residing in these sediments act as trophic links between organic matter production/accumulation and other oceanic environments, stimulate benthic microbial productivity and biogeochemical cycling, and are used as indicators of habitat quality (Gillett et al., 2021). Within these flat seascapes, pockmarks function as unique habitat islands, often colonized by crinoids that provide essential shelter for rockfish (Cochrane et al., 2017). Due to the lack of alternative high-relief features (e.g., large boulders, rocky outcrops), fragile biological communities within these pockmarks are particularly sensitive to physical disturbances (Cochrane et al., 2017), such as disruption and sediment resuspension from OSW development. Cable and anchor installation may resuspend sediment in soft bottom habitats, smothering filter feeders, increase scouring, and convert previously softbottom areas to hardbottom habitats (SEER, 2022).

Pelagic Zone

For purposes of this document, the pelagic zone is defined as the entire water column from nearshore to deep offshore, functioning as a continuous, interconnected environment defined by the distribution of phytoplankton and zooplankton. As the foundation of the food web, these planktonic communities drive primary production and facilitate energy transfer to higher trophic levels. Productivity is governed by the interplay of wind-driven circulation, stratification, and seafloor topography. These physical forces create "ecosystem hotspots", vast, high-density patches of plankton and krill, that can span hundreds of kilometers (Fiechter et al., 2020; Santora et al., 2011). Because prey aggregates at specific oceanographic features like fronts and eddies, these signatures act as essential habitat markers for marine mammals and highly migratory fish (Palacios et al., 2006), making the health of this habitat essential for the stability of the broader ecosystem.

Physical Oceanographic Forces

A suite of physical oceanographic processes (coastal and curl-driven upwelling, mesoscale eddies and filaments, offshore Ekman transport, and longshore circulation) were prioritized because they act as foundational drivers of the CCLME, and any significant alteration by OSW infrastructure would have cascading effects on biological productivity as well as fish and invertebrate populations. Productivity is primarily driven by coastal upwelling, where winds blowing southward along the coast bring deep water toward the ocean's surface, and curl-driven upwelling, where spatial wind variations trigger nutrient delivery further offshore (Jacox & Edwards, 2012). Once at the surface, these nutrients are redistributed by mesoscale eddies (rotating water features 10–100 km wide) and filaments (narrow, jet-like structures extending over 200 km seaward), which contribute to the cross-shelf transport of heat and organisms (Capet et al., 2008; Nagai et al., 2015). Near the coast, longshore transport (littoral drift) moves water and sediment parallel to the shore via wave and current energy (Ostendorf & Madsen, 1979). At the land-sea interface, estuarine circulation creates a powerful ecological pump driven by density differentials; fresh water flows seaward over an incoming "salt wedge" of dense, nutrient-rich seawater (Scroccaro et al., 2023). This circulation is vital, as it governs the retention of oxygen, nutrients, and larvae within estuarine nurseries (Scroccaro et al., 2023).

Humboldt Bay

As a shallow, primarily tidally driven system, Humboldt Bay serves as a critical stopover on the Pacific Flyway (Colwell et al., 2020) and a vital nursery for commercially important species, including salmonids and sturgeon (Schlosser & Eicher, 2012). Because of the estuary's ecological significance, the Framework explicitly considers the anticipated scale of developing a Heavy Lift Terminal[30] (HLT) for turbine staging and assembly, which risks fundamentally altering conditions for resident species (BERR, 2008).

Hydrodynamic models predict that port development-related dredging, infrastructure placement, and alterations to channel morphology could shift the bay's hydrography (Moffat & Nichol, 2024). These structural modifications could disrupt sediment transport, extend water residence times, liberate sequestered toxins or disease vectors, and alter larval retention. For instance, modified flow paths risk trapping larvae in unsuitable habitats or flushing them out to sea prematurely, disrupting regional recruitment (Garwood et al., 2022). While impacts on the immediate benthic community are expected to be temporary and confined to the construction phase (Eriander et al., 2017), the exact thresholds at which habitat loss, conversion, and dredging trigger irreversible estuarine regime shifts remain highly uncertain.

Beyond temporary construction disturbances, the long-term ecological consequences of novel habitat creation and permanent modification remain poorly understood (Taormina et al., 2018; Zupan et al., 2024). While the redistribution of displaced sediments during cable burial might create localized micro-habitats for some benthic infaunal species, port development introduces a more severe threat through irreversible habitat conversion: the transition of natural wetlands into industrial hardscape, representing a permanent loss of ecological function (Binkney et al., 2024).

These physical shifts underscore a critical knowledge gap regarding how artificial structures and construction-related sediment disruption interact with sensitive nearshore ecosystems (Bulleri & Chapman, 2010; Renner, 2025). Because these coastal environments serve as vital juvenile nurseries and highly efficient carbon sinks, targeted monitoring must determine how infrastructure-driven changes (from heavy sediment deposition to introduction of novel hard surfaces) interact with existing natural structures (Nightingale & Simenstad, 2001; Said et al., 2024). Deciphering whether these compounded structural changes will ultimately provide a net localized benefit or fundamentally disrupt the ecological integrity of these vulnerable nearshore zones is a vital next step for OSW monitoring.

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[30] https://humboldtbay.org/humboldt-bay-offshore-wind-heavy-lift-marine-terminal-project-3

Impacts to Nearshore Benthic and Pelagic Habitats and Ecosystems

In nearshore benthic and pelagic environments, habitat degradation and release of environmental pollutants are anticipated during construction and operation, with peak impacts likely during construction. Infrastructure installation (e.g. cables) may perturb benthic environments, resuspend sediment, and alter sediment transport regimes in sensitive habitats (e.g., estuaries, salt marshes, and mudflats) (Bulleri & Chapman, 2010) and harm suspension-feeding benthic organisms, including oyster and mussel species (Taormina et al., 2018). Habitat degradation may reduce nearshore habitat for aquatic and terrestrial biota, particularly nesting, roosting, and foraging habitat for birds and bats, and nursery grounds for commercially and ecologically valuable fish and invertebrate species (Nightingale & Simenstad, 2001).

Port dredging and development introduce several distinct physical and chemical stressors to nearshore environments, creating acute challenges for sensitive marine habitats. Mechanically, dredging resuspends benthic sediments and sharply increases turbidity. This drop in water clarity directly impairs light availability, which severely impacts foundational nearshore habitats like disrupting reproduction in shallow eelgrass (*Zostera marina*) beds (Springer et al., 2007; Tait, 2019; Ward & Beheshti, 2023).

Because eelgrass is a critical foundation species protected under the California Eelgrass Mitigation Policy[31], its degradation risks triggering widespread ecological cascades. These beds serve as vital nursery habitats for commercially and ecologically important species, including salmon, herring, and Dungeness crab (NOAA Fisheries, 2025; Ward & Beheshti, 2023). However, port-driven sedimentation, altered light availability, and potential localized algal blooms pose immediate, well-documented threats to their survival (Waycott et al., 2009; Lefcheck et al., 2017). When these habitats are disrupted, the effects quickly extend to bentho-pelagic invertebrates and fishes that rely on undisturbed soft substrates for settlement or depend on benthic prey (Johnston, 1981; Taormina et al., 2018).

While the localized vulnerability of eelgrass to dredging-related impacts are clear, significant uncertainty remains regarding how these immediate physical disturbances interact with and amplify macro-environmental stressors. For instance, broader climate patterns like the El Niño Southern Oscillation are suspected drivers of regional eelgrass loss. Currently, there is insufficient empirical evidence to determine how these large-

[31] https://www.fisheries.noaa.gov/west-coast/habitat-conservation/california-eelgrass-mitigation-policy-overview

scale climate shifts compare to, or compound with, the immediate, acute changes driven directly by port infrastructure development.

Beyond physical sedimentation, seafloor disturbance during port development poses a chemical threat through the release of sequestered environmental pollutants (Czerner et al., 2025). Dredging liberates heavy toxins (e.g., DDT, PCBs (Polychlorinated Biphenyls)) or dormant cysts (e.g., brevotoxins, domoic acid) trapped in the sediment, compromising water quality and the safety of the marine environment, with acute subsequent impacts on sensitive shellfish populations (BERR, 2008).

Finally, structural modifications along the shoreline can alter local hydrodynamics. The construction of new vessel berths or physical alterations to the seafloor at existing ports can disrupt natural currents and wave action, potentially driving accelerated erosion in surrounding coastal areas (U.S. Global Change Research Program et al., 2017).

Impacts to Offshore Benthic Habitats and Ecosystems

In the offshore benthic environment, habitat degradation and creation, alongside altered physical oceanographic processes during construction and operational phases, represent primary ecological concerns. During installation, cable burial, anchor placement, and chain dragging generate extensive sediment plumes that threaten to smother vulnerable epibenthic communities and disrupt the natural sediment transport regimes that maintain geological and biological integrity (Farr et al., 2021; McLean et al., 2022; Taormina et al., 2018). Slow-growing, habitat-forming species such as deep-sea sponges, corals, sea whips, sea pens, and crinoids are at particular risk of being crushed or buried (Cochrane et al., 2017; Hourigan et al., 2017; Selgrath et al., 2026). Recovery in these deep-water habitats is uniquely complex and protracted due to reduced wave energy, low current action, minimal sediment supply, and the slow growth rates of deep-sea invertebrates (SEER, 2022). Furthermore, ongoing localized soft-sediment scour can impact surrounding infaunal species, while the addition of hard scour protection measures can simultaneously increase habitat diversity for rock-dwelling organisms and initiate secondary scour along its edges (Byford et al., 2011; Kingma et al., 2024; SEER, 2022). Additionally, anti-corrosion measures introduce heavy metal contamination risks from materials like copper and steel, which possess high ecotoxicity for benthic invertebrates (Wang et al., 2023).

Because California’s offshore benthic environment is dominated by soft-bottom sediments, the introduction of anchors, scour protection, and cable protection measures can drive a fundamental, localized conversion toward hard-bottom ecological communities (Cochrane, 2024; Cochrane et al., 2023; Langhamer, 2012). These surfaces are rapidly colonized by fouling organisms, generating significant artificial reef effects through complex 3D architecture that attracts habitat-forming species and mobile predators (Degraer et al., 2020). These biological aggregations cause localized organic enrichment through waste accumulation and material "fallout" from the structures (De Borger et al., 2025; Meyer-Gutbrod et al., 2019). Similar to shell mounds around offshore oil and gas platforms, this shell and litter deposition creates novel micro-habitats and refugia while altering organic matter content (De Borger et al., 2021; Wolfson et al., 1979). While these reef effects may augment local biomass, they displace native soft-sediment specialists (Langhamer, 2012). In addition, they may also function as geographic stepping stones that facilitate the spread of non-native or invasive species across otherwise insurmountable open-water barriers (Adams et al., 2014; Andrews et al., 2025; Dannheim et al., 2025; Le Marchand et al., 2025; Reeds et al., 2018). Conversely, WEAs may act as de facto marine protected areas if they displace or exclude commercial fishing pressures; a long-term reduction in bottom-contact trawling could allow highly sensitive, overexploited benthic ecosystems a rare opportunity to fully recover (de Marignac et al., 2009; Hammar et al., 2016; Degraer et al., 2013).

A critical knowledge gap is the extent to which the physical presence of turbine arrays and subsea infrastructure will alter foundational oceanographic and biological processes at the seafloor interface. Although construction activities cause acute, short-term sediment suspension and temporary shifts in nutrient cycling (Farr et al., 2021), these impacts must be contextualized within existing baseline seabed disturbances. Compared to the widespread, chronic impacts of commercial bottom trawling, the physical footprint and sediment suspension generated by OSW are highly localized, and the seabed quickly stabilizes once construction concludes (Althaus et al., 2009; SEER, 2022). Depending on deep-sea current patterns, the localized transport and duration of these temporary sediment plumes may enhance certain benthic communities while smothering others. Because deep-sea biological processes are intrinsically tied to physical oceanography, yet the long-term impacts of massive infrastructure arrays on deep-water currents and carbon sequestration remain highly uncertain, characterizing these hydrographic and ecological shifts stands as a monitoring priority for ensuring long-term ecosystem integrity (Carpenter et al., 2016; Clark et al., 2014).

Impacts to Offshore Pelagic Habitats and Ecosystems

Changes to physical oceanographic processes induced by OSW infrastructure are expected to influence pelagic biological communities, with the magnitude of these shifts dictated by the total number, spacing, and spatial footprint of turbines within WEAs. While current modeling suggests that large-scale OSW infrastructure will have modest effects on total coastal upwelling strength, expanding turbine arrays increase the atmospheric wind wake, creating a "wind shadow" that reduces surface wind stress

(Raghukumar et al., 2023; Raghukumar et al., 2024). This alteration can disrupt Ekman transport and curl-driven upwelling, locally shifting its distribution by decreasing upwelling inshore and increasing it offshore, although within ranges consistent with natural variability (Raghukumar et al., 2023). However, the degree to which this modified wind stress disrupts the timing, location, and intensity of nutrient delivery remains a critical uncertainty (Raghukumar et al., 2024). Minor hydrographic shifts can alter flow patterns and localized primary productivity, potentially modifying plankton community size structure and affecting the foraging success of higher trophic levels (Harris et al., 2025; Rykaczewski & Checkley, 2008). Because surface current variability is the primary driver for transporting nutrients and phytoplankton, any major infrastructure-driven alterations could trigger geographically widespread biological consequences (Daewel et al., 2022; d'Ovidio et al., 2013; Krause et al., 2020; Messié & Chavez, 2017).

These physical disruptions present risks to population connectivity and regional recruitment dynamics, as dispersal of many marine organisms occurs during planktonic larval stages that are heavily dependent on undisturbed ocean currents (Ajmi et al., 2025; Chen et al., 2024; Gaylord & Gaines, 2000; Georgas et al., 2025). Furthermore, atmospheric wind wakes and floating foundations introduce added complexity by increasing ocean turbulence and modifying vertical mixing patterns, which may disrupt subsurface, shoreward zooplankton transport and offshore delivery of primary production via cross-shore filaments (Carr et al., 2008; Lathuilière et al., 2010; Raghukumar et al., 2024). The physical presence of OSW farms can also cause marine life (i.e. zooplankton, fish, seabirds etc.) to either aggregate near the structures or avoid them entirely (Russell et al., 2014; De Borger et al., 2025; Lamb et al., 2024; Shao et al., 2026). This shifting spatial distribution alters the concentration of biogenic particles and organic waste, creating a chain reaction that directly impacts light attenuation and water clarity in the water column (Salemink-Harry et al., 2025). Pelagic food webs face further behavioral disruptions from the artificial lighting mounted on OSW platforms, which can interfere with the synchronized diel vertical migration of zooplankton and fish between deep water and the surface (Cohen & Forward, 2009; Ohman, 1990).

Quantifying the biological consequences of these hydrographic modifications remains severely constrained by a lack of empirical data. Current understanding of pelagic impacts is largely restricted to shallow, unstratified seas on the continental shelf where fixed-bottom turbines are deployed, leaving the ecological effects of floating arrays in deep, upwelling-driven systems poorly understood (Dorrell et al., 2022; Floeter et al., 2022; Renner 2025). Due to a scarcity of in situ observations, pelagic assessments rely heavily on numerical models that have yet to be fully validated for deep-sea floating platforms. Predicting the exact location and timing of biological hotspots remains a significant challenge in strongly advective coastal upwelling systems, where ecosystem hotspots frequently become decoupled in space and time from their original nutrient sources and primary production (Messié et al., 2022). Consequently, determining how these infrastructure-driven physical changes will alter vertical nutrient flux, pelagic-benthic coupling, planktonic communities, and the foundational base of the marine food web remains a priority question for future monitoring.

5.3. Habitats, Ecosystems, and Oceanography Recommendations

Foundational Recommendations

Monitoring of habitats, ecosystems, and oceanography will set the stage for understanding impacts that affect all taxonomic groups. Foundational recommendations to prepare for monitoring habitats, ecosystems, and oceanography include:

- **Establish, Maintain and Enhance Long-Term Observation Networks** (e.g. CalCOFI, SCCOOS, and CeNCOOS) to support continued collection of physical, biogeochemical, and habitat variability data across spatial (statewide, regional, site-specific) and temporal scales. Add observing assets as needed to fill coverage gaps or to focus on local impacts. Prioritize maintaining existing monitoring programs and refine monitoring to improve detection of OSW related impacts to natural variability.
- **Coordinated Seafloor Mapping and Geophysical and Geotechnical Surveys:** Conduct broad-scale benthic and pelagic habitat and ecological mapping to establish essential physical and biological baselines, along with coincident geophysical and geotechnical surveys, ensuring OSW development and site-specific monitoring are informed by accurate seafloor data, inside and outside WEAs, as well as potential cable routes.
- **Scope Observing and Modeling that can Better Constrain Uncertainties with Respect to Infrastructure Impact on Upwelling**: Explore combinations of modeling and observational studies that could further refine the structure and magnitude of predicted impacts based on refined infrastructure deployment scenarios, as well as if it is feasible for an updated observing system designs to detect such changes.

Impact-Specific Recommendation tables

Below is a review of the potential sensors/data collector categories that can be used to collect data that address each impact topic and associated MQs (Tables 8-12). Relevant species and habitats are identified with each sensor in addition to an assessment of the sensors' opportunities and limitations. Cost and effort are assessed *relative* to other sensors used to monitor habitats, ecosystems, or oceanography. Where applicable, examples of West Coast monitoring programs and projects that employ these sensors were included to show their current application.

MQ: How might cable laying, sedimentation, and release of contaminants impact the nearshore environment?
MQ: What are the impacts to benthic habitats over repeated short-term and single long-term disturbance from construction?

Table 10. *Impact Topic: Impacts from infrastructure during construction phase*

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
Environmental Sample Collectors - Multi-Corer	Subtidal softbottom	Collects multiple cores at once, enabling replication in one sample; less disturbed sediment cores; variable tube/sample sizes. Preserves organic detritus	Logistical complexity, smaller sampling volumes, but can be done with replicate samples; may miss larger infauna (e.g. clams); doesn't work well in very sandy sediment. weather dependent.	Low to moderate Multiple staff are required for deployment, data collecting and retrieval making it labor intensive.	Scripps, California Cooperative Oceanic Fisheries Investigation (CalCOFI), Monterey Bay Aquarium Research Institute (MBARI), U.S. Geological Service (USGS), Southern California Coastal Water Research Project (SCCWRP)
Environmental Sample Collectors - Box Corer	Estuaries, pockmark fields, subtidal soft bottom, mudflats	Undisturbed stratigraphy, sample integrity, Collects infauna in soft sediment habitats; heavy duty, good for deeper environments.	Very Heavy, Limited penetration, often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor. High deployment time. Bow wave effect that can	Low to moderate Multiple staff are required for deployment, data collecting and retrieval making it labor intensive. Multiple staff are required for deployment, data collecting and	USGS, Moss Landing Marine Lab (MLML), SCCRWRP, San Francisco Estuary Institute (SFEI), OSW industry

[32] Most of these are not monitoring programs, but rather individual projects for specific research needs.

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
			blow off epifauna & phytodetritus; weak quantitative capability.	retrieval making it labor intensive.	
Environmental Sample Collectors - Grab Sampler	Estuaries, pockmark fields, subtidal soft bottom, mudflats, beach, coastal wetlands & salt marshes	Collects infauna in soft sediment habitats; lighter weight than box corer, better for shallower environments.	Often fails on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor. The bow wave created by sampler can wash away delicate surface layers, such as organisms (epifauna) and organic debris (phytodetritus). Also, it struggles to provide precise measurements, and samples can be lost if jaws fail to close.	Low to Moderate Multiple staff required for deployment, data collecting and retrieval making it labor intensive.	SCCRWRP, California State University (CSU) Monterey Bay, MLML
Environmental Sample Collectors - Sediment Profile Imagery (SPI)	Estuaries, pockmark fields, subtidal soft bottom, mudflats, beach, coastal wetlands & salt marshes	Captures cross-sectional images of the upper layer (~20 cm) of soft sediment habitats and the infauna, giving information on physical, chemical, and biological	Often fails on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor	Moderate Multiple staff required for deployment, data collecting and retrieval making it labor intensive. quite time-consuming to	USGS, Scripps, Army Corps

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
		processes (grain size, redox, etc.); rapid and cost-effective alternative to grab/corer sampling		process images afterward	
Imaging System - Drop-down Camera	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, hydrothermal vents	Versatile & customizable tool (e.g., mono or stereo, with or without lights, forward/downward facing, etc.) Can be deployed at any depth (with proper camera housing) & steep terrains; can be left for hours (continuous recording) to days (timelapse) and perhaps longer.	Dependent on battery duration & data storage; biofouling may build up on lenses if deployed long; not a precision-target tool in deeper environments because of possible drift as it's being lowered to the seafloor.	Low to Moderate Multiple staff required for deployment, data collecting and retrieval making it labor intensive; Data processing time is at least 3x recorded data duration	MLML Benthic Observation Survey Systems (BOSS), CSU Monterey Bay, MBARI, National Marine Fisheries Service (NMFS), Bureau of Ocean Energy Management (BOEM), OSW Industry

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
Imaging System - Video Sled	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, hydrothermal vents	Versatile & customizable tool (e.g., mono or stereo, with or without lights, forward/downward facing, etc.), Can be deployed at any depth (with proper camera housing) & terrains; cameras can be set to record continuously or on timelapse; tether can include cable for live transmission or not	Tethered therefore risk of entanglement near OSW structures or in kelp beds Suspended sleds highly subjected to swell at surface (even at depth) with motion transferred along tether; seafloor sleds limited to soft sediment or lightly coarse sediment terrains without significant obstacles Towing vessel gives the direction but sometimes operator can control pitch	Moderate to High Depending on size, 1-3 staff to handle and vessel with davit to A-frame to deploy; data processing time is at least 3x recorded data duration	USGS, California Seafloor Mapping Program, CSU Monterey Bay, BOEM, Marine Applied Research and Exploration (MARE)
Imaging System - ROV	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, pelagic, hydrothermal	Versatile and customizable tool to stream live and record images or videos, as well as to collect biological, oceanographical, and/or geological samples; can be deployed at pretty much any depths and terrains	Tethered so risk of entanglement near OSW structures or in kelp beds; highly subjected to swell at surface (even at depth) with motion transferred along tether; must work with live transmission to be directed; often needs experienced operator(s)	Low to High Depending on size and setup, could require large vessels and crew to handle and operate; small, handheld ones can be single-handed from shore or small vessel; data processing time is at least 3x	MARE, MBARI, Scripps, NMFS, OSW industry

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
	vents			recorded data duration	
Imaging System - AUV	Subtidal softbottom, pelagic	Can cover large areas of seafloor providing robust data on species composition, abundance and biomass	More complex topography requires more specialist AUVs, but many companies are building lower cost models with high degree of freedom navigation	Moderate to High Depending on size, 1-3 staff including some technical and engineering expertise.	Controlled, Agile, and Novel Observing Network (CANON) MBARI, Scripps, Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS), USGS
Environmental Sample Collectors - eDNA	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, pelagic, hydrothermal vents	Rapid, cost efficient, user friendly, versatile as water can be collected from the surface to the seafloor depending on target, but collection tool (e.g., handheld container, Niskin bottle, etc.) will need to be adapted to need	Captured genetic material may be exogenous and/or older, prioritize eRNA methods to ensure endogenous signals; actual volume of water needed for a reliable sample highly depends on conditions at sampling (e.g., turbidity, concentration in genetic material)	Low 1-2 staff usually sufficient to handle; lots of single-use supplies needed; sampler sterilization needed in-between sampling; on-site cold storage for samples	CalCOFI

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
Environmental Sample Collectors - Scuba Diver	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Relatively rapid to implement; versatile (can make visual observation, record imagery, collect samples, install/retrieve instruments); can access various habitats in areas that vessels or autonomous vehicles cannot go	Reliance on trained staff; limited in depth and duration; limited in sampling equipment they can carry (though vessels can be leveraged to drop off to/pick up from seafloor); can disturb animals and sediment	Low 2-3 staff usually, may require vessel if shore access isn't possible	Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)
Vessel Based Survey - Towed Dredge	Estuaries, pockmark fields, subtidal soft bottom, mudflats	Towed, heavy-duty; use to collect benthic/demersal organisms and rocks in coarse sediment habitats, where bottom trawls cannot operate	Towed, so risk of entanglement near OSW structures; dragged on the bottom, damaging benthic habitats; not selective tool, though things smaller than mesh size fall through. Can have biases from both size and body form such as soft bodies that don't last being netted.	Moderate Depending on size, 1-3 staff to handle; large ones to be deployed from a relatively large vessel with A-frame, smaller ones can be deployed from small vessels with a davit; 1-2 staff to sieve through haul on deck	Specific research projects and estuarine monitoring programs

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
Multibeam Echosounder (MBES)	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, hydrothermal vents	MBES is a type of sonar used to map the seabed. Data may include bathymetry, acoustic backscatter and water column data. They're commonly used for geological and oceanographic research as well as in the offshore oil and gas and offshore renewable energy sectors, as well as for cable routing.	This would likely be using autonomous equipment, such as an AUV with MBES. There may be some limitations on longevity of a mission or battery life.	Moderate to High Would require potential AUVs. Could also do ship-based MBES, but the costs of that may be more prohibitive than an AUV.	CSU Monterey Bay, USGS, MBARI, National Centers for Coastal Ocean Science (NCCOS)
Imaging System - Side-Scan Sonar	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, hydrothermal vents	Side-scan sonar is a type of active sonar used to detect objects on the seafloor and for mapping the seabed. It can be mounted to a ship's hull or be placed on another platform (e.g., AUV).	Potentially relies on vessels which can be impacted by vessel availability; high power draw if used with AUV	Moderate to High If using a vessel, this would be more cost prohibitive.	California Seafloor Mapping Program, a multi-institutional campaign to map CAs state waters

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects[32]
Environmental Sample Collectors - Sediment Traps	Estuaries, eelgrass beds, kelp beds, coastal wetlands & salt marshes, beach, mudflats, coastal ocean	Sediment traps may be used to detect changes in sedimentation rates for an area and would be useful for monitoring changes to sediment dynamics in coastal and estuarine habitats.	Sediment traps may have limited lifespan. There may also be challenges associated with different sediment grain sizes, where coarser sediment may be more effectively removed than fine particles. They may require more frequent maintenance.	Low to Moderate Depends on how many sediment traps need to be deployed. Would take 1-2 staff that would be responsible for deploying and retrieving the traps.	California Current Ecosystem Long-Term Ecological Research Site
ADCP	Estuaries, eelgrass beds, kelp beds, coastal wetlands & salt marshes, beach, mudflats, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, coastal ocean, pelagic, hydrothermal vents	Critical for gathering information on water velocities at various depths. May be included on a mooring, deployed from a vessel, or mounted to the seafloor. Could also have this integrated into other platforms.	Susceptible to biofouling for long deployments; relies on battery duration	Low to Moderate Depends on how the ADCP is deployed and for how long. Deployments at sea may take 1 - 2 staff and for instances where an ADCP is deployed on a mooring, that may be more involved, with ship time required.	Monterey Bay Time Series

MQ: What is the level of benthic habitat creation/degradation from OSW infrastructure?
MQ: What are the impacts of new colonization and community stabilization on and around infrastructure, including that of invasive species?
MQ: How might infrastructure create habitat opportunities and reef effects?

Table 11*. Impact Topic: Impacts from infrastructure during operations*

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample Collectors - Multi-Corer	Subtidal softbottom	Collects multiple cores at once, enabling replication in one go; less disturbed sediment cores; variable tube/sample sizes. No bow wave effect.	Smaller sampling volumes but can be done with replicate samples; may miss larger infauna (e.g. clams); doesn't work well in very sandy sediment. Heavy to operate.	Low to Moderate 2-3 staff to handle, relatively large vessel with A-frame, 1-2 staff to sieve through haul on deck	Scripps, MBARI, CalCOFI, USGS, SCCWRP
Environmental Sample Collectors - Box Corer	Pockmark fields, subtidal soft bottom	Use to collect infauna in soft sediment habitats; heavy duty, large volume of sample, good for deeper environments, Good for stratigraphy.	Often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor, so maybe not ideal around OSW infrastructure. Size and Weight heavy. Bow waves created by a sampler can wash away delicate surface layers, such as organisms (epifauna) and organic	Low to Moderate 2-3 staff to handle, relatively large vessel with A-frame, 1-2 staff to sieve through haul on deck	USGS, Scripps, MLML, BOEM, SCCWRP

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			debris (phytodetritus). Also, it struggles to provide precise measurements, and samples can be lost if jaws fail to close.		
Environmental Sample Collectors - Grab Sampler	Pockmark fields, subtidal soft bottom, beach	Use to collect infauna in soft sediment habitats; lighter weight than box corer, better for shallower environments	Easy and cheap, Versatile, Small footprint. Often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor, so maybe not ideal around OSW infrastructure. The bow wave created by sampler can wash away delicate surface layers, such as organisms (epifauna) and organic debris (phytodetritus). Also, it struggles to provide precise measurements, and samples can be lost if jaws fail to close.	Low to Moderate Depending on size, 1-3 staff to handle; large ones to be deployed from a relatively large vessel with A-frame, smaller ones can be deployed from small vessels with a davit; 1-2 staff to sieve through haul on deck	SCCWRP, Department of Water Resources (DWR), Integral consulting

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
SPI	Pockmark fields, subtidal soft bottom, beach	Fast, In-situ view, Turbidity resistant, Health Indicator: Clearly shows the "Redox Potential Discontinuity" (the oxygen line), which is the gold standard for measuring seafloor health. Use to capture cross-sectional images of the upper layer (~20 cm) of soft sediment habitats and the infauna, giving information on physical, chemical, and biological processes (grain size, redox, etc.); rapid and cost-effective alternative to grab/corer sampling	Often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor, so maybe not ideal around OSW infrastructure	Moderate 2-3 staff to handle; relatively large vessel with A-frame; quite time-consuming to process the images afterward	INSPIRE environmental, Integral, CSA Ocean Sciences, Army Corps, USGS

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Imaging System - Drop-down Camera	Eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, rocky intertidal, hydrothermal vents	Portable, Versatile and customizable tool (e.g., mono or stereo, w/ or w/o lights, forward/downward facing, etc.), Can be deployed at pretty much any depth (with proper camera housing) and all but very rough & steep terrains; can be left for hours (continuous recording) to days (timelapse) and perhaps longer	Dependent on battery duration and data storage; biofouling may build up on lenses if deployed long; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor, so maybe not ideal around OSW infrastructure. Fixed view, Susceptible to drift, Bait bias, Low mobility	Low to Moderate Depending on size, 1-3 staff to handle and vessel with davit to A-frame to deploy; data processing time is at least 3x recorded data duration	CSU Monterey Bay, MBARI, USGS, OSW industry, CalPoly
Imaging System - Video Sled	Eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, rocky intertidal, hydrothermal vents	Large-scale, Versatile and customizable tool (e.g., mono or stereo, with or without lights, forward/downward facing, etc.), can be deployed at any depth (with proper camera housing) and terrains; cameras can be set to record continuously or on timelapse; tether can include cable for live transmission or not.	No hovering ability, tethered therefore risk of entanglement near OSW structures or in kelp beds; suspended sleds highly subjected to swell at surface (even at depth) with motion transferred along tether; seafloor sleds limited to soft sediment or lightly coarse sediment terrains without significant obstacles; towing vessel	Moderate to High Depending on size, 1-3 staff to handle and vessel with davit to A-frame to deploy; data processing time is at least 3x recorded data duration	USGS, CSU Monterey Bay, NOAA Sanctuaries, OSW industry

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Continuous transects, Close to benthos, Deeper than diver access	gives the direction but sometimes operator can control pitch. Angle issues, Terrain limits		
Imaging System - ROV	Eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, rocky intertidal, pelagic, hydrothermal vents	Versatile and customizable tool to stream live and record images or videos, as well as to collect biological, oceanographical, and/or geological samples; can be deployed at pretty much any depths and terrains. Hovers, Equipped with robotic arm, infinite depth reach, real time data.	Slow speed, Tethered therefore risk of entanglement near OSW structures or in kelp beds; highly subjected to swell at surface (even at depth) with motion transferred along tether; must work with live transmission to be directed; often needs experienced operator(s). Ship dependency, High cost, Lights penetrate only so far.	Low to High Depending on size and setup, could require large vessels and crew to handle and operate; small, handheld ones can be single-handed from shore or small vessel; data processing time is at least 3x recorded data duration	MARE MBARI, Scripps, NOAA, USGS, SWFSC, OSW industry

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample Collectors - eDNA	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, mudflats, rocky intertidal, pelagic, hydrothermal vents	Rapid, cost efficient, user friendly, versatile Water can be collected from the surface to the seafloor depending on target, but collection tool (e.g., handheld container, Niskin bottle, etc.) will need to be adapted to need. Finds the hidden biota, Simple logistics in water, costs scalable, Scope entire ecosystem, NO harm in sampling.	Captured genetic material, may be exogenous and/or older. Contamination risks, Lab bottleneck where most of work occurs. Absence does not equate non-existence. No abundance data. Prioritize eRNA methods to ensure endogenous signals; actual volume of water needed for a reliable sample highly depends on conditions at sampling (e.g., turbidity, concentration in genetic material).	Low 1-2 staff usually sufficient to handle; lots of single-use supplies needed; sampler sterilization needed in-between sampling; on-site cold storage for samples	CalCOFI, Cal eDNA project, Scripps, MBARI, NMFS, SCCWRP
Environmental Sample Collectors - Scuba Diver	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, rocky reefs	Quick to implement; versatile (can make visual observation, record imagery, collect samples, install/retrieve instruments); can access various habitats in areas that vessels or autonomous vehicles cannot go. High	Reliance on trained divers; limited in depth and duration; limited in sampling equipment divers can carry (though vessels can be leveraged to drop off to/pick up from seafloor); can disturb animals and sediment. Human error,	Low 2-3 staff usually, may require vessel if shore access isn't possible	PISCO, Occidental College, ReefCheck

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		precision, Multitasking tool. Low infrastructure, Acuity	Short Duration, Depth limits, Risks and insurance, Visibility		
Vessel Based Survey - Towed Dredge	Pockmark fields, subtidal soft bottom	Used to collect benthic/demersal organisms and rocks in coarse sediment habitats, where bottom trawls cannot operate. Large sample. Excellent for taxonomy. Versatile. Broad sweep. Extreme depths. Towed, heavy-duty	Towed, so risk of entanglement near OSW structures; dragged on the bottom, damaging benthic habitats; not selective tool. Destructive, smashed samples, non-quantitative, Only captures large stuff.	Moderate Depending on size, 1-3 staff to handle; large ones to be deployed from a relatively large vessel with A-frame, smaller ones can be deployed from small vessels with a davit; 1-2 staff to sieve through haul on deck	Scripps, Cal Academy, EXPRESS, NOAA
ADCP	Estuaries, eelgrass beds, kelp beds, rocky outcrops/banks, tar mounds (asphalt volcanoes), pockmark fields, canyon walls, seamounts, deep-sea coral & sponge reefs, subtidal soft bottom, pelagic, hydrothermal vents	Critical for gathering information on water velocities at various depths. Full profile, non-intrusive, long term, mobile or fixed, need navigation safety. Can be included on a mooring, deployed from a vessel, or mounted to the seafloor. Could also have this integrated into other platforms.	Susceptible to biofouling for long deployments; relies on battery duration. A blanking dead zone in front (1-2m); particle dependent, fails in clear water. Side-Lobe Interference: Sound reflecting off the surface or a hard bottom can "corrupt" the data in the last 10% of the water column. Complex Math: Calculating the true	Low to Moderate Depends on how ADCP is deployed and for how long. Deployments at sea may take 1 - 2 staff and for instances where an ADCP is deployed on a mooring, that may be more involved, with ship time required.	California Current Ecosystem Long-Term Ecological Research Site, UC Davis, Scripps, CalPoly, Schatz Research, USGS, MBARI

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			water speed from a moving ship requires very high-end GPS to "subtract" the ship's motion.		
Imaging System - AUV	Subtidal soft bottom, pelagic	Surveys can cover large areas of seafloor providing robust data on species composition, abundance and biomass.	More complex topography requires more specialist AUVs, but many companies are building lower-cost models with high degree-of-freedom navigation.	Moderate to High Depending on size, 1-3 staff including some technical and engineering expertise.	MARE

MQ: How will port development, such as channel dredging, impact nearshore habitats and soft-bottom communities?

Table 12. *Impact Topic: Impacts from port improvements*

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample Collectors - Box Corer	Estuaries, subtidal softbottom, mudflats	Collects infauna in soft sediment habitats; heavy duty, good for deeper environments. See limitations above.	Often fails on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor	Low to Moderate 2-3 staff to handle, relatively large vessel with A-frame, 1-2 staff to sieve through haul on deck	Consulting firms
Environmental Sample Collectors - Grab Sampler	Estuaries, subtidal soft bottom, mudflats, beach, coastal wetlands & salt marshes	Collects infauna in soft sediment habitats; lighter weight than box corer, better for shallower environments. See limitations above.	Often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor	Low to Moderate Depending on size, 1-3 staff to handle; large ones to be deployed from a relatively large vessel with A-frame, smaller ones can be deployed from small vessels with a davit; 1-2 staff to sieve through haul on deck	Specific research projects, Consulting firms
Sediment Profiling Image (SPI)	Estuaries, subtidal soft bottom, mudflats, beach, coastal wetlands & salt marshes	Captures cross-sectional images of the upper layer (~20 cm) of soft sediment habitats and the infauna, giving information on physical, chemical, and biological processes (grain size, redox, etc.);	Often fail on mixed coarse sediment; not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor.	Moderate 2-3 staff to handle; relatively large vessel with A-frame; quite time-consuming to process the images afterward	Consulting firms, USGS

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		rapid and cost-effective alternative to grab/corer sampling.			
Imaging System - Drop-down Camera	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Versatile and customizable tool (e.g., mono or stereo, w/ or w/o lights, forward/downward facing, etc.), can be deployed at any depth (with proper camera housing) and all but very rough & steep terrains Can be left for hours (continuous recording) to days (timelapse) and perhaps longer	Dependent on battery duration and data storage; biofouling may build up on lenses if deployed long. Not a precision-target tool in deeper environments due to possible drift as it's being lowered to the seafloor	Low to Moderate Depending on size, 1-3 staff to handle and vessel with davit to A-frame to deploy; data processing time is at least 3x recorded data duration	Consulting firms, Specific research projects, Army Corps
Imaging System - ROV	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Versatile and customizable tool to stream live & record images or videos, as well as to collect biological, oceanographical, & geological samples; can be deployed at pretty much any depths & terrains.	Tethered; Risk of entanglement near OSW structures or in kelp beds; highly subjected to swell at surface (even at depth) with motion transferred along tether; has to work with live transmission to be directed; often needs experienced operator(s).	Low to High Depending on size and setup, could require large vessels and crew to handle and operate; small, handheld ones can be single-handed from shore or small vessel; data processing time is at least 3x recorded data duration	MARE

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample Collectors - eDNA	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Rapid, cost efficient, user friendly; Water can be collected from the surface to the seafloor depending on target, but collection tools (e.g., handheld container, Niskin bottle, etc.) will need to be adapted to need.	Captured genetic material may be exogenous and/or older, prioritize eRNA methods to ensure endogenous signals; actual volume of water needed for a reliable sample highly depends on conditions at sampling (e.g., turbidity, concentration in genetic material)	Low 1-2 staff usually sufficient to handle; lots of single-use supplies needed; sampler sterilization needed in-between sampling; on-site cold storage for samples	Consulting firms, USGS, SCCWRP
Environmental Sample Collectors - Scuba Diver	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom	Relatively rapid to implement; versatile (can make visual observation, record imagery, collect samples, install/retrieve instruments); can access various habitats in areas that vessels or autonomous vehicles cannot go	Reliance on trained staff; limited in depth and duration; limited in sampling equipment they can carry (though vessels can be leveraged to drop off to/pick up from seafloor); can disturb animals and sediment	Low 2-3 staff usually, may require vessel if shore access isn't possible	PISCO

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Multibeam Echosounder (MBES)	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Type of sonar used to map the seabed. Data can include bathymetry, acoustic backscatter and water column data. Commonly used for geological and oceanographic research, offshore oil and gas, offshore renewable energy sectors & cable routing.	Likely be using autonomous equipment, such as an AUV with MBES. Limitations on longevity of a mission or battery life.	Moderate to High Would require potential AUVs. Optional to do ship-based MBES, but the costs of that may be more prohibitive than an AUV.	USGS, NOAA, Consulting firms
Imaging System - Side-Scan Sonar	Estuaries, eelgrass beds, kelp beds, subtidal soft bottom, mudflats, rocky intertidal	Type of active sonar used to detect objects on the seafloor; for mapping the seabed. Can be mounted to a ship's hull or be placed on another platform (e.g., AUV).	Relies on vessels which can be impacted by vessel availability; high power draw if used with AUV	Moderate to High If using a vessel, this would be more cost prohibitive.	USGS, CSU Monterey Bay, Consulting firms, National Park Service (NPS)

Sensors/ Data Collectors	Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample Collectors - Sediment Traps	Estuaries, eelgrass beds, kelp beds, coastal wetlands & salt marshes, beach, mudflats	Used to detect changes in sedimentation rates for an area; and useful for monitoring changes to sediment dynamics in coastal and estuarine habitats.	Limited lifespan. Challenges associated with different sediment grain sizes, where coarser sediment may be more effectively removed than fine particles. They may require more frequent maintenance.	Low to Moderate It depends on how many sediment traps need to be deployed. Would take 1-2 staff that would be responsible for deploying and retrieving the traps.	USGS, CSU Monterey Bay, Consulting firms, NPS
ADCP	Estuaries, eelgrass beds, kelp beds, coastal wetlands & salt marshes, beach, mudflats, subtidal soft bottom	Full profile at every depth simultaneously, velocities at various depths. Non-intrusive, Long-term duration, Mobile or Fixed, Need pilot training. May be included on a mooring, deployed from a vessel, or mounted to the seafloor; or integrated into other platforms.	Susceptible to biofouling for long deployments; relies on battery duration Blanking zone, Particle dependent	Low to Moderate Depends on how the ADCP is deployed and for how long. Deployments at sea may take 1 - 2 staff and for instances where an ADCP is deployed on a mooring, that may be more involved, with ship time required.	UC Davis, Scripps, Schatz-Cal Poly Humboldt, USGS, NOAA Sanctuaries, MBARI

MQ: How might OSW impact lateral nutrient transport and primary production and zooplankton retention in nearshore habitats?
MQ: How might altered upwelling, hydrodynamics, or nutrient fluxes impact plankton community structure and biomass?
MQ: What are the impacts of wind-driven changes affecting onshore and offshore transport of plankton and life history?
MQ: What are the impacts to phytoplankton or zooplankton biomass, size distribution and life histories inside the WEAs?

Table 13. *Impact Topic: Biological oceanographic impacts*

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental sample collector – Vessel Net Tows	Pelagic	Collects information on phytoplankton, zooplankton, and other small larval stages of marine organisms. Actual sample. Affordable, Large samples, Historical baseline	Samples are time and site-specific. Damages samples, Labor intensive, Sampler avoidance, Mesh specificity, Clogging	Variable	CalCOFI, NOAA-SWFSC, Pacific Offshore Wind Consortium (POWC), Tenera Consulting
Environmental sample collectors – Mobile Survey AUVs ROVs etc.	Pelagic	Persistent constant sampling over days, Stability, Silent	Data lag, Entanglement potential, Can not touch anything	Variable	MBARI, Scripps, CSU Monterey Bay
Imaging systems – Satellite Remote Sensing	Pelagic	High temporal frequency, Once launched it is economical, Multiple variables collected, Historical dataset	Surface only, High launch risk, Could interference, Sensor drift,	Variable	NASA Jet Propulsion Lab, NOAA CoastWatch, UC Santa Cruz Kudela Lab
Vessel based survey - CTD casts	Pelagic	High quality data, Collects physics, biogeochemistry and biology variables from	Requires ship support, limited number of stations per day in ship time. Point data, Heavy	Medium	California Cooperative Oceanic Fisheries Investigations, Scripps, UC Davis, UC Santa

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		both water samples & sensors. Compatible with eDNA sampling, real time,	logistics, Slow process, Weather sensitive		Barbara, NMFS, USGS
ADCP	Pelagic near shore, offshore, benthic	Critical for gathering information on water velocities at various depths. 3D view, remotely senses, mapping while mobile Can be included on a mooring, deployed from a vessel, or mounted to the seafloor; or integrated into other platforms.	Susceptible to biofouling for long deployments; relies on battery duration. Blanking zone, acoustic noise,	Low to Moderate Depends on how the ADCP is deployed and for how long. Deployments at sea may take 1 - 2 staff and for instances where an ADCP is deployed on a mooring, that may be more involved, with ship time required.	CalCOFI, Applied California Current Ecosystem Studies (ACCESS), CeNCOOS, SCCOOS, USGS, US Davis, US Santa Cruz, MBARI, OSW industry
Imaging System - AUV	Offshore seafloor areas, especially of lower topographic variability, water column areas using underwater microscopes, macro-plankton cameras (e.g. for Krill and other prey taxa of managed species)	High quality data, Able to magnify and multibeam, Can cover large areas of seafloor providing robust data on species composition, abundance and biomass, with repeat surveys. Free Data: Once satellite is launched, data is often	More complex topography requires more specialist AUVs, but many companies are building lower cost models with more capable navigation. Battery issues, Data lag, Processing load. Most satellites can't see	Moderate to High Depending on size, 1-3 staff including some technical and engineering expertise.	Monterey Bay Time Series, MBARI, Scripps, NMFS- SWFSC, USGS

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		open-source and free. Measures temperature, chlorophyll (color), sea level (height), and even wind speed. Daily Updates: Satellites pass over California daily, allowing us to track the exact start of an upwelling event. Can detect "wind wake" behind offshore wind farms, which is vital for answering questions about hydrodynamics.	features smaller than 1 km; "scour" from a single turbine is too small to see. High Launch Cost: It costs hundreds of millions of dollars to put sensor in orbit. Cloud Interference: California's famous marine layer (fog) blocks "Ocean Color" and Temperature sensors completely. Surface Only: Satellites cannot "see" through water. Tell nothing about the bottom 99% of the ocean.		
Mobile Platform - Glider	Pelagic, surface	Can cover repeat ocean sections with currents, Temperature, Salinity, Chl-a, backscatter, pH nitrate & oxygen with an endurance >100 days. 24/7 monitoring, High-resolution data, economical, real-time data. Modules for active	Can be deployed by small vessels, operated from shore. No physical sample, navigation hazards, small payload.	Very effective for the amount and quality of observations	California Underwater Glider Network, Scripps, MBARI, IOOS, CCE-LTER California Current Longterm Ecological Research, Naval Post Graduate School

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		bioacoustics surveys, PAM & imaging systems can also be added for biological oceanographic applications including marine mammals, prey taxa & more.			

MQ: What is the risk of change in the magnitude and spatial structure of upwelling, physical circulation and nutrient transport both inside and outside (downwind) of the WEAs?

Table 14. *Impact Topic: Physical oceanographic impacts*

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Vessel based survey - CTD casts	Pelagic	Can collect physics, biogeochemistry & biology variables from both water samples & sensors. Provides the vertical density profiles (isopycnals) needed to prove if upwelling is actually being "altered" as models predict. When paired with a Rosette, it's the only way to get real water to measure Nitrate, confirming if a change in circulation is actually reducing food for plankton.	Requires ship support, limited number of stations per day in ship time. Snapshots Only: A CTD cast takes minutes; upwelling changes happen over weeks. It can miss the "peak" of an event. In deep WEAs, a single CTD cast can take 2 hours, making it hard to map the spatial structure quickly. Unlike an AUV, a CTD cast doesn't show how water moves *laterally* between turbines.	Medium	CalCOFI, Integral Consulting, EXPRESS, USGS
Environmental sample collectors - Mobile Survey AUVs ROVs etc.		AUVs can "sawtooth" through a WEA to map the exact spatial (5.3) of upwelling, which a	In floating OSW sites, AUVs and ROVs face a high risk of entanglement with "dynamic" mooring	Medium	MBARI, NOAA, USGS Integral

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		stationary sensor would miss. ROVs can hover centimeters from a cable to measure scour pits and sediment ripples with extreme detail. They are quiet and don't disturb physical processes (upwelling) they are trying to measure.	lines and power cables. ROVs are Tethered to ship, meaning they can only survey a small area around a vessel at one time. Carrying high-end sensors for nutrient transport (like nitrate sensors) drains AUV batteries quickly. Millions of data points from a single AUV mission take weeks of expert work to turn into a usable map.		
Satellite Remote Sensing	Surface ocean	Strong spatial & temporal capability.	Not well suited at the coast or in estuaries.	Low Limited to related data value adds	NASA, IOOS, NOAA, UC Santa Cruz, Farallon's Institute
Fixed-point Mooring/Buoy	Estuaries to open ocean, pelagic and benthic	Wide variation in application from meteorological data, waves, currents, temperature, salinity, biogeochemistry, biology	Point locations, limit spatial insight. "Blind" to anything happening even a mile away. It only knows what	Medium Can be focal points for joint work	California Current Ecosystem Long-Term Ecological Research Site, IOOS, Scripps, Cal Poly, US Davis, NOAA, OSW Industry

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		& ecosystems variables. Captures rare events (storms, oil spills, plankton blooms) that ships might miss. A single mooring can have sensors at the surface, mid-water, and on the benthos simultaneously.	is happening at its specific coordinates. Requires expensive ship time to visit the site, pull the heavy anchor, and swap out batteries/sensors. High risk of being hit by ships, entangled in fishing gear, or (rarely) tampered with by people.		
Lander Based Survey	Benthic boundary layer	Can measure resuspension & sedimentation events, marine life activity.	Single point observations for each lander, limited spatial insight.	Context dependent	
Glider	Pelagic, surface	Can cover repeat ocean sections with currents, Temperature, Salinity, Chl-a, backscatter, pH nitrate & oxygen with & endurance >100 days. Modules for active bioacoustic surveys, PAM & imaging systems can be added for biological oceanographic applications including	Gliders move very slowly (~0.25 m/s). They can be "blown off course" by strong California currents. Every time they surface to transmit data, they are at risk of being hit by ships or entangled in kelp/fishing gear. The vehicles themselves are expensive ($150k–	Very effective for amount & quality of observations	California Underwater Glider Network, IOOS, MBARI, Naval Post Graduate school, NOAA Fisheries

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		marine mammals, prey taxa & more. They don't just stay on the surface; they "sawtooth" from the surface to 1,000 meters, mapping the entire water column. A glider mission costs a fraction of a research vessel's daily rate ($25k–$50k/day for a ship vs. almost nothing once launched).	$250k), and losing one in a storm is a major financial blow. Over a 100-day mission, sensors can get "dirty" (biofouling), making the data at the end of the trip less accurate than the start.		
Uncrewed surface vessel	Surface, towed sub-surface	Can cover repeat ocean sections with Temperature, Salinity, Chl-a, backscatter, pH nitrate & oxygen within a few days. **Months at Sea:** Can stay out for 6–12 months using only wind and solar power; no refueling needed. **Real-Time Satellite Link.** Costs reduced no ship time. Can tow equipment. Can carry biological payloads including for	Can be deployed from shore, by small vessels, operated from shore. Despite "Auto-Pilot" and AIS, there is a risk of collision with fishing boats or cargo ships in busy lanes. Most USVs travel at 1–3 knots. They can't "rush" to a new location if an event starts elsewhere.	Very effective for amount & quality of observations	CANON, Saildrone, NOAA, Liquid Robotics, OSW industry

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		eDNA, imaging, PAM, water samplers and acoustic animal tag receivers.			
Long-range AUV	Pelagic, surface	Can cover repeat ocean sections with Temperature, Salinity, Chl-a, backscatter, pH nitrate and oxygen within a few days. Can carry biological payloads including for eDNA, imaging, PAM, water samplers and acoustic animal tag receivers. Can stay at sea for over a month, covering thousands of kilometers on a single charge. Can carry the Environmental Sample Processor, which "bottles" water or filters DNA while underwater.	Can be deployed by small vessels, operated from shore. Because they are slim and energy-efficient, they can't carry heavy "work-class" robotic arms or large sonar. They must surface periodically to get a GPS fix and "call home" via Iridium satellite, which takes time and energy. arrays.	Very effective for the amount and quality of observations	CANON, MBARI, NOAA, Scripps

Sensors/ Data Collectors	Priority Habitats	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
High-frequency radar	Pelagic, estuaries surface	Data can provide gridded, time-variant surface current speed and direction.	OSW infrastructures can interfere with sensing systems, a mitigation planning effort has been ongoing nationally.	Very effective for amount and quality of observations	IOOS
Profiling floats	Surface, subsurface pelagic	Data can provide periodic profiles of ocean physics and biogeochemistry; that form part of a global array via the Argo Program.	For offshore use only, drifting where floats could likely drift out of areas of interest within weeks or months.	Very effective for amount and quality of observations	Argo Floats
Climate indicator	Surface ocean	Data can provide atmospheric pressure, sea surface temperatures.	Gives regional indication of climate conditions, linked to El Niño Southern Oscillation and related indicators.	Very effective for amount and quality of observations	Farallon Institute's Multivariate Ocean Climate Indicator

6. Marine Mammals and Sea Turtles

6.1 Marine Mammals and Sea Turtles Results

6.2 Marine Mammals and Sea Turtles Discussion

6.3 Marine Mammals and Sea Turtles Recommendations

6. Marine Mammals and Sea Turtles

6.1. Marine Mammals and Sea Turtles Results

Marine mammals and sea turtles were grouped into four ecological subgroups: bay and estuary, resident (nearshore and offshore species), nearshore transient, and offshore transient. Given the importance of when, where, and how future OSW activities would interact with species, we took a spatio-temporal, ecological perspective in segregating species. We recognize that taxonomic differences are important in certain regards, such as taxa-specific characteristics of hearing. But ecological features including whether species are migratory or resident and perform critical life functions in shallow or deep water will have overarching implications for potential risk and were used in segregating the assessment. The marine mammal and sea turtle subgroups are defined below.

- Bay and Estuary species were defined as those that spend all or a substantial portion of their life within a bay or estuary.
- Resident species were defined as those that spend all or a substantial portion of their life within a relatively defined geographic area (both nearshore and offshore).
- Nearshore transient species were defined as those occurring in waters <250 m depth which do not occupy a fixed habitat, often moving in response to prey distribution.
- Offshore transient species were defined as those occurring in waters >250 m depth which have a broad range, do not occupy a fixed habitat, and often move in response to prey distribution.

Across all subgroups, vessel traffic, noise, and infrastructure were identified as high priority IPFs. Noise, infrastructure, and EMF were identified as knowledge gaps across some of the subgroups. As with other species groups, basic information about distribution and behavior of priority species in development areas as well as specific information about the nature of development operations will be valuable.

Marine Mammal and Sea Turtle Species Prioritization

Species were prioritized based on likely exposure to OSW development, sensitivity to potential impacts, and ecological or management significance (Table 15).

Table 15. *Species prioritization results across all marine mammal and sea turtle subgroups.*

Marine Mammal and Sea Turtle Species Prioritization Results
High Priority Species
Bay and Estuary Harbor porpoise (*Phocoena phocoena*), Harbor seal (*Phoca vitulina*), Sea otter (*Enhydra lutris*) **Resident (Nearshore and Offshore)** Baird's beaked whale (*Berardius bairdii*), Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's/goose beaked whale (*Ziphius cavirostris*) **Nearshore Transient** Gray whale (*Eschrichtius robustus*), Blue whale (*Balaenoptera musculus*), Killer whale (*Orcinus orca*), Leatherback sea turtle (*Dermochelys coriacea*), Loggerhead sea turtle (*Caretta caretta*), Olive Ridley sea turtle (*Lepidochelys olivacea*) **Offshore Transient** Fin whale (*Balaenoptera physalus*)
Medium Priority
Resident (Nearshore and Offshore) Bottlenose dolphin (*Tursiops truncatus*), Dall's porpoise (*Phocoenoides dalli*) **Nearshore Transient** Humpback whale (*Megaptera novaeangliae*), California sea lion (*Zalophus californianus*)
Low Priority
Nearshore Transient Dwarf sperm whale (*Kogia sima*), Pygmy sperm whale (*Kogia breviceps*), Long-beaked common dolphin (*Delphinus capensis*), Minke whale (*Balaenoptera acutorostrata*), Pacific white sided dolphin (*Aethalodelphis obliquidens*), Short-beaked Common dolphin (*Delphinus delphis*), Steller sea lion (*Eumetopias jubatus*), Northern fur seal (*Callorhinus ursinus*) **Offshore Transient** Sperm whale (*Physeter macrocephalus*), Short-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), Northern elephant seal (*Mirounga angustirostris*)
Not Likely to be Exposed to Impacts
Offshore Transient Guadalupe fur seal (*Arctocephalus townsendi*)
Not Feasible to Monitor
Offshore Transient Bryde's whale (*Balaenoptera brydei*), North Pacific right whale (*Eubalaena japonica*), Sei whale (*Balaenoptera borealis*)

The high priority species in Table 15 are considered in the tables below that describe IPFs and impacts. The development phases for offshore wind include pre-construction, construction, and operations. For bay and estuary marine mammals and sea turtles, construction includes port development.

Bay and Estuary Marine Mammals and Sea Turtles

The bay and estuary subgroup identified several IPFs and associated impacts as high priority (Table 16). Potential impacts from vessel traffic included habitat alteration and spatial avoidance; in the extreme, vessel collision, should it occur, could result in injury or mortality, but mitigation for avoiding vessel collision and the potential for human health and safety risk associated with it keep the likelihood of occurring low, and priority species are unlikely to experience population level impacts should a vessel collision occur. Potential impacts from noise included temporary masking, spatial avoidance, and habitat alteration. Impacts from infrastructure may include habitat alteration and spatial avoidance. Bays and estuaries will experience port development, assembly and towing of infrastructure, and a base level of vessel traffic and towing associated with long-term maintenance. Bay and estuarine marine mammals can occur in the estuaries, eelgrass, kelp, mudflats, and salt marshes. See Table 15 for high priority species for bay and estuary systems.

Table 16. *IPFs and associated impacts by development phase for high priority species, and attributed habitats for bay and estuary marine mammals and sea turtles*

IPF	Impact	Development Phase	Priority Species	Habitats
Vessel Traffic	Alteration of habitat	Construction, Operation	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats Salt marshes
	Spatial Avoidance	Construction, Operation	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats Salt marshes
Noise	Behavioral change (including potential severe	Construction	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats

IPF	Impact	Development Phase	Priority Species	Habitats
	responses such as habitat abandonment and associated reproductive failure)			Salt marshes
	Alteration of Habitat	Operation	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats Salt marshes
Infrastructure	Alteration of Habitat	Construction	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats Salt marshes
	Spatial Avoidance	Construction	Harbor seals Harbor porpoises Sea otters	Estuaries Eelgrass beds Kelp beds Mudflats Salt marshes

Resident (Nearshore and Offshore) Marine Mammals

The resident (nearshore and offshore) marine mammal and sea turtle subgroup identified noise and infrastructure as the high priority IPFs, potentially resulting in impacting injury or mortality and causing entanglement (Table 17). Beaked whales were the only priority species in this group (Table 15).

Table 17. *IPFs and associated impacts by development phase for high priority species, and attributed habitats for resident (nearshore and offshore) marine mammals and sea turtles*

IPF	Impact	Development Phase	Priority Species	Habitats
Noise	Behavioral change	Construction	Beaked whales	Pelagic zone

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Alteration of habitat	Construction, Operation	Beaked whales	Pelagic zone

Nearshore Transient Marine Mammals and Sea Turtles

The high priority IPFs for nearshore transient marine mammals and sea turtles were vessel traffic and infrastructure (Table 18). Priority species are listed in Table 13. Habitats of these species include the pelagic zone and can extend into nearshore areas like mudflats and softbottom for sea turtles.

Table 18. *IPFs and associated impacts by development phase, high priority species, and attributed habitats for nearshore transient marine mammals and sea turtles*

IPF	Impact	Development Phase	Priority Species	Habitats
Vessel Traffic	Alteration of habitat	Construction, Operation	Gray whales Sea turtles Killer whales	Pelagic zone Mudflats Subtidal softbottom
Infrastructure	Alteration of habitat	Construction, Operation	Gray whales Sea turtles Killer whales	Pelagic zone Mudflats Subtidal softbottom

Nearshore Transient Marine Mammals and Sea Turtles Knowledge Gaps

The priority knowledge gap identified for nearshore transient species was EMF impacts on sea turtles (Table 19).

Table 19. *Knowledge gaps for IPFs and associated impacts by development phase for priority species of nearshore transient marine mammals and sea turtles*

Knowledge Gap	Priority Species	Habitats
The impact of EMF on alteration of habitat during construction and operation.	Sea turtles	Pelagic zone Subtidal softbottom
The impact of EMF on spatial avoidance during construction and operation.	Sea turtles	Pelagic zone Subtidal softbottom

Offshore Transient Marine Mammals and Sea Turtles

High priority IPFs for offshore transients were vessel traffic and infrastructure (Table 20).

Table 20. *IPFs and associated impacts by development phase for high priority species of offshore transient marine mammals and sea turtles*

IPF	Impact	Development Phase	Priority Species	Habitats
Vessel Traffic	Injury/mortality	Construction, Operation	Blue whales Fin whales Sea turtles Offshore killer whales	Pelagic zone Seamounts Hydrothermal vents Canyon walls
Infrastructure	Injury/mortality	Construction, Operation	Blue whales Fin whales Sea turtles Offshore killer whales	Pelagic zone Seamounts Hydrothermal vents Canyon walls

Offshore Transient Marine Mammals and Sea Turtles Knowledge Gaps

Priority knowledge gaps identified for offshore transient species included noise impacts on entanglement risk and the potential for infrastructure to increase entanglement risk. Additional knowledge gaps included the potential for EMF to alter sea turtle habitat use and spatial avoidance (Table 21). Although the impact of EMF on offshore transient cetaceans is also uncertain, this impact was not considered a high priority for species other than sea turtles by the WG.

Table 21. *Knowledge gaps for IPFs and associated impacts by development phase, priority species and associated habitats for offshore transient marine mammals and sea turtles*

Knowledge Gap	Priority Species	Habitats
Impact of noise during construction & operation.	Blue whales Fin whales Sea turtles	Pelagic zone Seamounts Hydrothermal vents Canyon walls
Impact of infrastructure on entanglement risk during construction & operation.	Blue whales Fin whales Sea turtles	Pelagic zone Seamounts Hydrothermal vents Canyon walls

Knowledge Gap	Priority Species	Habitats
Impact of EMF on alteration of habitat during construction & operation.	Sea turtles	Pelagic zone Seamounts
Impact of EMF on spatial avoidance during construction & operation.	Sea turtles	Pelagic zone Seamounts

6.2. Marine Mammals and Sea Turtles Discussion

The West Coast waters support many marine mammal species across bays and estuaries, nearshore, and offshore environments. Offshore WEAs overlap with habitats used by both resident and transient species during key life history stages including breeding, migration, and foraging.

Impacts from Noise

Marine mammals rely heavily on sound for essential life functions, including communication, foraging, predator avoidance, and spatial orientation. Although these species have evolved in naturally noisy ocean environments, anthropogenic noise has a relatively recent and increasingly widespread impact on marine ecosystems (Hildebrand, 2009). Impacts range from behavioral disturbance affecting feeding and reproductive behaviors to more severe outcomes, including mortality in some species (Blair et al., 2016; Filadelfo et al., 2009; Nowacek et al., 2007; Southall et al., 2009), though noise levels expected from floating offshore wind site assessment, construction, and operation is not expected to result in injury or mortality to marine mammals or sea turtles. Species that exhibit strong site fidelity or rely on localized habitats may be particularly vulnerable to noise exposure where alternative habitat is limited (Forney et al., 2017).

Impacts from Vessel Traffic

The construction and operation phases of OSW development will likely result in an increase in vessel traffic between shore and the OSW project areas. This increase may lead to greater vessel collision risk and an increase in vessel-based ocean noise. Vessel collisions are one of the top human threats to whale populations worldwide (Rockwood et al., 2020), yet the specific intensity and movement patterns of vessels supporting floating OSW development remain an area requiring further study (Rockwood et al., 2020; SEER, 2022). Underwater vessel noise is a pervasive and continuous anthropogenic impact for marine mammals. Vessel noise overlaps with the communication and hearing frequencies of many marine mammals, reducing the distance over which animals can detect one another (Hemery et al., 2024). The increase in vessel traffic during construction and operation of OSW could mask communications, limiting the effective range of social calls and foraging cues (Hemery et al., 2024). In response to elevated vessel noise, marine mammals have been documented to exhibit behavioral changes such as spatial or temporal avoidance, which may reduce foraging opportunities, alter social behaviors, or shift migration routes (Hemery et al., 2024).

Impacts from infrastructure

OSW infrastructure alters the marine environment and could pose a potential risk of entanglement, displacement, or attraction for marine mammals and sea turtles. A primary potential impact arises around displacement and habitat alteration if turbine structures alter habitat or lead to spatial avoidance, particularly for large migratory marine mammals whose foraging or migration ranges overlap with OSW development areas (Hemery et al., 2024). In contrast, some studies have reported attraction of pinnipeds and odontocetes to operational fixed turbines, likely associated with localized increases in prey due to the artificial reef effect (Benhemma-Le Gall et al., 2021; De Paula & Carmo, 2022, Horwath et al., 2021, Raoux et al., 2017). In addition, entanglement on infrastructure represents a potential impact for marine mammals and sea turtles. Primary entanglement[33] is considered most likely impossible, given the size and tension of the proposed floating OSW farm mooring lines and cables (White et al., 2024). Secondary[34] and tertiary[35] entanglement, which are considered possible, have not been documented in floating OSW farms, but have been observed on oil and gas platforms (Harnois et al., 2015, Marmo et al., 2013; Maxwell et al., 2022). Whether the presence of windfarms increases the risk of entanglement given that marine debris is present regardless of windfarm presence is uncertain, and likelihood of entanglement associated with windfarms is significantly lower than likelihood of behavioral reactions or responses to noise and habitat alteration (which have been documented, unlike entanglement in windfarms), though none of these changes are likely to result in population-level effects unless they occur at scale over long periods for large or

[33] Primary entanglement refers to individuals becoming entangled or restricted by the turbine's underwater components (Harnois et al., 2015, Harris et al., 2025).

[34] Secondary entanglement involves individuals being caught or restricted by man-made materials (e.g., ghost fishing lines or nets) that are already entangled on the infrastructure (Harnois et al., 2015, Harris et al., 2025, Wawrzynkowski et al., 2025).

[35] Tertiary entanglement represents a more indirect, often physiological threat that occurs when an animal is entangled in debris which subsequently becomes snagged on floating OSW infrastructure (Harris et al., 2025).

reproductively important portions of the populations or meaningfully contribute to cumulative impacts from other sources.

High Priority Marine Mammal and Sea Turtle Species

Species were prioritized based on exposure to OSW development, sensitivity to potential impacts, and ecological significance (Table 15). The high priority species identified by the scientific WGs in the results section include:

Harbor porpoise (*Phocoena phocoena*)
Harbor porpoises are year-round residents along the central and northern California coast, occupying bays as well as shallow continental shelf habitat (<200 m deep) (Carretta et al., 2009, 2017; Chivers & Greenman, 2022; K. A. Forney et al., 2014), including the Morro Bay specific stock. Harbor porpoises rely heavily on echolocation for foraging and are highly sensitive to anthropogenic noise, with documented avoidance and displacement in response to vessel traffic, seismic surveys, and OSW turbines (Dyndo et al., 2015; Kyhn et al., 2015; Pirotta et al., 2014; Polacheck & Thorpe, 1990; Tougaard et al., 2009). Displacement from suitable foraging habitat may have energetic consequences due to their high metabolic demands and frequent foraging requirements (Lockyer, 2007; Read & Westgate, 1997; Yasui & Gaskin, 1986).

Harbor seal (*Phoca vitulina*)
Harbor seals are common residents of bays, estuaries, and nearshore coastal habitats along the West Coast and are highly sensitive to human disturbance. In terms of auditory physiology, harbor seals are the most sensitive marine mammal to both airborne and underwater noise within the specific frequency ranges expected from OSW development. Because of this high vocal and acoustic sensitivity, they face an elevated risk of experiencing behavioral disruption, acoustic masking, or permanent hearing loss from industrial activities. Dedicated acoustic modeling must be conducted to establish explicit injury and exposure thresholds tailored to their highly sensitive hearing criteria to prevent widespread auditory impacts during project development. Harbor seals rely on underwater vocalizations and acoustic cues during breeding and pup rearing periods and have strong site fidelity to established haul-out sites. Anthropogenic noise and increased vessel activity associated with OSW development may disrupt communication and behavior during sensitive breeding periods, resulting in increased pup mortality, particularly in areas where haul out and foraging habitats overlap with OSW construction and operations (Hastie et al., 2015; Tougaard et al., 2009).

Sea otter (*Enhydra lutris*)
Sea otters are nearshore residents that depend on bay and estuary habitats along the coast of California (Tinker et al., 2019). Functioning at the absolute limit of their

physiological tolerances, sea otters possess metabolic costs more than twice those of other marine mammals, making them uniquely vulnerable to lethal energetic imbalances from short-term noise disturbances or resource displacement. Adult females are asynchronous breeders, making seasonal noise mitigations ineffective, and are highly susceptible to fatal end-stage lactation syndrome, meaning even minor rest interruptions or behavioral disruptions can trigger direct mortality. Furthermore, territory-defending males are highly unlikely to utilize spatial avoidance to escape noise hazards, and the entire species is strictly confined to nearshore waters within a few hundred meters of the coast to rear pups. While their hearing sensitivity is less acute than harbor seals and more aligned with sea lions, targeted modeling is urgently required to predict the exact thresholds where construction noise will cause auditory injury, masking, or fatal metabolic distress. Sea otters rely on surface and shallow waters to forage, and exhibit strong site fidelity, particularly during pup rearing periods. Increased vessel activity and noise associated with OSW development near Morro Bay WEAs may disrupt behavior, elevate energetic costs, and result in avoidance of critical habitat, with potential implications for reductions in reproductive success (Barrett et al., 2025).

Gray whale (*Eschrichtius robustus*)

Gray whales are of particular concern due to the recent mortality event between 2019 and 2023 (Raverty et al., 2024), which has left the population potentially more sensitive to impacts. In addition, the Western North Pacific gray whale distinct population segment is listed as ‘endangered’ under the ESA and ‘critically endangered’ by the International Union for the Conservation of Nature (IUCN) (Weller et al., 2003). Individuals from this population also migrate along the West Coast and may be exposed to risks including vessel collision, entanglement, and anthropogenic noise (Bradford et al., 2009; Carretta et al., 2017). Offshore industrial activities have been associated with behavioral disturbance, acoustic impacts, and habitat modification that may affect gray whale foraging and migration patterns (Reeves, 2005; Weller, 2023).

Beaked whales (*Ziphiidae*)

Beaked whales are elusive deep diving odontocetes that are widely recognized as highly sensitive to anthropogenic noise (Southall et al., 2007; 2009). Behavioral responses such as ceasing foraging and altered habitat use have been documented from multiple sound sources, including vessel traffic, echosounders, military sonar, air gun surveys, and seismic surveys (Aguilar de Soto, 2006; Cholewiak et al., 2017; Pirotta et al., 2014; DeRuiter et al., 2026; Southall et al., 2026). Several beaked whale species are found in offshore waters along the West Coast that spatially overlap with proposed OSW development areas, raising concern that construction and operational noise could cause behavioral disruption or displacement from key foraging habitats (DeRuiter et al., 2026; Southall et al., 2017, 2019, 2021, 2026).

Blue whale (*Balaenoptera musculus*)

Blue whales are listed as 'endangered' under the ESA and have long seasonal migrations through offshore California waters to forage in highly productive areas (Calambokidis et al., 2015; Carretta et al., 2022). Blue whales rely on low-frequency acoustic communication over long distances and may be affected by noise sources, such as vessel noise or construction, that overlap with their auditory range (Širović & Oleson, 2022). As large, surface-oriented animals, that forage on dense aggregations of krill, blue whales may be particularly vulnerable to disturbance, displacement from productive habitat, and increased risk of vessel collision in areas of increased offshore activity (Goldbogen et al., 2012; Mercado-Santana et al., 2017; Reilly & Thayer, 1990; Stafford et al., 2007). Blue whales have been shown to track prey aggregations associated with dynamic circulation features (Fahlbusch et al., 2022, 2024; Ryan et al., 2022), emphasizing the importance of understanding regional circulation patterns in relation to WEAs.

Fin whale (*Balaenoptera physalus*)

Fin whales exhibit seasonal shifts in distribution, with increased presence off central California in summer and northern Baja California in winter, while some individuals may remain year-round in southern California waters (Bloom et al., 2025; Falcone et al., 2022; Scales et al., 2017). As generalist feeders, fin whales exploit a broader range of prey, including micronekton, squid, and schooling fish, which may support more flexible habitat use and repeated use of productive areas (Mizroch et al., 2009). This dietary flexibility may buffer fin whales from localized prey variability but also increases the potential for spatial overlap with OSW development across the range of their habitats. Fin whales rely on low frequency acoustic communication over long distances and may be affected by noise sources that overlap with their auditory range (Širović & Oleson, 2022).

Killer whale (*Orcinus orca*)

Killer whales occur in multiple ecotypes along the U.S. West Coast, including resident, transient, and offshore populations that use both nearshore and offshore habitats. The Southern Resident killer whale population is listed as 'endangered' under the ESA (Reynolds et al., 2009) and faces key threats including reduced availability of preferred prey (primarily Chinook salmon), chronic and acute noise and disturbance from vessel traffic, and high contaminant loads (PCBs) (NMFS 2008). Additional vessel activity and noise associated with OSW development may exacerbate these existing stressors, particularly in areas where critical habitat and migration corridors overlap with project activities.

Sea Turtles *(Chelonia midas, Dermochelys coriacea, Caretta caretta, Lepidochelys olivacea)*

Sea turtles use both nearshore and offshore waters along the West Coast, using these habitats for migration and foraging. East Pacific green sea turtles are year-round residents in Southern California, where they forage on eelgrass (NOAA Fisheries, 2024). Loggerhead and olive ridley sea turtles occur more intermittently as nearshore transient species (Eguchi et al., 2018; NOAA Fisheries, 2020). While leatherback sea turtles are more commonly associated with offshore, productive foraging areas (NOAA Fisheries, 2025). Nearly all leatherback sea turtles occupying the CCLME are adults or subadults and therefore contribute to recruitment and population viability. Because leatherbacks are an ESA-listed endangered species and, therefore, removal of reproducing adults from the population may have population-level impacts, so potential for mortality, although unlikely, is a concern.

Impacts to Bay and Estuary Marine Mammals and Sea Turtles

For bay and estuary species, infrastructure development, vessel traffic, and noise were identified as priority IPFs, with main potential impacts including alteration of habitat and spatial avoidance (Table 16). Prioritization reflects the spatially constrained nature of bay and estuarine systems and the high site fidelity of priority species such as harbor porpoises, and harbor seals (Table 16).

Humboldt Bay serves as a vital sanctuary for marine mammals, providing a rare combination of haul-out sites, nutrient-rich foraging grounds, and a sheltered rest stop along the migratory corridor of the CCLME. Pacific harbor seals are prominent, permanent residents for the bay, utilizing sandbars and mudflats that are exposed during low tide as resting, molting and haul out sites. Seals require dry land to thermoregulate, sleep, and socialize. The bay is also a significant pupping and nursery habitat from March through June as mothers give birth on the secluded tidal flats (Sullivan, 1980). The calm waters allow pups to develop swimming skills and blubber reserves before entering the heavy surf and intense predation along the coast. The bay is also an important foraging area, supporting prey such as Pacific staghorn sculpin, various flatfish, and seasonally abundant Pacific herring.

Infrastructure development, particularly the proposed HLT and turbine staging area in Humboldt Bay, would be located within this primary transit corridor used by high priority species, including harbor seals, and harbor porpoises. Humboldt Bay's narrow mouth and tidal dynamics concentrate marine mammals into confined channels during low tide, increasing their spatial overlap with construction activities, vessel traffic, and associated elevated noise. In this spatially constrained environment, even localized increases in activity may result in disproportionate exposure for species exhibiting strong site fidelity to specific haul out, foraging, and transit areas (Blanchet et al., 2021; Lowry et al., 2008). Limited ability to avoid disturbance may force individuals into suboptimal habitats (Grigg et al., 2012), particularly given life history constraints that reduce flexibility in habitat use for some of some priority species (Forney et al., 2017).

While relatively more is known about the distribution and densities of bay and estuarine species than offshore species in general, uncertainties remain regarding fine scale habitat use and behavioral patterns prior to development. It was prioritized to monitor for impacts from infrastructure and Humboldt Bay port development due to its potential for habitat alteration and spatial avoidance, with permanent structures likely modifying habitats used by harbor seals and harbor porpoises.

Noise in bays and estuaries was prioritized due to the behavioral sensitivity, life history traits, and site fidelity of harbor porpoises and harbor seals. Increased noise from construction and vessel traffic may propagate over longer spatial scales depending on the noise source and its contribution relative to existing anthropogenic stressors.

Harbor porpoises are frequent visitors to the deeper portions of the Entrance Channel and North Bay. Porpoises are extremely sensitive to underwater noise (Forney et al., 2017; Tougaard et al., 2020) making them a primary species of concern regarding the increased vessel traffic and dredging associated with port development. Elevated noise from construction, in-bay infrastructure, and vessel traffic may mask echolocation used for foraging and navigation, disrupt communications between individuals, and reduce the effectiveness of acoustic cues for predator avoidance (Verfuss et al., 2005, Clausen et al., 2011, Linnenschmidt et al., 2013).

Given their residency and well-documented behavioral sensitivity to disturbance, including OSW energy development, California harbor porpoise stocks may experience repeated displacement from critical foraging habitat during multi-year construction phases (Forney et al., 2017). Harbor seals are particularly sensitive to disturbance, flushing from haulouts when disturbed (Blundell and Pendleton, 2015). They may be especially vulnerable during breeding seasons, as noise may disrupt underwater communication during mating and pup-rearing (Hastie et al., 2015; Tougaard et al., 2009). Sea otters, which rely on surface and subsurface foraging and pup care, may experience behavioral disruption and increased energetic costs associated with elevated noise and vessel activity. These acoustic impacts may result in spatial avoidance of important habitats and could impact individual reproductive success.

Vessel traffic during both construction and operation may increase the risk of vessel interactions, particularly within these confined transit corridors, and was highlighted as a major concern for harbor seals (Armad et al., 2023; Jansen et al., 2015). Repeated vessel activity was described by WG members to be associated with habitat alteration and spatial avoidance among high priority species. For harbor seals, increased vessel traffic and construction activities associated with infrastructure may disturb established haul-out and pupping areas (Becker et al., 2009). Harbor porpoises may be particularly vulnerable to displacement from preferred foraging grounds due to vessel presence and associated noise (Forney et al., 2017).

Impacts to Resident (Nearshore and Offshore) Marine Mammals

The priority IPFs for nearshore and offshore resident marine mammals were noise and infrastructure (Table 17). It should be clearly noted that while some species (e.g., bottlenose dolphins) are well known to be generally more resident (non-migratory), other species included in this grouping, including the highest priority species given their particular sensitivity (i.e., beaked whales) are far less understood.

For resident species, such as beaked whales, the risk associated with OSW development may be elevated (Forney et al., 2017). A knowledge gap persists regarding their long-term movement patterns within proposed lease areas. While current assessments operate under the assumption of residency, the actual site fidelity and seasonal occupancy of these cryptic taxa remain largely unquantified. Understanding the degree of residency is important; if these populations are truly localized, they will face a higher probability of chronic exposure to underwater noise and habitat displacement (Moore & Barlow, 2013). Conversely, it is found their movements are more transient or driven by shifting oceanographic fronts; beaked whales' vulnerability may vary spatially and temporally.

The potential for prolonged exposure to resident species highlights the importance of understanding fine scale habitat use within OSW development areas. For many resident high priority taxa, particularly deep diving species such as beaked whales, limited detectability and subsurface behavior present challenges for accurately characterizing distribution and behavioral responses. These constraints suggest that monitoring approaches will need to account for mostly subsurface activity, as well as variability in detection probability across species and habitats. In addition, distinguishing between behavioral avoidance, displacement, and continued habitat use in the presence of OSW infrastructure will be important to assess potential impacts.

Infrastructure was prioritized due to the risk of entanglement associated with marine debris becoming ensnared on infrastructure, particularly for resident taxa that may utilize the habitat around these physical structures regularly. The frequent, repeated use of offshore habitats by beaked whales (Baggett et al., 2025), may increase the likelihood of interaction with structural components or associated gear.

The elusive behavior of these offshore resident species brings up key questions, especially prior to construction, including the distribution, density, and key behavioral patterns of these species in WEAs. Resident marine mammals may experience more consistent exposure to impacts from OSW-related activities across construction and operations due to the site fidelity of resident species.

Impacts to Nearshore Transient Marine Mammals and Sea Turtles

The priority IPFs for nearshore transient marine mammals and sea turtles were vessel traffic and infrastructure (Table 18). Certain species are known to be more susceptible to vessel collision risk (e.g. gray whales, killer whales, sea turtles).

Nearshore transient species present unique challenges due to their movement through coastal corridors and variable temporal presence. Because these species are transient and not continuously present within a given area, capturing pre-construction baseline conditions, and detecting changes in distribution or behavior may require sustained, spatially extensive monitoring approaches.

For migratory species such as the endangered gray whale[36], whose coastal migration corridors overlap with nearshore development and vessel transit routes, distinguishing between natural migratory behavior and responses to OSW related activities may be particularly challenging. It was noted that while OSW lease areas are located further offshore, gray whale migratory routes may intersect with nearshore components of development, including transmission cable routes and associated increased vessel traffic, increasing exposure to disturbance and risk of vessel collision during migration periods (Slaathaug et al. 2026). Sea turtles, especially leatherbacks, were highlighted due to declining populations, relatively slow swimming speeds, and habitat overlap with vessel activity, which may elevate the risk of vessel collision. Transient killer whales, which periodically utilize the nearshore waters for foraging or traveling, may be impacted by an increase in vessel traffic, which may impact their movement or foraging patterns (Houghton et al., 2015; Lusseau et al., 2009). Increased vessel traffic during construction and operations in nearshore waters may increase the potential for vessel

36 The ESA allows for splitting of species into Distinct Population Segments (DPS) for listing. The Eastern North Pacific DPS is not listed as endangered and its population has grown to approximately 27,000 and has been most recently reported as increasing despite several unusual mortality events (NMFS 2021). The Western North Pacific DPS overlaps spatiotemporally with the Eastern North Pacific DPS and is listed as endangered. They primarily feed off the coast of Russia and overwinter in Asia, but studies have detected this population off the coast of California (Carretta et al., 2022).

collision across taxa. Vessel collision risk is low, in part, due to avoidance measures that are required for OSW.

Infrastructure may introduce secondary or tertiary entanglement hazards within nearshore waters and transit corridors, increasing the risk for high priority transient species, including gray whales, sea turtles, and transient killer whales (Duncan et al., 2017). Mooring lines and inter-array cables, associated with OSW, suspended in the water column can act as snag points for drift nets, crab pots, and longlines, a risk that is largely known (PNNL, 2026). However, currently there is a limited empirical understanding of how large-scale arrays, with multiple lines and dynamic cables draped between devices, may influence these processes. Species may therefore experience increased exposure to infrastructure-related hazards where habitats overlap with OSW development areas (PNNL, 2026). Tertiary entanglement risks may accumulate over time, as individuals already carrying entangling material (e.g., fishing gear) become further entangled through interactions with OSW infrastructure (Harris et al., 2025). Additionally, infrastructure may create a localized ‘reef effect’ that attracts prey and predators, potentially increasing the probability of encountering snagged gear. Monitoring these risks is challenging, as secondary entanglement would mainly happen deep in the water column, far below the surface, if it occurs.

There is also the potential for animals to become incapacitated by the ingestion of smaller debris associated with infrastructure maintenance or degradation. Sea turtles often mistake floating debris, such as fragments of protective cable wrapping, for prey like jellyfish or salps. Once ingested, these materials can cause the "float syndrome," where gas trapped in the gut prevents the turtle from diving, leaving them permanently buoyant and vulnerable to vessel collision or starvation (Polyak et al., 2025). This typically results in delayed mortality with a slow decline in health that is rarely attributed to a specific project unless a necropsy is performed.

A knowledge gap due to lack of data and understanding of impact includes EMF impacts on potential alteration of habitat use and spatial avoidance (Table 19). Sea turtles rely on magnetic fields for navigation during coastal transits. The introduction of EMF from OSW cables and infrastructure could potentially interfere with this sensory mechanism and alter movement patterns and habitat use, although data gaps exist in terms of the EMF fields for the proposed OSW developments. Given the limited information on the EMF emitted by these cables, the spatial scale of response, and whether transient taxa alter movement patterns in proximity to EMF sources, the potential impact is not fully understood.

Impacts to Offshore Transient Marine Mammals and Sea Turtles

Priority IPFs for offshore transients were vessel traffic and infrastructure during construction and operations (Table 20). Priority offshore transient species include blue whales, fin whales, sea turtles, and offshore killer whales.

Offshore transient species have a large range and are variably distributed, which may complicate efforts to characterize baseline conditions and detect changes in occurrence or behavior within OSW development areas. For large migratory species such as blue and fin whales, distinguishing between natural shifts in distribution (e.g. driven by prey availability or oceanographic conditions) and responses to OSW-related activities may be particularly challenging.

Increased vessel traffic may elevate the risk of vessel collision for large baleen whales, such as blue and fin whales, due to their large body size and their reliance on surfacing to breathe (Nichol et al., 2017; Redfern et al., 2020; Rockwood et al., 2021; Welsh & Witherington, 2023). Sea turtles are also surface oriented, frequently occupying the upper water column habitats, increasing the risk of vessel collision from increased vessel traffic. Offshore killer whales, which travel and forage in epipelagic waters, may also experience elevated risk during periods of overlap with the increase in vessel traffic. Vessel collision risk is low, in part, due to avoidance measures that are required for OSW.

Infrastructure was prioritized due to in-water structural components that may introduce physical hazards within offshore habitats and transit corridors, increasing the potential displacement. Large baleen whales, such as blue and fin whales, may be more vulnerable to secondary or tertiary entanglement due to their large body size and limited maneuverability, which may increase the likelihood of interaction with in-water structures or associated gear. Sea turtles, especially leatherbacks, may also be susceptible to vessel collision or entanglement due to their surface behavior and frequent use of the upper water column. Offshore killer whales, which periodically move through offshore waters while traveling or foraging, may similarly experience increased exposure to infrastructure-related hazards where these habitats overlap with OSW development areas. Again, vessel collision risk is low, in part, due to avoidance measures that are required for OSW. Entanglement risk is also expected to be low, and it is unclear how much risk is elevated by the presence of OSW relative to the pre-existing marine debris, which is not generated by the windfarm.

The effects of noise on navigation and detection of structures and vessels remain poorly understood (Table 21). Elevated noise may reduce an animal's ability to detect and avoid structures, potentially increasing interaction risk or avoidance of wind farm areas. The direction and magnitude of these behavioral responses remain poorly understood, though marine mammals and sea turtles currently navigate through the Gulf of Mexico, the North Sea, and other industrial environments without significant instances of vessel collision, entanglement, or displacement indicated by published studies and agency documentation.

EMF from offshore cables represents an additional knowledge gap, particularly for sea turtles that rely on geomagnetic cues for navigation (Table 21). The extent to which EMF may alter habitat use, cause spatial avoidance, or disrupt migratory pathways remains poorly characterized, as does the spatial scale of behavioral response and the extent to which offshore transient species modify movement patterns around these IPFs.

6.3. Marine Mammals and Sea Turtles Recommendations

Foundational Recommendations

To support effective long-term monitoring for marine mammals and sea turtles, the following foundational recommendations should be prioritized:

- **Obtain needed spatial and temporal distribution and density data** using integrated, multi-method monitoring for strategically selected species Employ advanced integrated, multi-method monitoring to coordinate acoustic, visual, tagging, and oceanographic approaches to assess species exposure, distribution, habitat use, and behavioral responses.
- **Account for spatial and temporal variability** to account for spatial and temporal variability in species' distributions, target monitoring within high-use habitats, migration corridors, and feeding areas with seasonal patterns and priority species.
- **Assess Pre-Construction Abundance and Distribution of Taxa** Improve characterization and understanding of species abundance, distribution, timing of sensitive life history periods, and ecology and movement patterns. Establishing this pre-construction baseline will be essential for evaluating variability and detecting project-related changes.
- **Prioritize long-term acoustic monitoring** Prioritize long-term acoustic monitoring, building on existing programs, to establish comprehensive pre-construction baseline soundscapes and maintain passive acoustic monitoring (PAM) throughout all project phases to track noise and species vocalization changes within and beyond WEAs.

Impact-Specific Recommendation Tables

Monitoring recommendations for marine mammals and sea turtles focus on understanding impacts from increased noise, infrastructure, vessel presence, and non-acoustic IPFs (e.g., EMFs and lighting).

Below is a review of each sensor/data collector identified for assessing each impact topic and associated MQs (Tables 22-26). For each sensor, priority species were identified in addition to a summary of key opportunities and limitations. Cost and effort assessments as presented in the tables are *relative* to other sensors used to monitor marine mammals and sea turtles. Where applicable, examples of monitoring programs and projects along the entire West Coast that employ these sensors were included to show their current application.

MQ: How does noise from OSW activities alter movement and behavioral patterns of priority species?
MQ: How does the risk of increased ambient noise impact a species ability to detect and avoid gear, potentially leading to higher rates of entanglement?

Table 22. *Impact Topic: Monitoring for Acoustic Impacts and Behavioral Modifications*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Acoustics - PAM	Baird's beaked whale Blainville's beaked whale Cuvier's/Goose beaked Blue whale Fin whale Gray whale Harbor porpoise Killer whale	Established deployment, data collection & analytical methods (i.e. species-specific classifiers for most species). Data can provide location & time-specific detection of vocalizing species revealing habitat utilization & species distribution. Archival, non-directional PAM detection ranges are well understood; array designs must differ by species. Advanced PAM arrays can include density estimation.	PAM can only detect vocalizing animals; vocal behavior varies by species, sex, age & behavioral state (e.g. some spp., harbor porpoises, more continuously echolocating than others). Archival systems require retrieval & post-processing; real-time & localization-capable systems more complex (e.g. Monterey Bay, SB Channel) but are expensive. Real time buoys available but more expensive; localization is possible & can be valuable but more complicated, expensive	Moderate to High Archival, non-directional sensors relatively cost-effective to deploy, but analysis costs often substantial & increase with # of instruments. Real-time & directional systems are substantially more expensive but provide greater temporal resolution & operational utility.	MBARI PAM, NOAA Ocean Noise Reference Station Network, PAM of Marine Mammals in Southern California Range Complex, NOAA ONMS: Ocean Sound Observation Network Cascadia Research & UCSC: use PAM with acoustic tagging, MBARI Baleen Whale Behavioral Ecology, MBARI Blue Whale Observatory

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
			& variably applicable for different species. Some species alter acoustic behavior (i.e., ceasing vocalizing) with noise disturbance; ability to track & characterize with PAM can detect the change but then not the animals.		
Tagging	Blue whale Fin whale Gray whale Leatherback turtle	Tagging sensors are mature and have been applied to these species for broad scale/coarse (satellite telemetry and acoustic tags), fine-scale high resolution movement, & acoustic behavior. Extensive baseline data exists for these species in some areas, but limited tag deployments in WEAs. New tag studies have been able to fill gaps in	Sample size is often small; Deployments constrained by weather, logistics, permitting, animal handling requirements, and species-specific expertise. Tagging programs require specific expertise, authorization, and potential IACUC oversight (e.g. implant tags) and acoustic tags require receivers to be effective.	High Costs vary by species, sample size, & field conditions; since tagging generally requires substantial investment. Pre-deployment costs are high, though behavioral data obtained from tags is often uniquely informative; Tagging studies have formed a direct empirical basis of risk assessments & policy development. Satellite	Cascadia Research Collective, SOCAL -BRS, Hopkins & UCSC: tagging studies and sensor development, MBARI PAM, OSU: long-term satellite telemetry efforts, IOOS Animal Telemetry Network, NOAA ONMS: Ocean Sound Observation Network, UPwell Turtles, NOAA SWFSC, MLML

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		time/space/resolution; there are increasing numbers of receiver arrays which can be used for multi-species detections. Studies have also been used to conduct opportunistic & experimental behavioral response studies	However, proven, safe, effective tools & applications have overcome these issues for all four of these species.	tags provide real time data on movement and habitat use.	Northeast Pacific Acoustic Telemetry (N-PAcT), Upwell Turtles/NOAA SWFSC: regional sea turtle tagging work, involving satellite and acoustic tags.
Visual Observation – Aerial Surveys	Gray whale Fin whale Blue whale Harbor porpoise Harbor seal Leatherback turtle	Aerial surveys useful for broad-scale assessments of species distribution, movement, & habitat use; established transect methods exist for multiple species. Uncrewed aerial systems (UAS) can improve repeatability & reduce cost & risk, particularly for nearshore species (e.g., increasingly common for nearshore seal species). Aerial surveys for sea turtles can be effective	Detection strongly affected by weather, sea state, & animal availability at the surface. Generally limited in ability to detect anything other than large-scale shifts in distribution or habitat use; low power to detect subtle displacement or behavioral responses. Crewed surveys involve safety & logistical constraints	Moderate to High Crewed aerial surveys are expensive & difficult to implement. UAS-based surveys reduce costs in nearshore applications, yet costs remain context-dependent, and implementation offshore is challenging. Data collection costs generally higher than PAM & tagging on per-unit basis.	Applied California Current Ecosystem Studies, Harbor porpoise aerial surveys (NOAA-SWFSC), NOAA Channel Islands National Marine Sanctuary Foundation Whale Aerial Survey Program, Upwell/NOAA: Sea Turtles

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		but variable depending on species; existing surveys from Morro Bay to Point Reyes.		Limited surveys in WEAs; particularly Humboldt due to weather & operating conditions.	
Visual Observations – Vessel Surveys (Observers)	Blue whale Fin whale Harbor porpoise Gray whale Sea Otter	Provides direct observations of distribution, group composition, & behavior at finer spatial & temporal scales than aerial surveys. Methods well established & can be integrated with concurrent oceanographic & acoustic data collection from vessel platforms.	Spatial coverage limited; due to slow vessel speeds. Observations constrained by surface availability & environmental conditions. Vessel presence may influence animal behavior, introducing potential bias. Sample sizes can be limited.	High Large-scale surveys using dedicated research vessels are costly. Small boat surveys are efficient and can consistently cover the area at lower cost with more flexibility to accommodate local weather conditions in nearshore areas Opportunistic & citizen science platforms (e.g., HappyWhale) can reduce costs but may introduce variability in data quality & spatial coverage.	CalCOFI, Applied California Current Ecosystem Studies, Pacific Marine Assessment Program for Protected Species survey, NOAA white ship line-transect surveys; provided foundational data for stock assessments, though effort is irregular & seasonally biased, NMML conducting coastwide nearshore cetacean surveys during PCFG period

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Biological/Physiological Samplers – Biopsy	Cuvier's/ Goose beaked whale Blue whale Fin whale Gray whale Harbor seal Sea Otter Leatherback turtle	Sampling methods (e.g., biopsy, fecal, blow) are well established & provide information on sex, health, & physiological condition. Used to assess exposure & response to disturbance (e.g., stress hormones like cortisol). Tagging platforms can provide complementary physiological metrics (e.g., heart rate, respiration, body condition).	Sample collection can be logistically challenging & invasive, requiring permits & specialized expertise. Sample sizes often small. Interpretation of results requires species-specific baseline data, which may be limited or unavailable.	Moderate Sampling can be cost-effective when integrated with existing field efforts, but analytical costs & limited sample sizes can increase overall effort.	NOAA SWFSC: has led and applied methods for cortisol analysis in exposure response studies, MLML, Cascadia Research Collective, OSU, Hopkins/ UCSC Marine Station, Cal Poly Humboldt, Upwell Turtles/NOAA: conduct comprehensive body condition assessments (sex, health, physiological metrics, sample collection) on captured leatherbacks

MQ: To what extent does the increase in vessel traffic during both the construction and maintenance phases heighten the risk of lethal vessel strikes for marine mammals and sea turtles?

Table 23. *Impact Topic: Monitoring for Vessel Traffic and Strike Risk*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Acoustics - PAM	Baird's beaked whale Blue whale Fin whale Gray whale Harbor porpoise Killer whale Leatherback sea turtle	Established deployment, data collection & analytical methods (i.e. species-specific classifiers for most species). Data can provide location and time-specific detection of vocalizing species revealing habitat utilization and species distribution. Archival, non-directional PAM detection ranges are well understood Advanced PAM arrays can include density estimation. Offer substantial return on investment (ROI) & ability to monitor taxa consecutively.	PAM only detects vocalizing animals, yet vocal behavior varies by species, sex, age class, & behavioral state. Some species may reduce or cease vocalizing in response to disturbance, which can limit detectability. Lack ground-truthing with at-sea observations. Archival systems require retrieval & post-processing, while real-time & localization-capable systems are more complex & costly; Overcoming these limitations requires a targeted and well-designed deployment strategy relative to potential vessel traffic.	Moderate to High Archival, non-directional instruments relatively cost-effective to deploy, but analysis costs are often substantial & increase with # of units. Real-time & directional instruments are substantially more expensive but provide greater temporal resolution & operational utility. For vessel strike particularly, use of real time sensors (Benioff) offers some operational awareness, but without localization, precision of whale location is limited. Overall moderate effort for relatively high return,	MBARI Baleen Whale Behavioral Ecology, MBARI Blue Whale Observatory, MBARI PAM, NOAA ONMS: Ocean Sound Observation Network, PAM of Marine Mammals in Southern California Range Complex (SOCAL), NOAA Ocean Noise Reference Station Network, Benioff: CINMS, Cascadia Research Collective, Point Blue: modeling work, Blue Whales Blue Skies (BWBS): Vessel Speed Reduction (VSR) initiative

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		Integration of PAM & Automatic Identification System (AIS) data before and during changes in vessel traffic could be very productive and cost-effective.	Array designs must differ by species. Extensive baseline data given lack of PAM data in some areas (Humboldt); required to evaluate potential strike risk. Limitations more in the effective design than in availability or cost of the sensor.	but analysis time significant. AIS data acquisition & analysis to overlay is relatively cheap & easy.	
Tagging	Blue whale Fin whale Gray whale Leatherback sea Turtle Harbor seal	Tagging sensors are mature and have been applied to these species for broad scale/coarse (satellite telemetry & acoustic tags), fine-scale high resolution movement, & acoustic behavior. Extensive baseline data exists for these species in some areas, but limited tag deployments in WEAs.	Sample size is often small; Deployments constrained by weather, logistics, permitting, animal handling requirements, and species-specific expertise. Tagging programs require specific expertise, authorization, and potential IACUC oversight (e.g. implant tags). And acoustic tags require receivers, though there is an increasing	High Generally, requires substantial investment, cost varies by species, ample size, and field conditions Pre-deployment costs high, scales with level of effort, archival or real time dependent. Targeted studies in targeted areas can be relatively efficient.	IOOS Animal Telemetry Network, NOAA ONMS: Ocean Sound Observation Network, Northeast Pacific N-PAcT, UPwell Turtles, NOAA SWFSC, MLML, Cascadia Research Collective, OSU, Cal Poly Humboldt, NOAA

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		New tag studies have been able to fill gaps; Studies have also been used to conduct opportunistic & experimental behavioral response studies For harbor seals, tags involve capturing & instrumenting animals (proven technique but associated risks). Use of tags on whales & turtles in WEAs to examine fine scale interactions with vessels thru AIS. AIS data & direct observations have been done by multiple groups	number of receiver arrays. However, proven, safe, effective tools & applications can overcome these constraints Goals, species priorities, key questions need to be identified to be cost effective & targeted to evaluate strike risk.	Important to understand movement patterns of species to tag animals in key areas	
Visual Observations – Vessel Surveys (Observers)	Blue whale Fin whale Gray whale Harbor porpoise Sea Otter	Vessel-based observers on commercial & industry vessels are an easy platform of opportunity and established as a method for evaluating strike risk.	Limited opportunities for NOAA white ship surveys. Recommend leverage commercial and industry vessels as platforms, but sample size limitations.	High Full scale line transect surveys; Very expensive & likely unrealistic; Much more cost effective for platforms of opportunity from industry vessels.	CalCOFI, Applied California Current Ecosystem Studies, Pacific Marine Assessment Program for Protected Species survey, NOAA white ship line-transect surveys; provided foundational data for stock

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		Large-scale line transect observations provide broad patterns of habitat use but probably not fine-scale aspects of strike risk		Local, small boat surveys would be cost effective in nearshore waters	assessments, though effort is irregular & seasonally biased.
Imaging systems – Photo ID	Blue whale Cuvier's/Goose Beaked Fin whale Gray whale Killer whale Harbor seal Sea Otter	Use of photo ID to identify repeat use of habitat could provide insight into strike risk & habitat utilization. Could be more applicable for some species (seals, killer whales, gray whales) given increased ability to sample. Photo ID databases exist for most of these species & well established.	Difficult to get to statistical power for some species in key areas (e.g., beaked whales) using imaging unless considerable effort. Limitations could be reduced if integrated into existing survey/tagging efforts	Moderate to High Highly cost effective if integrated into existing/other monitoring. NOTE: Most cost effective for nearshore or bay/estuarine species vs offshore species	CalCOFI, NOAA Rockfish Recruitment and Ecosystem Assessment Survey, NOAA ONMS: Ocean Sound Observation Network, UPwell Turtles, NOAA SWFSC, MLML, Cascadia Research Collective, OSU, Cal Poly Humboldt, NOAA and National Marine Mammal Lab (NMML)

MQ: To what extent will the projected increase in vessel traffic during the construction and maintenance phases heighten the risk of spatial avoidance and vessel strikes?

Table 24. *Impact Topic: Monitoring for Spatial Distribution due to infrastructure and vessel presence*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Acoustics - PAM	Baird's beaked whale Blue whale Fin whale Gray whale Harbor porpoise Killer whale	Established deployment, data collection & analytical methods (i.e. species-specific classifiers for most species). Data can provide location and time-specific detection of vocalizing species revealing habitat utilization and species distribution. Archival, non-directional PAM detection ranges are well understood Advanced PAM arrays can include density estimation. Offer substantial ROI & ability to monitor taxa consecutively. Integration of PAM & AIS data before and during	PAM only detects vocalizing animals, yet vocal behavior varies by species, sex, age class, & behavioral state. Some species may reduce or cease vocalizing in response to disturbance, which can limit detectability. Archival systems require retrieval & post-processing, while real-time & localization-capable systems are more complex & costly. Overcoming limitations requires a targeted and well-designed deployment strategy relative to vessel traffic lanes. Extensive baseline data esp. given lack of PAM	Moderate Archival, non-directional units relatively cost-effective to deploy, but analysis costs are often substantial & increase with # of units. Real-time & directional systems substantially more expensive but provide greater temporal resolution & operational utility. For vessel strike, use of real time sensors (Benioff) offers some operational awareness & possibly adaptive mgt., but without localization precision is more limited Moderate effort for relatively high return but	MBARI PAM, NOAA, ONR Station Network, PAM of Marine Mammals in Southern California Range Complex (SOCAL), NOAA ONMS: Ocean Sound Observation Network, Cascadia Research & UCSC: incorporated PAM components into acoustic tagging, MBARI Baleen Whale Behavioral Ecology, MBARI Blue Whale Observatory, BWBS: Vessel Speed Reduction (VSR) Program

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		changes in vessel traffic could be very productive and cost-effective.	data in some areas (Humboldt) required to evaluate potential strike risk. Array designs must differ by species. Limitations more in the effective design than in availability or cost of the tools.	don't underestimate analysis time. AIS data acquisition and analysis has become relatively cheap and easy.	
Tagging	Blue whale Fin whale Gray whale Leatherback sea turtle Harbor Seal Sea Otter	Tagging sensors are mature and have been applied to these species for broad scale/coarse (satellite telemetry & acoustic tags), fine-scale high resolution movement, & acoustic behavior. Extensive baseline data exists for these species in some areas, but limited tag deployments in WEAs. New tag studies have been able to fill gaps;	Sample size is often small; Deployments constrained by weather, logistics, permitting, animal handling requirements, and species-specific expertise. Tagging programs require specific expertise, authorization, and potential IACUC oversight (e.g. implant tags). Acoustic tags require a receiver to be effective	High Scales with level of effort and whether archival or real time. Generally, requires substantial investment. Costs vary by species, sample size, & field conditions. Pre-deployment costs high, though behavioral data obtained from tags is often uniquely informative; Tagging studies have formed direct empirical basis of	IOOS Animal Telemetry Network, NOAA ONMS: Ocean Sound Observation Network, N-PAcT, UPwell Turtles, NOAA SWFSC, MLML, Cascadia Research Collective, OSU, Cal Poly Humboldt, NOAA

Sensors/ Data Collectors	**Species**	**Opportunities**	**Limitations**	**Cost/Effort**	**Example Monitoring Programs & Projects**
		Studies have also been used to conduct opportunistic & experimental behavioral response studies For harbor seals, tags involve capturing & and instrumenting animals (a known, proven technique but comes with risks). Use of tags on whales and turtles in WEAs to examine existing areas and looking in fine scale at interactions with vessels using AIS data & and even direct observations has been done by multiple groups	Proven, safe, effective tools, applications, and increased receiver arrays can overcome these limitations. Goals, priority species, key questions need to be identified to be cost effective & targeted to evaluate strike risk.	risk assessments & policy development Targeted studies in target areas can be done relatively efficiently (e.g. understanding movement patterns in key habitat areas).	
Visual Observations – Vessel Surveys (Observers)	Blue whale Fin whale Gray whale Harbor porpoise Sea Otter	Vessel-based observers on commercial & industry vessels are an easy platform of opportunity and established as a method for evaluating strike risk.	Limited opportunities for NOAA white ship surveys. Recommend leverage commercial and industry vessels as platforms, but sample size limitations.	High Full scale line transect surveys; very expensive & likely unrealistic. Much more cost effective for platforms of	CalCOFI, Applied California Current Ecosystem Studies, Pacific Marine Assessment Program for Protected Species survey, NOAA white ship line-transect surveys; provided foundational

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		Large scale line transect observations would provide broad patterns of habitat use but probably not fine scale aspects of strike risk		opportunity from industry vessels. Small boat surveys are cost effective and more adaptable to local conditions - particularly for nearshore animals.	data for stock assessments, though effort is irregular & seasonally biased.
Imaging systems – Photo ID	Blue whale Cuvier's/goose beaked whale Fin whale Gray whale Killer whale Harbor seal Sea Otter	Use of photo ID to identify repeated use of habitat could provide insight into strike risk as well as habitat utilization; Could be more applicable for some species (e.g., seals, killer whales, gray whales) given increased ability to sample. Photo ID databases exist for most of these species and are well established.	Difficult to get to statistical power for some species in key areas (e.g., beaked whales in OSW) using these techniques without a lot of effort. Limitations could be reduced if integrated into existing survey tagging efforts	High if standalone project Highly cost effective if integrated into existing/other monitoring. More cost effective for nearshore or bay/estuarine vs. offshore species. Small boat surveys are cost effective and more adaptable to local conditions - particularly for nearshore animals	CalCOFI, Cal Poly Humboldt, NMML, Cascadia Research Collective, NOAA Rockfish Recruitment and Ecosystem Assessment Survey, NOAA ONMS: Ocean Sound Observation Network, UPwell Turtles, NOAA SWFSC, MLML

MQ: What are the specific risks of primary, secondary, or tertiary entanglement for marine species during both the construction phase and long-term operations?

MQ: To what extent could species detect and avoid cables and activities that could result in entanglement?

Table 25. *Impact Topic: Monitoring for Entanglement Risk*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Acoustics - PAM	Blue whale Fin whale Gray whale	Established deployment, data collection & analytical methods (i.e. species-specific classifiers for most species). Data can provide location and time-specific detection of vocalizing species revealing habitat utilization and species distribution. Archival, non-directional PAM detection ranges are well understood Advanced PAM arrays can include density estimation.	Data has limited utility for evaluating actual entanglement risk; risk cannot be accurately assessed until final project designs are established & specific offshore configurations are known. Array designs must differ by species. Limited design efficacy; Ineffective in fine-scale analysis of these impacts Limited PAM monitoring exists in WEAs, especially in the Humboldt region.	Low to Moderate Variable depending on questions. Targeted deployments of cheaper simpler systems are effective.	MBARI PAM, NOAA Ocean Noise Reference Station Network, PAM of Marine Mammals in Southern California Range Complex (SOCAL), NOAA ONMS: Ocean Sound Observation Network, Cascadia Research & UCSC: incorporated PAM components into acoustic tagging, MBARI Baleen Whale Behavioral Ecology, MBARI Blue Whale Observatory

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Visual Observation – Aerial Surveys	Blue whale Fin whale Gray whale	Aerial surveys useful for broad-scale assessments of species distribution, movement, & habitat use (exposure risk); established transect methods exist for multiple species. UAS can improve repeatability & reduce cost & risk, particularly for nearshore species.	Not precise enough to record entanglement interactions in real-time due to intermittent survey frequency; insufficient to prove entanglement Detection strongly affected by weather, sea state, & animal availability at the surface. Limited existing surveys in WEAs and transit corridors, especially the Humboldt Bay area.	Low to Moderate Variable depending on question; Cost prohibitive for transect surveys. Cost is lower for opportunistic surveys but that's unlikely to be effective in WEAS, where entanglement would occur.	Applied California Current Ecosystem Studies, Harbor porpoise aerial surveys (NOAA-SWFSC), NOAA Channel Islands National Marine Sanctuary Foundation Whale Aerial Survey Program, Upwell/NOAA: Sea Turtles
Tagging	Blue whale Fin whale Gray whale Leatherback sea turtle	Probably best method for these species to measure exposure risk of & responses to systems that may cause entanglement. Fine-scale aspects of movement, variability in movement & response can be quantified using combination of tags	Often small sample size, likelihood of whales moving through WEAs that would likely be tagged in other areas. Need to use longer-term archival tags that involve dart attachments potentially (though these are available and have been proven effective and largely low impact)	Moderate to High Depends on species, season, level of effort. Proven technology & known results would be the only realistic way to get at fine-scale movement & behavior and ROI. If successful could be HIGH value	IOOS Animal Telemetry Network, NOAA ONMS: Ocean Sound Observation Network, N-PAcT, MLML, Cascadia Research Collective, OSU, NOAA and HSU: seals, UPwell Turtles, NOAA SWFSC

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
			Acoustic tags require receiver arrays to be effective, though there is an increasing number of receiver array deployments on the West coast.		

MQ: How might non-acoustic environmental changes—such as artificial lighting, the creation of artificial reefs, or increased turbidity—impact foraging or the quality of available prey?
MQ: To what degree do EMFs pose a risk to behavioral patterns, navigation, or physiological health of sea turtles?

Table 26. *Impact Topic: Monitoring for non-acoustic environmental impacts (EMF, Lighting, artificial reefs)*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Acoustics - PAM	Blue whale Fin whale Gray whale Olive ridley sea turtle Loggerhead sea turtle Leatherback sea turtle Green sea turtle	Essential for identifying when and where these species occur, and how they utilize specific habitats prior to development; PAM data have limited utility for evaluating actual entanglement risk, which cannot be accurately assessed until final project designs are established & specific offshore configurations are known. Data can provide location and time-specific detection of vocalizing species revealing habitat utilization and species distribution.	Similar issues require a strategic plan but can be highly effective for marine mammals. Ineffective for sea turtles.	Moderate to High Archival, non-directional sensors relatively cost-effective to deploy, but analysis costs often substantial & increase with # of instruments. Real-time & directional systems are substantially more expensive but provide greater temporal resolution & operational utility. Efforts to do fine-scale PAM localization can be quite expensive.	MBARI PAM, NOAA Ocean Noise Reference Station Network, PAM of Marine Mammals in Southern California Range Complex (SOCAL), NOAA ONMS: Ocean Sound Observation Network, Cascadia Research & UCSC: incorporated PAM components into acoustic tagging, MBARI Baleen Whale Behavioral Ecology, MBARI Blue Whale Observatory, BWBS: Vessel Speed Reduction (VSR) Program

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
Visual Observation – Aerial Surveys	Blue whale Fin whale Gray whale Green sea turtle Leatherback sea turtle Loggerhead sea turtle Olive ridley sea turtle	Aerial surveys useful for broad-scale assessments of species distribution, movement, & habitat use (exposure risk); established transect methods exist for multiple species. UAS can improve repeatability & reduce cost & risk, particularly for nearshore species (e.g., increasingly common for nearshore seal species). Aerial surveys for sea turtles can be effective but variable depending on species; existing surveys from Morro Bay to Point Reyes.	Detection strongly affected by weather, sea state, & animal availability at the surface. Generally limited in ability to detect anything other than large-scale shifts in distribution or habitat use; low power to detect subtle displacement or behavioral responses. Crewed surveys involve safety & logistical constraints aspects for designing risk assessment. Likely of limited use for actually measuring fine-scale impacts of question	Variable depending on question; Cost prohibitive for transect surveys. Cost is lower for opportunistic, but that's unlikely to be effective in WEAS, where exposure would occur.	NOAA Santa Barbara Channel Aerial surveys, Applied California Current Ecosystem Studies, Upwell/NOAA: Sea Turtles
Visual Observations – Vessel Surveys (Observers)	Blue whale Fin whale Gray whale Green sea turtle Leatherback sea turtle Loggerhead sea turtle Olive Ridley sea turtle	Provides direct observations of distribution, group composition, & behavior at finer spatial &	Spatial coverage limited; due to slow vessel speeds. Observations constrained by surface availability &	High More cost effective if integrated into existing/other monitoring.	CalCOFI, Applied California Current Ecosystem Studies, Pacific Marine Assessment Program for Protected Species survey, NOAA white ship

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
		temporal scales than aerial surveys. Methods well established & can be integrated with concurrent oceanographic & acoustic data collection from vessel platforms. Visual surveys for sea turtles can be effective but variable depending on species	environmental conditions. Vessel presence may influence animal behavior, introducing potential bias. Sample sizes can be limited.	More cost effective for nearshore or bay/estuarine vs. offshore species Small boat surveys are cost effective - particularly for nearshore species and can be responsive to local conditions	line-transect surveys; provided foundational data for stock assessments, though effort is irregular & seasonally biased, Cal Poly Humboldt, NMML/NOAA
Tagging	Blue whale Fin whale Gray whale Leatherback sea turtle	Probably best method for these species to measure risk of & responses to systems that may cause entanglement because of scale required. Fine-scale aspects of movement, variability in movement & response can be quantified using combination of tags	Sample size, likelihood of whales moving through WEAs. Species likely tagged elsewhere. Need to use longer-term archival tags	Moderate Proven technology & known results would be the only realistic way to get at fine-scale movement & behavior and ROI. High value if successful, though pre-deployment costs high. Tens to hundreds of kilometers for targeted efforts that can yield vital data if strategic tagging.	Cascadia Research Collective, Stanford, OSU, Upwell Turtles/NOAA: Vessel based captures and tagging along CA's Central Coast (primarily Farallon's Islands/Half Moon Bay/Point Reyes/Monterey Bay, and in the Pacific NW (working out of Westport, WA), within/around potential WEAs

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost/Effort	Example Monitoring Programs & Projects
				Can scale and be quite expensive for a substantial effort	
Visual Observations - Shore-based Survey	Gray whale Harbor seal	Proven tools to track & identify individuals. Should be coupled with photo ID. Shore-based visual observations could also include & be coupled with aerial observations using uncrewed systems	Will require extensive baseline data before development to disentangle impacts on nearshore species from other disturbances.	Low to Moderate Lower; vessels not required. Best approaches will integrate visual survey with photo ID & aerial observations from uncrewed systems	Extensive ongoing work with shore-based gray whale surveys: southern and central CA, Citizen science, NOAA/SWFSC: Piedras Blancas, Cambria, Multiple harbor seal monitoring programs in different areas i.e., citizen science & research teams, Humboldt
Environmental Sample Collectors - eDNA	Blue whale Fin whale Gray whale Green sea turtle Leatherback sea turtle Loggerhead sea turtle Olive ridley sea turtle	Promising technology to identify presence/absence of some species at broad scales; still evolving	No off the shelf proven technology for any species. Not fully established for marine mammals - As it evolves, may become ready to evaluate questions as developments begin. Not yet realistic.	Moderate Sample collection can be quite simple & cheap, only requires vessel time. Analysis can be biggest cost. Given lack of maturity of methods, harder to evaluate.	NOAA SWFSC, OSU, Private sector industry development, and research teams

7. Marine Birds and Bats

7.1 Marine Birds and Bats Results

7.2 Marine Birds and Bats Discussion

7.3 Marine Birds and Bats Recommendations

7. Marine Birds and Bats

7.1 Marine Birds and Bats Results

The Marine Birds and Bats WG was divided into three subgroups to support focused discussions aligned with members' expertise: nearshore marine birds, offshore marine birds, and bats. Given substantial overlap in findings between the nearshore and offshore marine bird subgroups, their results are consolidated for reporting. Bats are known to occur offshore California, particularly during migration, but their movement patterns, behavior, and use of offshore habitats remain poorly understood. As port development and onshore construction plans progress, potential impacts to coastal birds and bats, particularly the loss of breeding and foraging areas, should be evaluated. The species considered in each subgroup are defined below.

- Marine bird species include all species that spend substantial time foraging in the waters of the CCLME. Coastal species that do not use marine habitats, and species that are thought to only transit over the ocean primarily in nearshore waters during migration (e.g., songbirds and most shorebirds) were excluded.
- Bat species include all bat species that have been observed or may be expected to visit coastal and marine areas offshore from California

Across both subgroups, infrastructure was identified as the only high-priority IPF, with impacts varying by species' distribution, behavior, and life history. Although the relative importance of specific infrastructure-related impacts differed among subgroups, core concerns (e.g., collision risk and altered energy cost and resource access from displacement) were consistent across taxa.

Marine Bird and Bat Species Prioritization

Marine bird and bat species were prioritized based on clear potential for, or significant uncertainty about, exposure to OSW energy development, high sensitivity to impacts from OSW energy development, and significant management relevance (Table 27). Accordingly, high-priority designation should not be interpreted as evidence of high vulnerability, but rather as an indication of priority for additional monitoring and research, driven by either anticipated risk or key uncertainties that warrant resolution. The impacts of OSW on marine birds are reasonably well-studied globally compared to impacts on other marine and coastal taxa; therefore a number of publications were used to supplement expert discussion in the formation of the marine birds results. The marine bird species list was generated by taking the union of species included in the OSW vulnerability index developed by Kelsey et al. (2025) and those with modeled distributions in the CCLME Leirness et al. (2021), resulting in a working list of 91 species. Bats in the offshore environment are considerably less characterized and therefore species were assessed for exposure and sensitivity by WG experts.

Table 27. *Species prioritization results across marine birds and bat subgroups*

Marine Bird and Bat Species Prioritization Results
High Priority
Marine Birds Red Phalarope (*Phalaropus fulicarius*), Red-necked Phalarope (*Phalaropus lobatus*), Scripps's Murrelet (*Synthliboramphus scrippsi*), Guadalupe Murrelet (*Synthliboramphus hypoleucus*), Craveri's Murrelet (*Synthliboramphus craveri*), Cassin's Auklet (*Ptychoramphus aleuticus*), Short-tailed Albatross (*Phoebastria albatrus),* Ashy Storm-Petrel (*Hydrobates homochroa*), Leach's Storm-Petrel (*Hydrobates leucorhous*), Townsend's Storm-Petrel (*Hydrobates socorroensis*), Hawaiian Petrel (*Pterodroma sandwichensis*), Pink-footed Shearwater (*Ardenna creatopus*)
Bats Hoary bat (*Lasiurus cinereus*), Mexican free-tailed bat (*Tadarida brasiliensis*), Silver haired bat (*Lasionycteris noctivagans*), Western red bat (*Lasiurus frantzii*)
Medium Priority
Marine Birds Brant (*Branta bernicla*), Rhinoceros Auklet (*Cerorhinca monocerata*), Short-billed Gull (*Larus brachyrhynchus*), Herring Gull (*Larus argentatus*), California Gull (*Larus californicus),* Glaucous-winged Gull (*Larus glaucescens*), Iceland Gull (*Larus glaucoides*), Red-billed Tropicbird (*Phaethon aethereus*), Common Loon (*Gavia immer*), Black Storm-Petrel (*Hydrobates melania*), Sooty Shearwater (*Ardenna grisea*), Red-footed Booby (*Sula sula*), Cocos Booby (*Sula brewsteri*), Masked Booby (*Sula dactylatra*), Nazca Booby (*Sula granti*), Blue-footed Booby (*Sula nebouxii*)
Bats Big brown bat (*Eptesicus fuscus),* California myotis (*Myotis californicus*), Canyon bat (*Parastrellus hesperus*), Fringed myotis (*Myotis thysanodes*), Little brown bat (*Myotis lucifugus*), Pallid bat (*Antrozous pallidus*), Townsend's big-eared bat (*Corynorhinus townsendii*), Western mastiff bat (*Eumops perotis*), Western yellow bat (*Lasiurus xanthinus*), Yuma myotis (*Myotis yumanensis*)
Low Priority
Marine Birds Long-tailed Jaeger (*Stercorarius longicaudus*), Parasitic Jaeger (*Stercorarius parasiticus*), Pomarine Jaeger (*Stercorarius pomarinus*), South Polar Skua (*Stercorarius maccormicki*), Pigeon Guillemot (*Cepphus columba*), Black-legged Kittiwake (*Rissa tridactyla*), Sabine's Gull (*Xema sabini*), Bonaparte's Gull (*Chroicocephalus philadelphia*), Western Gull (*Larus occidentalis*), Arctic Tern (*Sterna paradisaea*), Black-footed Albatross (*Phoebastria nigripes*), Northern Fulmar (*Fulmarus glacialis*), Buller's Shearwater (*Ardenna bulleri*)

Marine Bird and Bat Species Prioritization Results
Not Likely to be Exposed to Impacts
Marine Birds Harlequin Duck (*Histrionicus histrionicus*), Surf Scoter (*Melanitta perspicillata*), White-winged Scoter (*Melanitta deglandi*), Black Scoter (*Melanitta americana*), Long-tailed Duck (*Clangula hyemalis*), Common Merganser (*Mergus merganser*), Red-breasted Merganser (*Mergus serrator*), Wilson's Phalarope (*Phalaropus tricolor*), Parakeet Auklet (*Aethia psittacula*), Tufted Puffin (*Fratercula cirrhata*), Horned Puffin (*Fratercula corniculata*), Common Murre (*Uria aalge*), Marbled Murrelet (*Brachyramphus marmoratus*), Ancient Murrelet (*Synthliboramphus antiquus*), Heermann's Gull (*Larus heermanni*), Ring-billed Gull (*Larus delawarensis*), Black Skimmer (*Rynchops niger*), Least Tern (*Sternula antillarum*), Caspian Tern (*Hydroprogne caspia*), Forster's Tern (*Sterna forsteri*), Common Tern (*Sterna hirundo*), Elegant Tern (*Thalasseus elegans*), Royal Tern (*Thalasseus maximus*), Gull-billed Tern (*Gelochelidon nilotica*), Black Tern (*Chlidonias niger*), Red-necked Grebe (*Podiceps grisegena*), Eared Grebe (*Podiceps nigricollis*), Horned Grebe (*Podiceps auritus*), Western Grebe (*Aechmophorus occidentalis*), Clark's Grebe (*Aechmophorus clarkii*), Red-throated Loon (*Gavia stellata*), Pacific Loon (*Gavia pacifica*), Yellow-billed Loon (*Gavia adamsii*), Laysan Albatross (*Phoebastria immutabilis*), Fork-tailed Storm-Petrel (*Hydrobates furcatus*), Least Storm-Petrel (*Hydrobates microsoma*), Wilson's Storm-Petrel (*Oceanites oceanicus*), Murphy's Petrel (*Pterodroma ultima*), Mottled Petrel (*Pterodroma inexpectata*), Cook's Petrel (*Pterodroma cookii*), Flesh-footed Shearwater (*Ardenna carneipes*), Short-tailed Shearwater (*Ardenna tenuirostris*), Black-vented Shearwater (*Puffinus opisthomelas*), Manx Shearwater (*Puffinus puffinus*), Brandt's Cormorant (*Urile penicillatus*), Pelagic Cormorant (*Urile pelagicus*), Double-crested Cormorant (*Nannopterum auritum*), American White Pelican (*Pelecanus erythrorhynchos*), Brown Pelican (*Pelecanus occidentalis*)

Marine Birds

For marine birds, the only priority IPF identified was infrastructure during the operational phase, specifically injury and mortality from collision risk with turbine blades (Table 28). Collision risk varies by species, depending on factors such as the proportion of time spent in flight, flight height, and avoidance behavior. As a result, marine bird exposure was considered to overlap with the physical footprint of OSW facilities. This step was primarily informed by estimates of each species' projected annual distributional overlap with OSW areas currently identified in the CCLME (Ellis et al., in prep.). Sensitivity was informed by the vulnerability index developed by Kelsey et al. (2025), which developed metrics of species' sensitivity to displacement from and collision with OSW infrastructure based on behavioral and life-history traits derived from the literature. Species with high uncertainty in collision or displacement risk were additionally identified by working group chairs based on limitations in the underlying metrics used in Kelsey et al. (2025), as well as gaps in the broader literature on these impact pathways for some taxa (e.g., Lamb et al., 2024). WGs emphasized that even relatively low collision rates may pose population-level risks for sensitive species. High-priority species for this impact represent a subset of the overall high priority species list, defined by either high sensitivity to collision[1] or substantial uncertainty in that sensitivity[2]. These species include Red and Red-necked Phalaropes, Short-tailed Albatross, Hawaiian Petrel, and Pink-footed Shearwater.

Table 28. *IPFs and associated impacts by development phase, high priority species, and habitats for marine birds*

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Injury/mortality	Operation	Red Phalarope[1,2] Red-necked Phalarope[1,2] Short-tailed Albatross[2] Hawaiian Petrel[2] Pink-footed Shearwater[2]	Offshore pelagic regions suitable for floating wind development

[1] High sensitivity to collision with OSW energy infrastructure.

[2] High uncertainty associated with collision with OSW infrastructure.

Marine Bird Knowledge Gaps

Knowledge gaps identified for marine birds are the effects of OSW infrastructure on energy use and resource access, reflecting potential displacement impacts during the operational phase (Table 29). High-priority species for this impact were defined by either high sensitivity to displacement or substantial uncertainty in that sensitivity2. These include Scripps's Murrelet, Guadalupe Murrelet, Craveri's Murrelet, Short-tailed Albatross, Ashy Storm-Petrel, Leach's Storm-Petrel, Townsend's Storm-Petrel, Hawaiian Petrel, and Pink-footed Shearwater. These impacts are expected to occur in offshore pelagic regions with OSW development, where avoidance of infrastructure may alter movement patterns, subsequently altering energetic costs or access to prey resources.

Table 29. *Knowledge gaps associated with IPF and impacts by development phase, priority species and associated habitats for marine birds*

Knowledge Gap	Priority Species	Habitats
The impact of infrastructure on energy cost during operation	Scripps's Murrelet[1] Guadalupe Murrelet[1] Craveri's Murrelet[1] Cassin's Auklet[1] Short-tailed Albatross[2] Ashy Storm-Petrel[1] Leach's Storm-Petrel[1] Townsend's Storm-Petrel[1] Hawaiian Petrel[2] Pink-footed Shearwater[2]	Offshore pelagic regions suitable for floating wind development
The impact of infrastructure on resource access during operation	Scripps's Murrelet[1] Guadalupe Murrelet[1] Craveri's Murrelet[1] Cassin's Auklet[1] Short-tailed Albatross[2] Ashy Storm-Petrel[1] Leach's Storm-Petrel[1] Townsend's Storm-Petrel[1] Hawaiian Petrel[2] Pink-footed Shearwater[2]	Offshore pelagic regions suitable for floating wind development

[1] High sensitivity to displacement from OSW infrastructure.

[2] High uncertainty associated with displacement from OSW infrastructure.

Bats

Bats represent a high-priority knowledge gap in the offshore environment. No high priority IPFs were identified for bats because their use of offshore environments is relatively understudied; consequently, all high-priority concerns were identified as knowledge gaps.

Bat Knowledge Gaps

Knowledge gaps for bats relate to potential impacts from OSW infrastructure, noise, and lighting during operations (Table 30). These include the risk of injury or mortality from infrastructure during operations for hoary bats, Mexican free-tailed bats, silver-haired bats, and western red bats. Infrastructure was also associated with increased energy cost and changes in resource access during operations for all high priority bat species. Noise and lighting were associated with increased energy cost during operations for all priority species.

Table 30. *Knowledge gaps associated with IPF-impacts by development phase, priority species and associated habitats for bats*

Knowledge Gap	Priority Species
Bat habitat use in the offshore environment.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat
The impact of infrastructure on injury/mortality during operation.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat
The impact of infrastructure on energy cost during operation.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat
The impact of infrastructure on resource access during operation.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat
The impact of noise on energy cost during operation.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat
The impact of lighting on energy cost during operation.	Hoary bat Mexican free-tailed bats Silver-haired bat Western red bat

7.2. Marine Birds and Bats Discussion

The CCLME supports a diverse assemblage of more than 90 species of marine birds and contains important habitat for both locally breeding species and migratory seabirds, driven by strong upwelling that sustains high productivity of plankton, krill, and forage fish. These conditions make the region an important habitat for both locally breeding and migratory seabirds.

Bat occurrence in the CCLME remains poorly understood. While some species, most notably the hoary bat, have been documented migrating over open water and using offshore islands (Cryan & Brown, 2007; Allison & Butryn, 2020), the frequency, drivers, and ecological importance of offshore habitat use are uncertain. While traditionally viewed as terrestrial mammals, acoustic monitoring and historical records from the Channel Islands and Farallon Islands confirm that these species regularly navigate the maritime environment, where they face unique energetic demands (Pelletier et al., 2013; Solick & Newman, 2021). However, these occurrences are likely transient and associated with migration or use of islands as stopover habitat, rather than sustained use of marine environments comparable to that of marine birds (Peterson et al., 2014). Certain species are known to migrate along the Pacific coast, and others are known to occupy islands in the Pacific, suggesting some level of offshore presence. The lack of observations could be due to either or both lack of effort by researchers, or actual lack of bat presence, but this is unknown (Solick & Newman, 2021).

Impacts from Infrastructure

OSW infrastructure was identified as the only high-priority IPF for marine birds, with the potential to cause injury and mortality, as well as displacement-related effects such as increased energetic costs and altered resource access (Croll et al., 2022; Goodale et al., 2019; Peschko et al., 2020). Among these impacts, injury and mortality from collision risk during the operational phase was the only impact classified as high priority. Although collision events may occur less frequently than displacement, they may result in direct mortality and are therefore of clear ecological and management concern if they occur at meaningful levels. As a result, improving estimates of collision rates is a priority.

Displacement-related impacts were identified as knowledge gaps. Avoidance of OSW infrastructure and associated changes in movement or habitat use have been widely documented in other regions and are likely to occur more broadly across species than collision (Lamb et al., 2024). However, the extent to which these behavioral responses translate into population-level consequences remains highly uncertain (Searle et al., 2023), particularly in the CCLME context. This uncertainty is driven in part by limited information on the spatial configuration and scale of future offshore wind development (Lamb et al., 2024). Reducing these uncertainties is therefore a key research need. Unlike terrestrial wind farms, where collisions are well-documented drivers of high mortality, the offshore environment introduces unique attraction factors; bats may be drawn to turbines as potential roosting sites or concentrated foraging hubs for insects attracted to aviation lighting (Ahlén et al., 2009; Cryan et al., 2014). The expansive scale of proposed WEAs along the Pacific Flyway could create a cumulative "sink" effect, where the combination of collision risk and the energetic costs of avoidance behavior threatens the long-term viability of migratory populations already facing continental-scale declines (Frick et al., 2017; Solick & Newman, 2021).

High Priority Marine Bird and Bat Species

The high priority species identified by the species prioritization decision tree are:

Red and Red-necked Phalaropes (*Phalaropus fulicarius* and *P. lobatus*)
Red and Red-necked Phalaropes, members of the shorebird family, are both highly pelagic species that are observed in the CCLME throughout the year, with densities estimated to be highest during migration (Leirness et al., 2021, Rubega et al., 2020, Tracy et al., 2020). Leirness et al. (2021) produced a grouped distribution model using observations of all phalarope species present in the region due to high proportions of unidentified phalarope observations in the underlying at-sea survey data used to create models. The production of a species-specific distribution model for this species would refine understanding of exposure to OSW farms, particularly as the grouped Phalarope spp. model estimates some overlap with currently identified WEAs in California and Oregon (Ellis et al., in prep).

Kelsey et al. (2025) estimated collision sensitivity to be relatively very high for phalaropes. However, there is very little published literature on phalarope flight behavior, thus this high collision sensitivity ranking is heavily influenced by a single high estimate of flight overlap with turbine RSZs that was not based on empirical data (Robinson Willmott et al. 2013). Additional research on phalarope flight behavior would be important to refine understanding of collision probability.

Red-necked Phalaropes are currently listed as Least Concern by the IUCN; however, the populations may be threatened by declining water levels in inland hypersaline lakes used as stopovers on migrations. Significant recent declines have been observed in migratory flock sizes, indicating potential population declines that are as of yet not well understood (Rubega et al., 2020). Red Phalaropes in contrast are strictly pelagic and are subsequently more data limited, and while they are similarly listed as Least Concern by the IUCN, significant uncertainty in the likelihood of the impacts of OSW for all species make additional research and monitoring a priority.

Scripps's, Guadalupe, and Craveri's Murrelet (*Synthliboramphus scrippsi*, *S. hypoleucus*, and *S. craveri*)

Scripps's Murrelet, Guadalupe Murrelet, and Craveri's Murrelet are small alcids that occur within the CCLME throughout the year, though their distributions vary seasonally. Scripps's Murrelet breeds primarily on the Channel Islands and islands off the west coast of Baja California (Drost et al., 2020). Guadalupe Murrelet breeds predominantly on Guadalupe Island, with smaller numbers in the southern Channel Islands (Mlodinow & Pyle, 2023). Craveri's Murrelet breeds farther south along the Baja California coast and in the Gulf of California and is thought to occur within the CCLME primarily during the non-breeding season (Mlodinow et al., 2024). Accurate characterization of at-sea distributions for these species remains challenging due to difficulties distinguishing them in the field and historical taxonomic treatment that grouped them as a single species complex. As a result, Leirness et al. (2021) produced a combined distribution model for all three species. Development of species-specific models would improve estimates of exposure to offshore wind facilities, particularly given that the grouped model indicates some overlap with currently identified WEAs in California and Oregon (Ellis et al., in prep).

Sensitivity to collision is expected to be low, as murrelets spend most of their time on or near the water's surface. However, Kelsey et al. (2025) identified high sensitivity to displacement for these species, consistent with observed avoidance behavior in alcids at operational offshore wind facilities (Lamb et al., 2024). The population-level consequences of displacement remain uncertain but may be of particular concern if development occurs in key foraging areas used during the breeding season, or if repeated avoidance increases energetic costs for breeding adults.

All three species face multiple anthropogenic threats; most notably invasive predator impacts at island breeding colonies. Scripps's Murrelet and Craveri's Murrelet are classified as Vulnerable by the IUCN, while Guadalupe Murrelet is listed as Endangered due to its small population size and restricted breeding range. Scripps's and Guadalupe Murrelets are also listed as Threatened by the State of California. Given high uncertainty in exposure estimates, projected sensitivity to displacement, and existing conservation concerns, all three species are priorities for targeted monitoring and research.

Cassin's Auklet (*Ptychoramphus aleuticus*)

Cassin's auklets are small diving alcids with breeding colonies ranging from Alaska through Mexico (Manugian et al., 2015), including throughout California with large breeding colonies in the Channel Islands and on the Farallon Islands. Sensitivity to collision is expected to be low, as Cassin's Auklets spend most of their time on or near the water's surface. However, Kelsey et al. (2025) identified high sensitivity to displacement for these species, consistent with observed avoidance behavior in alcids at operational offshore wind facilities (Lamb et al., 2024). The population-level consequences of displacement remain uncertain but may be of particular concern if development occurs in key foraging areas used during the breeding season, or if repeated avoidance increases energetic costs for breeding adults. Cassin's Auklets are threatened by an array of anthropogenic threats, including oil spills and breeding habitat loss due to invasive species at island breeding colonies (Ainley et al., 2020), and are subsequently considered Near Threatened by the IUCN, a Species of Conservation Concern in California, a State Sensitive Species in Oregon, and a State Candidate Species in Washington.

Short-tailed Albatross (*Phoebastria albatrus*)

Short-tailed Albatross is a globally threatened species with an estimated population of fewer than 2,000 individuals (Carboneras et al., 2020). It's at-sea distribution is highly pelagic and associated with productive, upwelling regions, with most breeding occurring on islands in Japan. Individuals are only occasionally observed within the CCLME, and records are sufficiently sparse that distribution and habitat use in the region remain poorly characterized, resulting in substantial uncertainty in potential exposure to WEAs (Ellis et al., in prep). Sensitivity to OSW impacts is also uncertain. Kelsey et al. (2025) estimated relatively low sensitivity to both collision and displacement; however, empirical data on albatross flight behavior remain limited. Available studies suggest that individuals may spend a non-trivial proportion of time within the rotor-swept zone (RSZ) (e.g., up to ~10% of flight time; Miller et al., 2025), and that flight heights can increase under high wind conditions typical of OSW development areas (Schneider et al., 2025). Additional research on flight behavior under varying wind regimes is therefore needed to better resolve collision risk. Displacement is unlikely to represent a major impact in the CCLME, given the species' low regional abundance, transient occurrence, and the region's distance from breeding colonies. However, even low levels of collision mortality could have disproportionate consequences given the small global population. The species is classified as Vulnerable by the IUCN and listed as Endangered under the U.S. Endangered Species Act due to its limited population size and restricted breeding range (IUCN Red List of Threatened Species, 2026; Shuford & Gardali, 2008).

Ashy Storm-Petrel (*Hydrobates homochroa*)

Ashy Storm-Petrels are endemic to the CCLME, with almost all breeding colonies found on islands off the coast of California (Carter et al., 2016). They occupy waters associated with the shelfbreak and submarine canyons that bisect the continental slope, potentially overlapping with WEAs (Adams & Takekawa, 2008, Ellis et al., in prep, Leirness et al., 2021). Storm-Petrels are not known to typically fly at heights within the RSZ, but they do often fly at night and can exhibit light attraction. Kelsey et al. (2025) estimated moderate displacement sensitivity for the species, however, uncertainty exists in possible avoidance of storm-petrels to OSW farms due to a lack of empirical data on avoidance behavior in storm-petrels at operational offshore wind facilities (Deakin et al., 2022; Lamb et al., 2024). Due to this and their rapid population decline, endemism, year-round overlap with WEAs, and IUCN Endangered status, they were identified as a high priority species (Ford et al., 2025).

Leach's Storm-Petrel (Hydrobates leucorhous)

Leach's Storm-Petrel is an abundant offshore pelagic seabird that breeds widely across the Northern Hemisphere, including throughout the CCLME. During the breeding season, individuals typically forage within ~200 km of their colonies, though they may range farther offshore (Spear & Ainley, 2007).

Storm-Petrels generally fly close to the water surface and are not typically expected to enter the RSZ; however, they are primarily nocturnal and can be attracted to artificial light. Kelsey et al. (2025) estimated moderate sensitivity to displacement, but substantial uncertainty remains due to a lack of empirical data on storm-petrel responses to operational OSW facilities (Deakin et al., 2022, Lamb et al., 2024). Projected overlap with currently identified WEAs in California and Oregon is low (Ellis et al., in prep). However, underlying at-sea survey data (Leirness et al., 2021) may under-represent breeding-season foraging movements, as provisioning trips largely occur at night and are unlikely to be observed during vessel surveys. As a result, potential impacts from displacement, through reduced access to foraging habitat or increased energetic costs associated with avoidance, may be a concern. These effects could be particularly relevant for local breeding populations. The species is currently classified as Vulnerable by the IUCN due to documented population declines in recent decades (Pollet et al., 2021).

Townsend's Storm-Petrel (*Hydrobates socorroensis*)

Townsend's Storm-Petrel is a rare and endangered species only found off the coast of Mexico and in southern California. Individuals are only occasionally observed within the CCLME, and records are sufficiently sparse that distribution and habitat use in the region remain poorly characterized, resulting in substantial uncertainty in potential exposure to WEAs (Ellis et al., in prep). Occurrence within California waters is likely primarily in the Southern California Bight, such that exposure to WEAs is unlikely unless additional facilities are planned in the region (Kirwan et al., 2023).
Storm-petrels generally fly close to the water surface and are not typically expected to enter the RSZ; however, they are primarily nocturnal and can be attracted to artificial light. Kelsey et al. (2025) estimated moderate sensitivity to displacement, but substantial uncertainty remains due to a lack of empirical data on storm-petrel responses to operational offshore wind facilities (Deakin et al., 2022, Lamb et al., 2024). Displacement is unlikely to represent a major impact pathway in the CCLME, given the species' low regional abundance, transient occurrence, and the region's distance from

breeding colonies, however, the species is highlighted as a priority based on significant uncertainty and its status as an IUCN Endangered species.

Hawaiian Petrel (*Pterodroma sandwichensis*)

Hawaiian Petrel is an endangered species that nests only in the Hawaiian Islands, but ranges across much of the Pacific during its non-breeding season (Bailey et al., 2025). Records of observations in the CCLME are sufficiently sparse that distribution and habitat use in the region remain poorly characterized, resulting in substantial uncertainty in potential exposure to WEAs (Ellis et al., in prep). Sensitivity to OSW impacts is also uncertain. Kelsey et al. (2025) estimated relatively low sensitivity to collision; however, empirical data on petrel flight behavior remain limited. Available studies suggest that individuals may spend a non-trivial proportion of time within the RSZ (e.g., up to ~10% of flight time; Miller et al., 2025), and that flight heights can increase under high wind conditions typical of offshore wind development areas (Schneider et al., 2025). Additional research on flight behavior under varying wind regimes is therefore needed to better resolve collision risk. Kelsey et al. (2025) estimated moderate sensitivity to displacement, but substantial uncertainty remains due to a lack of empirical data on petrel responses to operational offshore wind facilities (Deakin et al., 2022; Lamb et al., 2024). Displacement is unlikely to represent a major impact pathway in the CCLME, given the species' low regional abundance, transient occurrence, and the region's distance from breeding colonies, however, the species is highlighted as a priority based on significant uncertainty and its status as an IUCN and USFWS Endangered species.

Pink-footed Shearwater (*Ardenna creatopus*)

Pink-footed Shearwater breeds on islands off central Chile, but the CCLME represents important habitat during migration and the non-breeding season (Carle et al., 2025). Within the region, the species is most strongly associated with outer shelf and shelf-break waters off central and southern California, resulting in high projected overlap with currently identified Wind Energy Areas (WEAs) in California and Oregon. Kelsey et al. (2025) estimated relatively low sensitivity to collision; however, empirical data on shearwater flight behavior remain limited. Available evidence suggests that individuals may spend a non-trivial proportion of time within the RSZ (e.g., up to ~10% of flight time; Miller et al., 2025), and that flight heights can increase under high wind conditions typical of offshore wind development areas (Schneider et al., 2025). Additional research on flight behavior under varying wind regimes is therefore needed to better resolve collision risk. Sensitivity to displacement was estimated as moderate (Kelsey et al., 2025) but remains uncertain due to limited empirical data on shearwater responses to operational offshore wind facilities (Deakin et al., 2022; Lamb et al., 2024). The species is classified as Vulnerable by the IUCN due to ongoing threats at breeding colonies and fisheries bycatch. Given its high projected overlap with offshore wind development and uncertainty in impact sensitivity, it is identified here as a priority for further monitoring and research.

Hoary bat (*Lasiurus cinereus*)

Hoary bats are the most commonly reported fatality at wind energy facilities in the USA (Arnett et al., 2008). The species is known to migrate south along the Pacific Coast and occupy the Channel Islands (Brown & Rainey, 2018) as well the Farallon Islands, specifically the Southeast island (32 miles off the CA coast), as a migratory stopover (Cryan & Brown, 2007). They are also the only extant bat species to colonize the Hawaiian Islands (Pinzari et al., 2020; Russell et al., 2015). The first hoary bat flying over the Pacific was documented by Kennerley et al., 2024 in October 2022 near the Humboldt WEA and they have been acoustically detected on offshore structures repeatedly (Solick & Newman, 2021). This new knowledge and the presence of hoary bats on offshore islands in the Pacific suggest there is at least some occurrence of bats over the CCLME (Kennerley et al., 2024; Solick & Newman, 2021).

Mexican free-tailed bat (*Tadarida brasiliensis*)

Preliminary detection studies and models for Mexican free-tailed bats show potential for seasonal offshore presence of this species since they occur along the Pacific Coast, however these studies were not conducted offshore where OSW will occur, so there is still high uncertainty regarding potential interactions with WEAS (Russell et al., 2005). Mexican free-tail bats have also been documented seasonally on numerous Channel Islands suggesting they are flying over the ocean at different times of the year (Brown & Rainey, 2018). Observations of roosting Mexican free-tail bats on the Southeast Farallon Island have been documented on iNaturalist during the fall.

Western red bat (*Lasiurus frantzii*)

Similar to Mexican free-tailed bats, modeling and detection studies have not been conducted in offshore waters; so, although offshore presence is possible, uncertainty remains (Pierson & Rainey, 2006; Solick & Newman, 2021). They are a California Species of Special Concern and a high conservation priority, due to known collision risks at terrestrial wind farms. It is not known if oceanic behavior would expose them to collision risk in the CCLME (Pierson & Rainey, 2006). Less is known about the use of the Pacific by western red bats, but similar to hoary bats, they use the Southeast Farallon Island as a stopover point during migration, indicating their potential presence offshore (Cryan & Brown, 2007).

Silver haired bat (*Lasionycteris noctivagans*)

Silver-haired bats are the third most commonly reported species at land-based wind energy facilities in the USA, and second most reported in western states (Peters et al., 2020). They are the second most commonly reported bat off the Atlantic coast (Solick &

Newman, 2021). Although their concentration along the Pacific coast is unknown, they have been detected offshore both visually (Pelletier et al., 2013) and with acoustic detectors (EPRI unpublished data). Although their occurrence in the WEAs is uncertain, there is a risk of interaction with offshore wind turbines.

Impacts to Marine Birds

Collision with infrastructure (turbine blades) represents the primary pathway for direct mortality during the operational phase of OSW development (Fox & Petersen, 2019). Collision risk is thought to vary substantially among taxa and is strongly influenced by flight behavior. Species that consistently fly below the RSZ (typically under ~25–30 m for floating turbines) or well above turbine height (≥200 m) are expected to face lower risk, whereas those that regularly transit or forage within the RSZ are more likely to be exposed (Furness et al., 2013; Johnston et al., 2014; Kelsey et al., 2025; Weiser et al., 2024; Schneider et al., 2024; Schneider et al., 2025). Although direct observations of offshore collisions are limited, collision mortality is well documented at onshore wind facilities, and established modeling frameworks provide a basis for estimating risk in offshore systems (Cook et al., 2025). However, these models remain sensitive to key parameters, particularly flight height, flight speed, and avoidance behavior, that are poorly constrained for many species (Searle et al., 2023).

The subset of high priority species whose populations could be most negatively affected by blade collisions are red phalarope, red-necked phalarope, short-tailed albatross, Hawaiian petrel, and pink-footed shearwater. Importantly, this list should not be interpreted as representing the species most likely to experience collisions. Rather, it highlights species for which additional monitoring and research on metrics influencing collision risk are most needed to reduce uncertainty of risk and effects and inform management. Collision risk is likely to extend to a broader set of species not included here, including those with substantial overlap with development areas but lower management concern (e.g., abundant species with comparatively stable populations), which were categorized as medium priority (Table 20). For the high-priority species identified above, key uncertainties, particularly around flight height distributions, diel variation, and responses to wind conditions, limit confidence in current risk estimates, though recent publications begin to address some uncertainties (Schneider et al., 2025). Targeted data collection, including increased emphasis on the development of approaches to quantify flight behavior using biologging (e.g., Felis et al., 2020; Davies et al., 2024) will aid collection of data across environmental conditions and substantially improve understanding of collision risk both for these species and for the broader taxa they represent.

Other IPFs, including vessel traffic, lighting, and noise, were classified as medium or low priority. Vessel traffic effects remain relatively poorly quantified but may warrant consideration in areas where construction or maintenance increases activity near sensitive habitats, such as breeding colonies. In contrast, mitigation measures to reduce lighting impacts are relatively well developed and should be incorporated into offshore wind planning and operations (Gulka et al., 2026).

Displacement associated with OSW infrastructure represents a knowledge gap in assessing impacts to marine birds, particularly through changes in energy expenditure and resource access during both construction and operation (Lamb et al., 2024). Displacement is typically inferred from changes in species distributions before and after development but attributing these changes to OSW infrastructure is challenging due to natural spatial and temporal variability in seabird habitat use (Searle et al., 2023). In addition, displacement responses vary widely among taxa, with some species exhibiting strong avoidance, others showing attraction, and many demonstrating no clear response (Dierschke et al., 2016). As a result, estimating the proportion of individuals displaced, and the population level consequences of that displacement, remains difficult.

At the individual level, displacement may affect species through increased energetic costs (e.g., longer foraging trips or avoidance of infrastructure) and/or reduced access to prey resources, with potential downstream effects on survival and reproductive success (Searle et al., 2023). However, empirical data linking behavioral responses to demographic outcomes are limited. While recent advances in spatial modeling (e.g., MRSea) and individual-based models (e.g., SeabORD) provide tools to estimate displacement effects, these approaches remain sensitive to poorly constrained parameters, particularly displacement and avoidance rates, as well as assumptions about habitat importance and energetic consequences (Searle et al., 2023). These uncertainties are especially pronounced for procellariiform species, for which empirical data on avoidance behavior and offshore responses to wind infrastructure remain limited (Lamb et al., 2024).

The subset of high-priority species associated with displacement-related knowledge gaps includes Scripps's Murrelet, Guadalupe Murrelet, Craveri's Murrelet, Cassin's Auklet, Short-tailed Albatross, Ashy Storm-Petrel, Leach's Storm-Petrel, Townsend's Storm-Petrel, Hawaiian Petrel, and Pink-footed Shearwater. As with collision, this list should not be interpreted as representing the species most likely to experience displacement. Rather, it identifies species for which additional research is most needed, based on a combination of projected or uncertain overlap with offshore wind development areas, anticipated or uncertain sensitivity to displacement, and management concern, particularly for species with poor or declining population status. Displacement effects are likely to extend to a broader suite of species not included here, including those with lower conservation concern that were categorized as medium priority under the decision framework (Table 20). For the high priority species identified above, uncertainties include the magnitude of avoidance responses to infrastructure, the importance of affected habitats for foraging and transit, and the extent to which altered movement patterns translate into increased energetic costs. Addressing these uncertainties will require targeted data collection, including use of biologgers to quantify movement and behavior, improved characterization of habitat use within and around the WEAs, and empirical estimation of avoidance rates. Resolving these knowledge gaps will be critical to determining whether displacement represents a meaningful population-level impact to species in the CCLME.

Impacts to Bats

The potential impact of OSW on bat populations in the CCLME represents a knowledge gap for all potential impacts, primarily because the distribution, migratory behavior and seasonal activity of West Coast bats remain largely uncharacterized (Platteeuw et al., 2017; Solick & Newman, 2021). Impact is contingent on offshore abundance and flight height overlap, but population-level consequences are currently unknown. The Pacific remains data poor regarding how bats use the OCS (Pelletier et al., 2013). Potential IPFs that were highlighted as potential concerns include infrastructure, vessel traffic, lighting, and alterations in oceanographic patterns. Without standardized, long-term acoustic monitoring in the proposed WEAs, it is currently impossible to determine the timing, altitude, or frequency of bat transit across the deep-water zones targeted for OSW (Pelletier et al., 2013), making it challenging to predict how OSW will impact bat populations.

Infrastructure impacts were highlighted due to collision risks, which are considerable for terrestrial wind farms, as well as altering resource access. While tree bats (such as the hoary bat), silver-haired bat, and Western red bat are known to migrate over land, evidence of their movement over the open Pacific is limited to incidental sightings on offshore islands and ships and acoustic activity on offshore rocks and islands (Cryan & Brown, 2007; Solick & Newman, 2021, Schulze et al., 2025). This could also impact energy costs if bats avoid the area entirely. A critical uncertainty involves how bats will interact with floating infrastructure. In terrestrial settings, bats are often attracted to turbines, potentially mistaking them for tall trees or "roosting magnets" (Cryan et al., 2014). In an offshore environment devoid of other vertical structures, this attraction may be intensified. Bat mortality has been shown to be variable depending on turbine blade height, varying by species. In Ontario, fatalities of hoary bats, silver-haired bats, and big brown bats, increased with increased maximum blade height of turbines, whereas for other species fatalities decreased with increased blade height (Anderson et al. 2022). Due to high levels of bat mortality documented at onshore wind farms (Pelletier et al., 2013), mortality from OSW collisions is thought to have potential population-level impacts for some species. However, the magnitude of offshore bat mortality is unknown and inherently difficult to study.

Artificial lighting on OSW infrastructure serves as a significant sensory attractant that can disrupt the natural flight behavior of both seabirds and bats. Illumination from turbine platforms, including required navigation, aviation, and maintenance lighting, can draw individuals toward structures, directly increasing the frequency of interactions within the RSZ and elevating collision risk (Dierschke et al., 2016). For migrating bats, these light sources may cause disorientation or active attraction, forcing alterations in flight paths that incur higher energetic costs during critical migratory phases (Cryan et al., 2014; Voigt et al., 2018). Artificial lighting and the "artificial reef effect" of floating platforms may concentrate insects, drawing bats into the RSZ and creating a lethal "ecological trap" (Pelletier et al., 2013; Voigt et al., 2021). This trapping effect increases the total time spent in proximity to rotating blades, effectively compounding the vulnerability of species that might otherwise bypass the OSW array (Goodale et al., 2019; Solick & Newman, 2021). Furthermore, attraction could result in bats being drawn offshore with increased energy expenditure and fewer foraging and roosting resources (Cryan et al., 2014; Guest et al., 2022; Jonasson et al., 2024).

If OSW development results in reduced onshore wind farms, there may be a net positive benefit to bat populations. However, this trade-off remains speculative without baseline data on offshore bat occurrence and mortality risk.

7.3 Marine Birds and Bats Recommendations

Foundational Recommendations

The first monitoring priority for seabirds and bats is to continue to establish a baseline understanding of species distribution, flight behavior, and offshore activity of each seabird and bat species within and around WEAs. The following recommendations for seabirds and bats should be prioritized:

- Continue to Invest in Regional Baseline Monitoring Conduct and continue to fund large-scale, multi-season baseline efforts (e.g., ACCESS and MOTUS) to characterize seabird and bat species distribution, flight behavior, and environmental drivers across regions.
- Advance Detection Technologies Invest in and validate scalable collision risk and avoidance detection systems (e.g., radar, acoustic, and sensor-based platforms) with real-time data capabilities.
- Prioritize High-Risk Habitats Focus monitoring in shelf and nearshore waters, OSW footprints, cable corridors, and port/infrastructure areas, with location-specific approaches rather than statewide generalizations.
- Target Priority Species Prioritize monitoring of high-risk and data-limited marine bird and bat species. By monitoring the high risk and data limited species, data will be collected on other bird/bat species by default.
- Gather and Refine Key Population Vital Rate Parameters Enhance colony and at-sea monitoring for key high vulnerability/high risk species to determine and enhance vital rate data like survival, mortality, generation time and birthrate that are necessary for effective impact attribution, population status monitoring and potential mitigation.

Impact-Specific Recommendation Tables

Monitoring recommendations for seabirds and bats highlight assessing collision risk, spatial distribution and response to infrastructure, and changes to prey types, quality and availability.

Below, sensors and data collectors are recommended for monitoring associated impact topics and MQs (Tables 31-33). Relevant species to be monitored with each data collector are attributed, and opportunities and limitations of each are evaluated. Cost and effort are also assessed relative to other sensors used to collect data on seabirds and bats. Where applicable, examples of West Coast monitoring programs and projects that employ these sensors were included to show their current application.

MQ: What is the risk of individual mortality from collision with turbine blades?
MQ: What is the risk of population-level consequences from collision mortality?
MQ: How does collision risk vary with time, space, and weather conditions?

Table 31. Impact Topic: Collision risk

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Imaging Systems - Cameras	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater	Low-moderate equipment cost approach to stationary (or potentially surface drone) species detection & identification. Track flight paths & heights & potentially detect interaction of individuals with rotor swept zones; Capturing these types of data is better accomplished with a multi-sensor system. Combining visible spectrum imaging with infrared & lidar can result in significantly better identification & data regarding flight heights & paths but also increases cost significantly.	At-sea conditions can be challenging for the systems and require an existing platform (e.g. OSW infrastructure) or a purpose-made deployment. Deployment and data processing cost/effort can vary widely depending upon whether a system needs to be self-contained or can be deployed on existing infrastructure with available power source. Visual imagery systems are only functional during daylight hours and good visibility conditions; Ineffective for species that have high nighttime activity (e.g., bats, some	Moderate to High Systems can range from relatively simple image capture to more complex with integrated image processing and remote data delivery. Data processing is either via high-effort manual processing or AI detection systems or a combination with cost for different methods varying widely. Use of data input to collision risk models; extensive analysis by experienced researchers but can also contribute to monitoring by providing lower effort results on presence/absence, relative abundance and	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			storm-petrels) and smaller, faster-flying species are harder to detect and identify. Data collection is limited to small areas adjacent to the cameras; systems are either best for collecting data to be applied in modeling efforts or need multiple deployments to collect broader data covering OSW installations. AI-driven species identification, flight path tracking and flight-height data are improving, but not as advanced and reliable as desirable.	seasonal space-use information. Visual imagery systems in offshore environments must be designed to withstand the elements.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Metocean condition sensors - LiDAR	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater	Enhancement to a detection and tracking sensor system by providing high-resolution data on 3-D movement; Alone, data can be used to explore overlap/interaction with the rotor swept zones and patterns in movement including flight height and meso- and micro-scale avoidance. In conjunction with high-resolution visible spectrum imagery and thermal imaging, LiDAR can both contribute to species identification and provide species-level information informing collision risk. Data can be gathered in poor weather conditions and at night and sensors can be deployed on a variety of platforms from vessels, aircraft and	Systems are expensive with very specific and high-skill data-processing required. Unstable platforms at sea can contribute to error and thus deployment can be limited by available platforms; May not be able to detect smaller species.	Moderate to High; Instruments vary in cost for different detection ranges, accuracy and resolution. Systems that can withstand marine environments add additional cost. Data processing is technically challenging and requires experts and considerable time. Significant complication and cost are added when used as part of an integrated package with visual spectrum and thermal imaging.	There are coastal systems/programs for metocean monitoring, but nothing offshore or specifically for birds/bats.

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		drones, to buoys and OSW infrastructure. Capable of detecting insects, providing additional data that can help inform resource use and attraction to OSW locations for insect-eating bat species.			
Tagging - Motus	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater Hoary Bat Mexican free-tailed bat Silver haired bat Western Red Bat	Useful for smaller species that cannot be tagged/tracked with GPS-enabled tags, especially bats; Motus tags do not require recovery for data collection as do non-transmitting GPS tags. Bats and smaller seabirds (e.g., Ashy storm-petrels, phalaropes) may experience energetic costs from attaching larger sensors, making motus one of the only	Limited to the range of antenna arrays which must either be permanently mounted on buoys or platforms or used from boats, drones or aircraft. Does not capture broader-scale movement at sea to provide context. Precise location data require good radio-frequency conditions, high-end antenna arrays and/or multiple receiver stations. Testing and installing effective arrays	Moderate to High Initial investment in setting up and testing a receiver array is significant but can function for long periods with minimal effort after. Ongoing effort to tag individuals time-consuming, costly and is best-used for targeted research on species and populations already identified as high-priority. Receiving equipment is moderately expensive,	Terrestrial only but increasing coastal stations that should provide some nearshore coverage. No specific "program"; tagging efforts mostly for bats and shorebirds to-date. Upcoming: San Francisco Bay Area Migratory Bat Inventory Project - will be Motus tagging migratory bats at National Parks (USGS/NPS)

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		ways to collect high-accuracy position data on these species.	is time-consuming and involved. Animals must be captured to install tags, which is often difficult, logistically complex and time-consuming, but unlike archival tags, no re-capture is required; Useful for small animals that cannot be tagged with transmitting GPS tags, (e.g., bats, small seabirds or land birds)	especially if long-distance antennas and remote data transmission are used; Individual tags cheaper than GPS tags.	
Imaging Systems - Thermal imaging/tracking	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater Silver Haired Bat Hoary Bat Mexican free-tailed bats Western Red Bat	Plays a key role in local data collection on meso- and micro-scale movement and interaction with turbines and other infrastructure. Models and AI can be used to identify taxa by size, shape and flight patterns; Thermal imaging can capture data at night, enabling monitoring of nocturnal	Limited range, may have difficulty identifying and tracking smaller targets and data quality can suffer with poor weather like hard rain or dense fog. While taxonomic identification based on various image features is improving, it is not highly reliable and performs best when using video to include patterns of movement. Like other	Moderate to High Expensive for initial purchase and deployment; require custom software and processing of data. Some systems have been developed and tested (e.g., ThermalTracker 3D); systems cover limited areas, so deployment of	PNNL, ThermalTracker3D

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		birds and bats. Has been integrated with other data collection such as visual and LiDAR capture to improve species identification and tracking data quality. Gold-standard systems/tools for gathering meso/micro-scale data on interactions with wind farms and identifying/quantifying collisions, especially as integrated data systems with additional sensors.	similar monitoring tools, thermal cameras require power, produce large amounts of data which can necessitate on-system processing and filtering, require appropriate platforms (buoys or OSW infrastructure) and need to be designed for harsh marine environments. Platform stability is important for effective function of these systems.	multiple units may be necessary to gather statistically valuable samples, raising costs.	
Mobile platform - UAV's /Drones	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater Hoary bat Western red bat Silver-haired bat Mexican free-tailed bat	A variety of UAVs and drones may be useful to 1) provide presence/absence and distribution data and 2) provide environmental sampling for modeling of distributions. Aerial drones can produce	An area of active development with great potential but also extensive limitations. Range and operation time is constrained by drone design and power capacities as are potential instrument	Moderate to High Design, development and testing of autonomous platforms is expensive, and production costs can still remain high; for existing systems, refinement is	Not ongoing monitoring, but a potential platform/tool is Saildrone.

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		imagery for visual counts/surveys over limited areas. Surface drones (e.g., Saildrone) can capture imagery, acoustic recording, radar and physical/biological oceanographic measurements. UAVs can collect physical/biological oceanographic data relevant to modeling species distributions and abundance. Advantages and opportunities include potential automation of data collection, more frequent and greater area coverage and lower long-term costs and safety of operations when compared to other related approaches like vessel-based and aerial surveys.	packages. These platforms may not provide ideal data collection setups (e.g., imagery from Saildrones vs. visual observers on survey vessels may reduce species identification). Data volume collected by UAVs/Drones is usually large, requiring effective processing and analysis pipelines to be developed. Effective systems are expensive and time-consuming to develop but have great promise.	often still needed to serve appropriate functions for data collection purposes. Many of the existing systems are commercially developed with associated purchase or pay-for-service costs.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Tagging	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater	Tagging is a broad category of methods from banding to satellite, or cellular transmitting GPS multi-sensor tags. Banding is low-cost but only provides information upon re-sighting, and location; Useful for limited space-use information, estimating survivorship, and population vital rates. GPS tags provide high-resolution position data appropriate to determining avoidance, displacement and movement patterns within a wind farm; GPS tagging is most appropriate to apply to high-priority species at risk of displacement that overlap significantly with OSW areas prior to and after construction.	All tagging requires the capturing individuals; Which has implications for animal welfare, permitting and logistics, cost and success with feasibility varying by tag type, species and location and tag size/weight/type limits deployment on smaller species. Trade-off between sensors/data gathered and both cost and longevity of tags; Because tags are deployed by capture, using them often necessitates access to breeding colonies which can be difficult or impossible depending on colony characteristics (e.g., burrowing, cryptic nesting, cliff nesting) and whether the species is a local breeder or migrant	Low to High Banding is a low-cost, low-information method. Costs (and data gathered); increase in cost to GLS tags, archival GPS and transmitting GPS tags and as additional sensors added. GPS tags generally cost in the thousands per tag and transmitting tags require network subscriptions that add cost. The cost of deployment (and retrieval when necessary) and data analysis is generally high.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Tags with submersion sensors, accelerometers, temperature sensors and cameras add valuable additional data that can be used to determine feeding, energetics, intra- and inter-species interactions and interactions with infrastructure, though additional sensors increase size/weight and decrease life-span due to battery life.	visitor. Since generally tags are deployed on a relatively small subset of a population, it can be challenging to infer population-level information, and an assumption must be made that the tagged individuals are representative of the broader population.		
Visual Observations - Vessel Based	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater	Used to collect abundance and distribution data for all species present; To identify changes in space-use, surveys must be conducted before and after installation and/or with a gradient sampling design. Strip transect counts and identification of seabirds provides a snapshot	Vessel-based visual observations provide a snapshot which may not be representative of distribution and abundance for unsampled times or conditions; The area covered by strip transects is moderate and must be interpolated via species distribution models to cover broader	High Costs vary significantly depending on the vessel used, area surveyed, number of surveys and sampling conducted. Large-vessel, "full-sampling" (i.e., seabird and mammal observations, acoustics and physical/biological oceanography) surveys	Applied California Current Ecosystem Studies, NOAA Rockfish Recruitment and Ecosystem Assessment Survey, CalCOFI, Wind to Whales

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		picture of multi-species distribution, gives the best information on abundance; With enough sampling can identify rarer species and vagrants. Data on flight direction and height can be gathered by visual observers Vessel surveys can collect extensive environmental data from physical oceanography to plankton tows to eDNA that are vital to modeling distribution and abundance; multi-species data gathered, paired environmental samples, and potential to combine surveys/data gathering with multiple taxa like marine mammals and fish.	areas. Repeated sampling necessary to provide a fuller, statistically representative data set that is valuable for evaluating displacement and/or avoidance. Vessel-based sampling is limited by ocean conditions; often results in biased samples that miss or under-represent seasons with rougher sea and weather conditions.	such as NOAA white ship surveys are extremely expensive, frequently requiring cost-sharing from multiple federal agencies.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Visual Observations - Aerial Surveys	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater	An alternative to vessels for collecting abundance and distribution data for all species present in a target region; To identify changes in space-use, surveys must be conducted before and after installation and/or with a gradient sampling design. Strip transect counts, and seabird IDs provide a snapshot of multi-species distribution, gives information on abundance and with enough sampling can identify rarer species and vagrants. Advantages are the multi-species data gathered and the potential to combine surveys/data gathering for marine mammals. Video or photo data	Strip-transect observations provide a snapshot which may not be representative of distribution and abundance for unsampled times or conditions. Aerial sampling is limited by ocean conditions and thus results in biased samples that miss or under-represent seasons with poor weather conditions. Safety is an important concern for this method. Repeated sampling before and after installation is necessary to provide a fuller, statistically representative data set that is valuable for evaluating displacement and/or avoidance. Providing enough	High Aerial surveys using small aircraft are expensive; Especially if special video or photo equipment and/or aircraft design. Drone-based surveys are possible and increasingly used; technical limitations in flight heights and durations. Costs increase with area, frequency and transect density.	USGS Aerial Surveys

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		collection can be used as inputs to AI species detection and identification algorithms to improve processing and decrease costs and provide permanent data record for reference that is not available with human data collection.	statistical power to determine avoidance/displacement in context of variability may be challenging or impossible depending on effect size; The area covered by strip transects is moderate and must be interpolated/extrapolated via species distribution models to cover broader areas. Without concurrently collected environmental data, models must rely on remotely sensed predictor variables.		
Acoustic Monitoring	Hoary Bat Mexican free-tailed bats Western Red Bat Silver-haired bat	Acoustic monitoring allows ID, presence and index of activity for bat species. Low-cost method for identifying presence of bats in offshore locations as an early indicator of	Requires a platform above water to install microphones and data storage, or transmission equipment which can be challenging at-sea. Detections indicate presence but cannot	Low to Moderate Equipment is relatively low-cost but must leverage a platform (such as buoys or OSW infrastructure) for data to accurately represent use or presence; Dedicated	USGS Offshore Acoustic Bat Study along the California Coastline, DOE Pacific Offshore Bat Study (EPRI, BCI, Stantec, USGS, Woods Hole), Equipment already deployed on many buoys, offshore rocks

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		exposure; Longer sampling can give information on seasonality and relative activity.	determine absence, making tracking an important next step to better quantify space-use and seasonality of species in the context of estimating risk and impact.	platforms are likely cost-preventative. Costs increase with coverage of more locations and longer time periods.	and islands, coastline, and inland comparison sites; Funding required to conduct equipment maintenance, data collection, analyses, and write up/publication.
Radar	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater Hoary Bat Mexican free-tailed bats Silver haired bat Western Red Bat	Provides an additional tool for larger spatial detection of flying animals in the vicinity of offshore wind lease areas or installations. Significantly larger detection area than either visual/thermal imagery or LiDAR; can provide data on spatial and seasonal space-use patterns and relative abundance of biological targets ranging from insects to large birds; can be used to collect data on flight heights and patterns.	Depending on the type, radar is generally only able to distinguish between broad classes of taxa, mostly based on the relative size of the targets and thus can't provide fine-grained taxonomic-level or species-level information. Does require a dedicated platform and there are challenges compensating for unstable platform movement to provide the most useful data; large amounts of collected data via onboard processing and/or remote data delivery is	Moderate to High Systems can vary significantly in strength and cost; those that can effectively detect biological targets at long distance and be deployed on buoy or OSW platforms tend to be higher-power systems. A number of different commercial systems that utilize a variety of radar types/configurations exist on the market.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Radar is especially useful for collecting data at potential OSW sites at early stages and at larger radii after installation; Alternatively, low-range, high-frequency systems can be used to monitor for close interactions of larger birds with OSW infrastructure.	an additional challenge.		
Accelerometer collision sensors	Red Phalarope Red-necked Phalarope Short-tailed Albatross Hawaiian Petrel Pink-footed Shearwater Hoary Bat Mexican free-tailed bats Silver haired bat Western Red Bat	Integrated, on-turbine systems for detecting collision events with rotors have the potential to provide the best information on collision rates and outcomes. Some of these systems exist in developed form, while others are currently in development. This technology often integrates vibration/accelerometer sensors, microphones and visual and/or thermal imagery to detect impacts, identify the	Few of these systems are at deployment maturity and refinement and development is needed to make these systems effective. Most of these types of systems require extensive integration with the turbines themselves, so extensive coordination with developers would be required. Installation and maintenance of these systems have consequences and costs for OSW operators. Detection of collision with	Moderate to High Complex, bespoke systems with multiple components and key software functions to synchronize and analyze multiple data streams. Integration with turbines is a key challenge including the ramifications for maintenance and operations of OSW facilities.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		species/taxon involved and determine the consequence/fate. These are highly engineered systems requiring analysis of time-synched data streams and integration with turbines. Given the inability to use carcass surveys at-sea, these types of systems provide one of the only reliable ways to measure collisions with greater certainty.	bats and smaller birds may be difficult or unreliable. These systems generally only monitor a single turbine, so deployment and effective data collection may require installation on multiple units.		

MQ: Does OSW activity and infrastructure WEAs and turbine infrastructure cause seabird or bat avoidance, displacement, and/or shifts in distribution changes?

MQ: Does OSW activity infrastructure WEAs attract seabird/bat species and create an ecological trap?

MQ: What is the energetic cost to seabirds or bats from displacement and/or avoidance?

Table 32. *Impact Topic: Spatial distribution and responses to infrastructure*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Tagging - Motus	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Hoary Bat Mexican free-tailed bats Silver-haired bat Western Red Bat	Useful for smaller species that cannot be tagged/tracked with GPS-enabled tags, especially bats; Motus tags do not require recovery for data collection as do non-transmitting GPS tags. Bats and smaller seabirds (e.g., Ashy storm-petrels, phalaropes) may experience energetic costs from attaching larger sensors, making motus one of the only ways to collect high-accuracy position data on these species.	Limited to the range of antenna arrays which must either be permanently mounted on buoys or platforms or used from boats, drones or aircraft. Does not capture broader-scale movement at sea to provide context. Precise location data require good radio-frequency conditions, high-end antenna arrays and/or multiple receiver stations. Testing and installing effective arrays is time-consuming and involved. Animals must be captured to install tags, which is often difficult, logistically complex and time-consuming, but unlike archival tags, no re-capture is required; Useful for small animals that cannot be tagged	Moderate to High Initial investment in setting up and testing a receiver array is significant but can function for long periods with minimal effort after. Ongoing effort to tag individuals is time-consuming and costly and is best-used for targeted research on species and populations already identified as high-priority. Receiving equipment is moderately expensive, especially if long-distance antennas and remote data transmission are used; individual tags can be much cheaper than GPS tags.	Upcoming: San Francisco Bay Area Migratory Bat Inventory Project - will be Motus tagging migratory bats at National Parks (USGS/NPS)

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			with transmitting GPS tags, (e.g., bats, small seabirds or land birds)		
Tagging	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater	Tagging is a broad category of methods from banding to satellite, or cellular transmitting GPS multi-sensor tags. Banding is low-cost but only provides information upon re-sighting, and location; Useful for limited space-use information, estimating survivorship, and population vital rates. GPS tags provide high-resolution position data appropriate to	All tagging requires the capturing individuals; Which has implications for animal welfare, permitting and logistics, cost and success with feasibility varying by tag type, species and location and tag size/weight/type limits deployment on smaller species. Trade-off between sensors/data gathered and both cost and longevity of tags; Because tags are	Low to High Banding is a low-cost, low-information method. Costs (and data gathered); increase in cost to GLS tags, archival GPS and transmitting GPS tags and as additional sensors added. GPS tags generally cost in the thousands per tag and transmitting tags require network subscriptions that add	Farallon Islands Seabird Program

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		determining avoidance, displacement and movement patterns within a wind farm; GPS tagging is most appropriate to apply to high-priority species at risk of displacement that overlap significantly with OSW areas prior to and after construction. Tags with submersion sensors, accelerometers, temperature sensors and cameras add valuable additional data that can be used to determine feeding, energetics, intra- and inter-species interactions and interactions with infrastructure, though additional sensors increase size/weight and decrease life-span due to battery life.	deployed by capture, using them often necessitates access to breeding colonies which can be difficult or impossible depending on colony characteristics (e.g., burrowing, cryptic nesting, cliff nesting) and whether the species is a local breeder or migrant visitor. Since generally tags are deployed on a relatively small subset of a population, it can be challenging to infer population-level information, and an assumption must be made that the tagged individuals are representative of the broader population. Addressing/studying avoidance/displacement requires GPS tags (banding and GLS tags are not useful) that are	cost. The cost of deployment (and retrieval when necessary) and data analysis is generally high.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			best deployed both before and after construction.		
Visual Observations - Vessel Based	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater	Used to collect abundance and distribution data for all species present; To identify changes in space-use, surveys must be conducted before and after installation and/or with a gradient sampling design. Strip transect counts and identification of seabirds provides a snapshot	Vessel-based visual observations provide a snapshot which may not be representative of distribution and abundance for unsampled times or conditions; The area covered by strip transects is moderate and must be interpolated via species distribution models to cover broader	High Costs vary significantly depending on the vessel used, area surveyed, number of surveys and sampling conducted. Large-vessel, "full-sampling" (i.e., seabird and mammal observations, acoustics and physical/biological oceanography) surveys	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		picture of multi-species distribution, gives the best information on abundance; With enough sampling can identify rarer species and vagrants. Data on flight direction and height can be gathered by visual observers Vessel surveys can collect extensive environmental data from physical oceanography to plankton tows to eDNA that are vital to modeling distribution and abundance; multi-species data gathered, paired environmental samples, and potential to combine surveys/data gathering with multiple taxa like marine mammals and fish.	areas. Repeated sampling necessary to provide a fuller, statistically representative data set that is valuable for evaluating displacement and/or avoidance. Vessel-based sampling is limited by ocean conditions; often results in biased samples that miss or under-represent seasons with rougher sea and weather conditions. Providing enough statistical power to determine avoidance/displacement in the context of variability may be challenging or impossible depending on effect size.	such as NOAA white ship surveys are extremely expensive, frequently requiring cost-sharing from multiple federal agencies.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Visual Observations - Aerial Surveys	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater	An alternative to vessels for collecting abundance and distribution data for all species present in a target region; To identify changes in space-use, surveys must be conducted before and after installation and/or with a gradient sampling design. Strip transect counts, and seabird IDs provide a snapshot of multi-species distribution, gives information on abundance and with enough sampling can identify rarer species and vagrants. Advantages are the multi-species data gathered and the potential to combine surveys/data gathering for marine mammals. Video or photo data	Strip-transect observations provide a snapshot which may not be representative of distribution and abundance for unsampled times or conditions. Aerial sampling is limited by ocean conditions and thus results in biased samples that miss or under-represent seasons with poor weather conditions. Safety is an important concern for this method. Repeated sampling before and after installation is necessary to provide a fuller, statistically representative data set that is valuable for evaluating displacement and/or avoidance. Providing enough	High Aerial surveys using small aircraft are expensive; Especially if special video or photo equipment and/or aircraft design. Drone-based surveys are possible and increasingly used; technical limitations in flight heights and durations. Costs increase with area, frequency and transect density.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		collection can be used as inputs to AI species detection and identification algorithms to improve processing and decrease costs and provide permanent data record for reference that is not available with human data collection.	statistical power to determine avoidance/displacement in context of variability may be challenging or impossible depending on effect size; The area covered by strip transects is moderate and must be interpolated/extrapolated via species distribution models to cover broader areas. Without concurrently collected environmental data, models must rely on remotely sensed predictor variables.		
Acoustic Monitoring	Hoary Bat Mexican free-tailed bats Silver-haired bat Western Red Bat	Acoustic monitoring allows ID, presence and index of activity for bat species. Low-cost method for identifying presence of bats in offshore locations as an early indicator of	Requires a platform above water to install microphones and data storage, or transmission equipment which can be challenging at-sea. Detections indicate presence but cannot	Low to Moderate Equipment is relatively low-cost but must leverage a platform (such as buoys or OSW infrastructure) for data to accurately represent use or presence; Dedicated	DOE Pacific Offshore Bat Study (EPRI, BCI, Stantec, USGS, Woods Hole), USGS Offshore Acoustic Bat Study along the California Coastline, Equipment already deployed on many buoys, offshore rocks

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		exposure; Longer sampling can give information on seasonality and relative activity.	determine absence, making tracking an important next step to better quantify space-use and seasonality of species in the context of estimating risk and impact; Difficult to determine statistically significant effects of displacement/avoidance using acoustic monitoring alone.	platforms are likely cost-preventative. Costs increase with coverage of more locations and longer time periods.	and islands, coastline, and inland comparison sites; Funding required to conduct equipment maintenance, data collection, analyses, and write up/publication.

How does OSW change the abundance and composition of seabird and bat prey species?
How do spatial distribution changes of seabirds and their prey due to OSW development impact prey accessibility?
Will nearshore seabirds and bats use OSW the infrastructure as islands to roost and forage?
Are offshore conditions conducive to insect activity providing bats with offshore foraging access?

Table 33. *Impact Topic: Resource change*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Tagging - Motus	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Hoary Bat Mexican free-tailed bats Silver Haired Bat Western Red Bat	Useful for smaller species that cannot be tagged/tracked with GPS-enabled tags, especially bats; Motus tags do not require recovery for data collection as do non-transmitting GPS tags. Bats and smaller seabirds (e.g., Ashy storm-petrels, phalaropes) may experience energetic costs from attaching larger sensors, making motus one of the only ways to collect high-accuracy position data on these species.	Limited to the range of antenna arrays which must either be permanently mounted on buoys or platforms or used from boats, drones or aircraft. Does not capture broader-scale movement at sea to provide context. Precise location data require good radio-frequency conditions, high-end antenna arrays and/or multiple receiver stations. Testing and installing effective arrays is time-consuming and involved. Animals must be captured to install tags, which is often difficult,	Moderate to High Initial investment in setting up and testing a receiver array is significant but can function for long periods with minimal effort after. Ongoing effort to tag individuals time-consuming, costly and is best-used for targeted research on species and populations already identified as high-priority. Receiving equipment is moderately expensive, especially if long-distance antennas and remote data transmission are used; Individual tags are cheaper than GPS	Upcoming: San Francisco Bay Area Migratory Bat Inventory Project - will be Motus tagging migratory bats at National Parks (USGS/NPS)

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			logistically complex and time-consuming, but unlike archival tags, no re-capture is required; Useful for small animals that cannot be tagged with transmitting GPS tags, (e.g., bats, small seabirds or land birds)	tags.	
Mobile platform - UAV's /Drones	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Hoary bat Western red bat Silver-haired bat Mexican free-tailed bat	A variety of UAVs and drones may be useful to 1) provide presence/absence and distribution data and 2) provide environmental sampling for modeling of distributions. Aerial drones can produce imagery for visual counts/surveys over limited areas. Surface drones (e.g., Saildrone) can capture imagery, acoustic recording, radar and physical/biological oceanographic	An area of active development with great potential but also extensive limitations. Range and operation time is constrained by drone design and power capacities as are potential instrument packages. These platforms may not provide ideal data collection setups (e.g., imagery from Saildrones vs. visual observers on survey vessels may reduce species identification). Data volume collected by	Moderate to High Design, development and testing of autonomous platforms is especially expensive, and production costs can still remain high. For existing systems, refinement is often still needed to serve appropriate functions for data collection purposes; Many of the existing systems are commercially developed with associated purchase or pay-for-service costs.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		measurements. UAVs can collect physical/biological oceanographic data relevant to modeling species distributions and abundance. Advantages and opportunities include potential automation of data collection, more frequent and greater area coverage and lower long-term costs and safety of operations when compared to other related approaches like vessel-based and aerial surveys.	UAVs/Drones is usually large, requiring effective processing and analysis pipelines to be developed. Effective systems are expensive and time-consuming to develop but have great promise. However, since the data from these systems does not directly measure resource-use, extra care for statistical power of model inference and implications of space-use changes is needed.		

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Tagging	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Maybe: Bats	Tagging is a broad category of methods from banding to satellite, or cellular transmitting GPS multi-sensor tags. Banding is low-cost but only provides information upon re-sighting, and location; Useful for limited space-use information, estimating survivorship, and population vital rates. GPS tags provide high-resolution position data appropriate to determining avoidance, displacement and movement patterns within a wind farm; GPS tagging is most appropriate to apply to high-priority species at risk of displacement that overlap significantly with OSW areas prior to and after construction.	All tagging requires the capturing individuals; Which has implications for animal welfare, permitting and logistics, cost and success with feasibility varying by tag type, species and location and tag size/weight/type limits deployment on smaller species. Trade-off between sensors/data gathered and both cost and longevity of tags; Because tags are deployed by capture, using them often necessitates access to breeding colonies which can be difficult or impossible depending on colony characteristics (e.g., burrowing, cryptic nesting, cliff nesting) and whether the species is a local breeder or migrant	Low to High Banding is a low-cost, low-information method. Costs (and data gathered); increase in cost to GLS tags, archival GPS and transmitting GPS tags and as additional sensors added. GPS tags generally cost in the thousands per tag and transmitting tags require network subscriptions that add cost. The cost of deployment (and retrieval when necessary) and data analysis is generally high.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Tags with submersion sensors, accelerometers, temperature sensors and cameras add valuable additional data that can be used to determine feeding, energetics, intra- and inter-species interactions and interactions with infrastructure, though additional sensors increase size/weight and decrease life-span due to battery life.	visitor. Since generally tags are deployed on a relatively small subset of a population, it can be challenging to infer population-level information, and an assumption must be made that the tagged individuals are representative of the broader population.		
Visual Observations - Vessel Based	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater	Used to collect abundance and distribution data for all species present; To identify changes in space-use, surveys must be conducted before and after installation and/or with a gradient sampling design. Strip transect counts and identification of seabirds provides a snapshot	Vessel-based visual observations provide a snapshot which may not be representative of distribution and abundance for unsampled times or conditions; The area covered by strip transects is moderate and must be interpolated via species distribution models to cover broader	High Costs vary significantly depending on the vessel used, area surveyed, number of surveys and sampling conducted. Large-vessel, "full-sampling" (i.e., seabird and mammal observations, acoustics and physical/biological oceanography) surveys	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		picture of multi-species distribution, gives the best information on abundance; With enough sampling can identify rarer species and vagrants. Data on flight direction and height can be gathered by visual observers Vessel surveys can collect extensive environmental data from physical oceanography to plankton tows to eDNA that are vital to modeling distribution and abundance; multi-species data gathered, paired environmental samples, and potential to combine surveys/data gathering with multiple taxa like marine mammals and fish.	areas. Repeated sampling necessary to provide a fuller, statistically representative data set that is valuable for evaluating displacement and/or avoidance. Vessel-based sampling is limited by ocean conditions; often results in biased samples that miss or under-represent seasons with rougher sea and weather conditions.	such as NOAA white ship surveys are extremely expensive, frequently requiring cost-sharing from multiple federal agencies.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Acoustic Monitoring	Hoary Bat Mexican free-tailed bats Silver-haired bat Western Red Bat	Acoustic monitoring allows ID, presence and index of activity for bat species. Low-cost method for identifying presence of bats in offshore locations as an early indicator of exposure; Longer sampling can give information on seasonality and relative activity	Requires a platform above water to install microphones and data storage, or transmission equipment which can be challenging at-sea. Detections indicate presence but cannot determine absence, making tracking an important next step to better quantify space-use and seasonality of species in the context of estimating risk and impact.	Low to Moderate Equipment is relatively low-cost, but must leverage a platform (such as buoys or OSW infrastructure) for data to accurately represent use or presence; Dedicated platforms are likely cost-preventative. Costs increase with coverage of more locations and longer time periods.	DOE Pacific Offshore Bat Study (EPRI, BCI, Stantec, USGS, Woods Hole), USGS Offshore Acoustic Bat Study along the California Coastline, Equipment already deployed on many buoys, offshore rocks and islands, coastline, and inland comparison sites; Funding required to conduct equipment maintenance, data collection, analyses, and write up/publication.
Colony Monitoring	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Maybe: Bats	Colony monitoring is an umbrella term that encompasses many potential data collection types and techniques. These include counts and breeding monitoring that can inform population size/trajectory, physiological	While colony monitoring is a well-established approach to collecting important population data, it is not as well-suited to informing definitive impacts from OSW installations. Colony monitoring techniques are generally time and labor-intensive,	Low to Moderate Most colony monitoring is labor-intensive so costs for trained biologists can be large over long-term monitoring programs. Increasingly, other approaches such as drone surveys are replacing or supplementing manual	Pelican roost profiles, SF Bay Area, Farallon Islands Seabird Program, Seabird Protection Network, Channel Islands NPS monitoring

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		measurements of individual health or energetics, and diet monitoring. Of particular relevance to resource change is diet monitoring which can include visual, dropped prey or fecal analyses, lavage, DNA metabarcoding and isotopes. Data collected on diet at the colony can only effectively inform changes in resource use/access due to OSW if paired with information on distribution/space-use and prey availability. Clearly identifying changes in resource use attributable to OSW farms is a challenging task in the context of natural variability. Data on species or taxon-level diet composition would be the	making them costly in the longer-term. Many species either do not breed colonially or breed in places/manners that make monitoring techniques difficult or impossible. Most methods also require various levels of disturbance/consequence for individuals.	techniques, with greater up-front costs but longer-term cost savings. Colony monitoring programs can vary significantly in cost based on a wide range of factors from what data is collected to accessibility, number of locations monitored and size of monitored populations.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		most valuable to contribute to assessing resource use impacts. More broadly, colony monitoring provides valuable information on population status/trends and vital rates that is useful for understanding population vulnerability to impacts in general.			
Biological/ physical samplers/monitors - Diet Sampling	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater Maybe: Bats	To understand seabird diet and how it may be affected by OSW, it is key to put that in context of what prey are available. Oceanographic sampling using net tows, active acoustics and plankton sampling systems provides key data on when and where prey are available and what the quality of those prey are. Data on krill, large plankton and fish distribution in and out of	Collecting and processing these types of data is challenging and costly and the extensive spatial and temporal variability in the California Current system makes attributing any changes to OSW very challenging; long-term, repeated surveys and sampling is necessary to address this potential impact.	High Cost varies widely depending on data collected, survey approach and especially frequency and extent of monitoring; extensive repeated surveys are vital to establish baselines, understand natural variability and detect changes, costs for useful programs are likely to be high.	Applied California Current Ecosystem Studies, CalCOFI, NOAA Rockfish Recruitment and Ecosystem Assessment Survey, NOAA white ship surveys

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		OSW areas as well as before and after installation is key to determining whether availability, composition and quality of resources are changing. This data in concert with distribution, telemetry, and feeding behavior/diet composition data can determine whether any changes to resources from OSW are having effects for seabirds.			
Environmental Sample collectors - eDNA	Scripps's Murrelet Guadalupe Murrelet Craveri's Murrelet Cassin's Auklet Short-tailed Albatross Ashy Storm-Petrel Leach's Storm-Petrel Townsend's Storm-Petrel Hawaiian Petrel Pink-footed Shearwater	Can provide presence and some information on relative abundance of organisms, including prey items like krill and fish. While this method is more suited toward general information on taxon presence/distribution, it might provide value to identify changing prey communities and abundances.	eDNA detection is an indicator of presence but cannot establish absence and relative abundance metrics are only useful for more common/numerous species. More direct measures of prey communities are preferrable, if possible but eDNA offers a valuable tool for more regular sampling that can	Moderate to High Sample collection is relatively cheap and can often be done opportunistically, but sample processing, DNA barcoding and data analysis is relatively costly. For effective use of this method, regular and many samples should be collected, increasing costs.	Applied California Current Ecosystem Studies, CalCOFI, NOAA white ship surveys

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			also inform other research like direct measures of fish and marine mammal community/abundance changes.		

8.Fish and Invertebrates

8. Fish and Invertebrates

8.1 Fish and Invertebrates Results

The Fish and Invertebrate WG was categorized into four ecological subgroups: demersal and benthic fishes, demersal and benthic invertebrates, highly migratory pelagics and forage species, and plankton.

- Demersal and benthic fish and invertebrates include species that live and feed on or near the seabed.
- Highly migratory species include pelagic species whose range extends extensively throughout the ocean.
- Forage fishes were defined as small fishes, including squid, that are common prey for higher trophic level taxa, including seabirds, marine mammals, and larger predatory fish.
- Plankton includes both zooplankton and phytoplankton which are both drifting organisms at the base of the food chain. The eggs and larvae of many fishes and invertebrates are planktonic.

Infrastructure was the primary IPF across all subgroups, though its ranking and impacts vary by subgroup and location in the water column. Benthic and demersal fishes and invertebrates are directly affected by transformation of soft-bottom habitats into hard-bottom, which can alter local biodiversity and community structure. Highly migratory and forage species face indirect impacts through shifted prey availability and the potential attraction to mid-water mooring and transmission lines, which may function as FADs. For plankton, OSW infrastructure changes water flow and upwelling patterns, which may disrupt their ability to grow and alters how different species interact, which can ripple through the entire food web. Plankton-specific monitoring questions are integrated into the impact-topic tables in Section 8.3 rather than treated as a separate impact category.

Fish and Invertebrate Species Prioritization

Fish and invertebrate species within each subgroup were further categorized into functional groups based on their ecological roles, life histories, and habitat requirements (Appendix F). The WG assigned priority rankings (high, medium, low, not likely to be exposed to impacts) to each functional group based on their assessment of potential impacts from OSW development (Table 34). These taxa and functional groups were designated as high priority because of their exposure and sensitivity to OSW impacts, economic importance, status as protected species under the ESA, California

Endangered Species Act, or NOAA priority species, or their foundational role in marine food webs.

Table 34. *Results from species prioritization for fish and invertebrates*

Fish and Invertebrate Species Prioritization Results
High Priority
Demersal and Benthic Fishes Deepwater slope specialists, Demersal groundfish, Elasmobranchs, Flatfishes, Rockfishes **Highly Migratory Pelagics and Forage Species** Coastal pelagic & forage fishes (including Northern Anchovy, Pacific Sardine, and Pacific Herring), Chinook salmon *(Oncorhynchus tshawytscha)*, Chum salmon *(Oncorhynchus keta)*, Coho salmon *(Oncorhynchus kisutch)*, Elasmobranchs, Eulachon *(Thaleichthys pacificus)*, Green sturgeon *(Acipenser medirostris)*, Market squid *(Doryteuthis opalescens)*, Pacific Herring *(Clupea Pallasii)*, Steelhead trout *(Oncorhynchus mykiss)* **Demersal and Benthic Invertebrates** Benthic grazers & scavengers, Bivalves & sessile invertebrates, Cephalopods, Mobile crustaceans **Plankton** Plankton: phytoplankton, zooplankton
Medium Priority
Highly Migratory Pelagics and Forage Species Shortfin mako shark *(Isurus oxyrinchus)*
Low Priority
Demersal and Benthic Fish Croakers & drums, Surfperches **Highly Migratory Pelagics and Forage Species** Jacks & barracuda, Other Salmonids, Sturgeons, Tope shark *(Galeorhinus galeus)*, Tunas & billfishes
Not Likely to be Exposed to Impacts
Highly Migratory Pelagics and Forage Species Oceanic whitetip shark *(Carcharhinus longimanus),* Scalloped hammerhead Shark *(Sphyrna lewini),* Sockeye salmon *(Oncorhynchus nerka)*

Demersal and Benthic Fishes

Infrastructure was identified as the IPF for demersal and benthic fishes during construction and operation. The WG identified a range of impacts associated with OSW infrastructure including changes in abundance and occurrence, demographic changes, community structure, habitat use and behavior changes, larval dispersal and recruitment changes, and physiology and condition change (Table 35).

Table 35. *IPFs and associated impacts by development phase, priority species, and attributed habitats for demersal and benthic fishes*

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Abundance/ Occurrence	Construction, Operation	Rockfishes, Flatfishes Demersal groundfish Elasmobranchs Deepwater slope specialists	Subtidal softbottom Rocky outcrops/banks Deep reefs
	Demographic Change	Construction, Operation	Rockfishes, Flatfishes Demersal groundfish Elasmobranchs Deepwater slope specialists	Subtidal softbottom Rocky outcrops/banks
	Community Changes	Construction, Operation	Rockfishes Flatfishes Demersal groundfish Elasmobranchs	Subtidal softbottom Rocky outcrops/banks Pockmark fields Deep reefs
	Habitat Use and Behavior Changes	Construction, Operation	Rockfishes Flatfishes Demersal groundfish Elasmobranchs Deepwater slope specialists	Subtidal softbottom Rocky outcrops/banks Pockmark fields Deep reefs
	Larval Dispersal and	Construction, Operation	Rockfishes Flatfishes	Rocky outcrops/banks Deep reefs

IPF	Impact	Development Phase	Priority Species	Habitats
	Recruitment Changes		Demersal groundfish Nearshore fishes	Estuaries Eelgrass beds Kelp beds Nearshore/ Coastal
	Physiology and Condition Change	Construction	Rockfishes Flatfishes Demersal groundfish Elasmobranchs	Subtidal softbottom Rocky outcrops/banks Deep reefs Estuaries

Highly Migratory Pelagics and Forage Species

Infrastructure was identified as the IPF for highly migratory pelagic and forage species during operation. The WG identified a range of potential impacts associated with the presence of OSW infrastructure, including changes in abundance and occurrence, habitat use, behavior change and changes in reproduction and recruitment (Table 36).

Table 36. *IPFs and associated impacts by development phase, priority species, and attributed habitats for highly migratory pelagics and forage species*

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Abundance/ Occurrence	Operation	Coastal pelagic & forage fishes Chinook salmon Chum salmon Coho salmon Steelhead trout	Pelagic zone Estuaries Eelgrass beds Saltmarshes
	Habitat Use	Operation	Coastal pelagic & forage fishes Elasmobranchs	Pelagic zone Estuaries Eelgrass beds Saltmarshes
	Behavior Change	Operation	Chinook salmon Chum salmon	Pelagic zone

IPF	Impact	Development Phase	Priority Species	Habitats
			Coho salmon Steelhead trout Elasmobranch	
	Reproduction Recruitment	Operation	Coastal pelagic & forage fishes	Pelagic zone Estuaries Eelgrass beds Saltmarshes

Highly Migratory Pelagics and Forage Species Knowledge Gaps

Impacts on abundance and occurrence of highly migratory pelagics and forage species from infrastructure during construction were identified as a knowledge gap (Table 37). Noise from construction may deter species, but the scale of construction and its overlap with migratory pelagic and forage species remains unknown and is difficult to study based on the migratory nature of these species.

Table 37. *Knowledge gap IPFs and associated impacts by development phase, priority species and associated habitats for Highly Migratory Pelagics and Forage Species*

Knowledge Gap	Priority Species	Habitats
The impact of infrastructure on abundance and occurrence during construction.	Chum salmon Elasmobranchs Green sturgeon Eulachon	Pelagic zone

Demersal and Benthic Invertebrates

Infrastructure was identified as the IPF for demersal and benthic invertebrates during construction and operation (Table 38). The WG identified impacts including changes in abundance and occurrence, community changes, habitat use and behavior and reproduction and recruitment.

Table 38. *IPFs and associated impacts by development phase, priority species, and attributed habitats for demersal and benthic Invertebrates*

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Abundance/ Occurrence	Construction, Operation	Benthic grazers & scavengers Bivalves & sessile invertebrates Mobile crustaceans Cephalopods	Subtidal softbottom Deep reefs Asphalt volcanoes Mudflats Eelgrass beds Saltmarshes
	Community Changes	Construction, Operation	Benthic grazers & scavengers Bivalves & sessile invertebrates Mobile crustaceans	Subtidal softbottom Deep reefs Rocky intertidal Eelgrass beds Saltmarshes
	Habitat Use and Behavior Changes	Construction, Operation	Benthic grazers & scavengers Mobile crustaceans Cephalopods	Subtidal softbottom Mudflats Pockmark fields Rocky intertidal Salt marshes Estuaries
	Reproduction Recruitment	Construction, Operation	Benthic grazers & scavengers Bivalves & sessile invertebrates Mobile crustaceans Cephalopods	Deep reefs Pockmark fields Estuaries Salt marshes Eelgrass beds Kelp beds Rocky outcrops/banks

IPF	Impact	Development Phase	Priority Species	Habitats
			Deepwater slope specialists	

Plankton

The IPF identified for plankton was infrastructure, associated with impacts to community change during operation (Table 39).

Table 39. *IPF and associated impacts by development phase, priority species, and attributed habitats for plankton*

IPF	Impact	Development Phase	Priority Species	Habitats
Infrastructure	Community Change	Operation	Plankton	Pelagic zone Estuaries

8.2 Fish and Invertebrate Discussion

The CCLME supports a diverse assemblage of fish and invertebrate species, driven by strong upwelling events that fuel high primary productivity (Kudela et al., 2008). This productivity supports ecosystems ranging from nearshore estuaries and kelp forests to the open ocean, where shoals of plankton-feeding anchovy, sardine, herring and market squid aggregate. Together, these habitats provide crucial nursery and foraging areas and support valuable commercial and recreational fisheries (Nickels et al., 2023; Thompson et al., 2019). Existing WEAs overlap with habitats used by benthic and pelagic fishes and invertebrates during key life history stages (Maxwell et al., 2013).

Impacts from Infrastructure

OSW infrastructure introduces new hard substrates to fish and invertebrate habitats, potentially changing existing community structures, facilitating spread of non-native species, and altering local oceanographic patterns. Underwater structures, such as turbine foundations and scour protection, function as artificial reefs (Gill et al., 2020; Knorrn et al., 2024; Watson et al., 2025; Wilber et al., 2022), introducing hard substrate for colonization by sessile invertebrates (Andersson & Öhman, 2010; Glarou et al., 2020; Green et al., 2022; Gutiérrez et al., 2022; Z. L. Hutchison et al., 2020; Langhamer, 2012; Lu et al., 2023). This new habitat may provide enhanced refugia for fish and mobile invertebrates due to potential displacement/exclusion of fishing effort (Labourgade, 2025; Langhamer, 2012; Raoux et al., 2017; White et al., 2024; Wilms et al., 2023). The resulting higher density of filter feeders and benthic invertebrates may increase local biodiversity and productivity and provide food for demersal fish and higher trophic levels (Slavik et al., 2019). However, transformation of soft bottom habitat to hard bottom may displace soft bottom fish and infaunal invertebrates (Dannheim et al., 2020; Dernie et al., 2003; Thrush et al., 2001). The reef effect may introduce opportunities for non-native or potentially invasive species to establish and expand their range (Langhamer, 2012), serving as stepping stones across biogeographical boundaries (Adams et al., 2014). Changes in water column mixing, driven by subsurface turbine structures, may alter plankton communities, potentially shifting larval transport and settlement patterns for invertebrates (Barbut et al., 2020; Floeter et al., 2017).

Within the port environment, the installation of artificial structures such as piers and pilings permanently alters intertidal and subtidal habitats. These structures introduce shading stressors while simultaneously serving as artificial reefs that promote epibiotic growth, accumulate drift algae, and artificially aggregate mobile invertebrate scavengers, forage fishes, and juvenile coastal teleosts, including rockfishes (*Sebastes* spp.), cabezon (*Scorpaenichthys marmoratus*), and lingcod (*Ophiodon elongatus*) (Schlosser, 2006). Furthermore, harbor expansion and channel-deepening dredging, particularly within places such as Humboldt Bay and potentially Port San Luis/Avila, will generate acute, temporary construction impacts such as elevated turbidity plumes and localized sedimentation. Over the long term, however, these bathymetric alterations permanently disrupt local estuarine hydrology, threatening the structural footprint of critical habitats including mudflats, eelgrass (*Zostera marina*) beds, and diverse subtidal and intertidal channel networks that support numerous fish species throughout the bay ecosystem. Dredging, other sediment displacement activities, and vessels serving infrastructure construction and operations potentially release toxins and pathogens that could have long term impacts on species and the fisheries and aquaculture dependent economy in estuary/bay environments and are covered more deeply in the habitats and ecosystems section.

High Priority Fish and Invertebrate Species and Functional Groups

These taxa and functional groups are designated as high priority because of their exposure and sensitivity to OSW impacts, economic importance, status as protected species under the ESA, California Endangered Species Act, or NOAA priority species, or their foundational role in marine food webs. High priority species and functional groups identified in the results section are discussed below.

Fish Taxa

High priority fish taxa range from protected anadromous species to deep water specialists and include:

Anadromous Salmonids and Green Sturgeon

Chinook, Coho, and Chum salmon, Steelhead trout and Green Sturgeon, were identified as high priority species. These species utilize the coastal shelf as a migratory corridor where OSW arrays and cables could alter movement patterns or the magnetic cues used for navigation (Naisbett-Jones & Lohman 2022). Other anthropogenic factors, especially migration barriers, habitat degradation, hatchery influence, increased sea surface temperature, and HABs, have reduced the adaptive capacity of most steelhead and salmon populations over the years which makes them more vulnerable to additional impacts (Crozier et al., 2019).

Coastal Pelagics and Forage Fishes

This group includes species such as Pacific sardine, northern anchovy, Pacific Herring and Eulachon which play an important role in linking plankton and higher trophic levels (McClatchie et al., 2018). They are considered a high priority group due to their role as a foundational prey resource for fish, marine mammals, and seabirds (Szoboszlai et al., 2015). A number of species in this group either are dependent on or utilize estuarine/bay habitats for shelter, foraging, reproduction, or recruitment. The distribution of coastal pelagics and forage fishes is highly responsive to variability in upwelling and primary productivity, which are primarily driven by large scale oceanographic processes (Santora et al., 2017), but may also be influenced on a local level by OSW. While current evidence suggests that turbine induced wind wake effects on upwelling are likely minimal (Raghukumar et al., 2023), other mechanisms such as localized turbulence from mooring systems and structural presence (including biofouling) may alter habitat conditions and prey aggregation, potentially further affecting forage fish distribution and availability.

Rockfishes, Demersal Groundfish, and Nearshore Fishes

With over 60 species in California waters, rockfishes (*Sebastes* spp.) alongside other ecologically and commercially important demersal groundfish—such as lingcod, sablefish (blackcod), thornyheads, and various flatfishes—play an integral role in marine food webs across the outer shelf and upper slope (M. Love et al., 1998; M. S. Love et al., 2021). Recruitment for rockfish and many associated groundfish is tightly coupled with coastal upwelling; strong spring upwelling delivers the nutrients required for plankton blooms, which serve as the primary food source for their pelagic larvae. However, very strong upwelling can be detrimental; if offshore transport (Ekman transport) is too intense, larvae may be swept too far from the specific shelf or reef habitats needed for settlement (Freeman et al., 2022). In these deeper offshore regions, OSW infrastructure will introduce novel hard substrate into primarily soft-bottom expanses. This will create localized "reef effects" from floating mooring anchors and inter-array cables, which may artificially aggregate structure-oriented species like lingcod and reef-associated rockfishes while potentially displacing soft-bottom specialists.

Moving closer to the coast, coastal demersal and nearshore fish assemblages (e.g. greenlings, sculpins) may be susceptible to localized seafloor disturbances associated with OSW export cable routing, landfall installations, and port expansion. Routine activities such as navigational dredging can further contribute to chronic benthic disturbance (Wenger et al., 2018). These nearshore impacts may be significant in regions like Humboldt Bay, where diverse coastal demersal species reside close to proposed port development and infrastructure hubs. While some species may be attracted to novel coastal structures like cable armoring, piers, or jetties, this artificial reef effect often comes at the expense of natural ecosystems (Kramer et al., 2015). For example, increased turbidity, sediment smothering, or physical scouring from nearshore construction can result in the degradation of natural kelp canopies and submerged vegetation, ultimately displacing the native coastal fish assemblages that rely on these critical shallow-water environments for shelter, foraging, and recruitment (Munsch et al., 2017).

Elasmobranchs

Sharks, skates, and rays are considered a high priority group due to their electro-receptive capabilities and unique sensory biology and life histories. These traits may make them uniquely sensitive to EMF emissions from inter-array and export cables (Z. Hutchison et al., 2018).

Deep-Water Slope Specialists and Flatfishes

Slope specialists such as sablefishes, thornyheads and grenadiers, and flatfishes (e.g., Dover sole and Pacific sanddabs) are uniquely vulnerable because they occupy the same soft bottom benthic footprint where floating OSW anchors would be placed. These species require soft sediment for burying, camouflage, and foraging (NOAA Fisheries, 2025). They will be subject to habitat loss and modification, in addition to long-term benthic disturbances from construction and operation of OSW infrastructure.

Invertebrate Groups

Invertebrates form the backbone of benthic and pelagic ecosystems (Chen, 2021). Monitoring efforts that focus on groups that are most susceptible to habitat conversion (soft-bottom to hard-bottom), shading, sedimentation, chemical pollution, release of pathogens, and invasive species (Lenihan et al., 2018; Moulton & Hacker, 2011) in addition to climate change impacts (Byrne & Przeslawski, 2013) will be crucial.

Benthic Grazers and Scavengers

This group includes slow moving or sessile invertebrates such as abalones, sea stars, sea cucumbers, and whelks. These echinoderms and gastropods are benthic organisms, inhabiting both soft and hard bottom habitats and are therefore likely sensitive to changes or impacts to the seafloor. They are also highly vulnerable to crushing as well as smothering from construction-related sedimentation (Hovel, 2025; Pinnegar et al., 2000).

Bivalves and Sessile Invertebrates

This group includes bivalves (e.g., mussels), sessile organisms (including anemones, barnacles, bryozoans, and tunicates) and structure-forming invertebrates like sponges and corals. These organisms inhabit both hard and soft substrates, where they provide complex biological architecture that enhances the structural diversity of the seafloor. Structure-forming invertebrates are designated as a high-priority species group due to their role as foundation species. Their complex physical architecture provides essential habitat, nursery grounds, and refugia for a diverse array of fish and mobile invertebrates. However, these organisms are exceptionally vulnerable to the localized stressors associated with construction activities. Specifically, sessile and slow-growing species face significant risks from construction-related sediment plumes that can smother organisms, impede filter-feeding, and interfere with larval settlement. They may also be damaged or displaced by anchoring systems and cable burial. At the same time, OSW infrastructure may create new habitat in the pelagic environment for planktonic larvae of these species to recruit to and grow on (e.g., mooring lines and anchors) (Dubois et al., 2025). Furthermore, the conversion of soft-bottom habitats to hard substrates (and vice versa) can fundamentally alter community composition, potentially displacing native populations in favor of opportunistic or non-native species (Hovel, 2025; Pinnegar et al., 2000).

Mobile Crustaceans

This group includes high value commercial species such as Dungeness crab (*Metacarcinus magister*), and California spiny lobster (*Panulirus interruptus*). These are high priority species due to their possible sensitivity to EMF from subsea cables, habitat modification (Love et al., 2017), and potential changes in recruitment success linked to altered larval transport (Hovel, 2025; Sunday et al., 2022; Williams et al., 2023). In addition to OSW impacts, warmer atmospheric temperatures may also alter or change upwelling and circulation patterns of the region (Rykaczewski & Dunne, 2010), which could affect food availability for larval lobster (Roemmich & McGowan, 1995), and alter dispersal and recruitment patterns (Pringle, 1986). Concurrently, ocean acidification is intensifying and is expected to negatively affect calcifying invertebrates such as gastropods and bivalves, which serve as key prey resources for this group (Whiteley, 2011).

Cephalopods

Market squid (*Doryteuthis opalescens*) are California's largest fishery by volume, and serve as a primary prey item for a diverse array of predators due to their high protein content and massive seasonal abundance (Suca et al., 2022). Juvenile market squid abundance is driven by local recruitment processes linked to sea surface temperature and upwelling dynamics, with finer-scale spatial variability reflecting the extent of upwelling dominated regions (Ralston et al. 2018; Suca et al., 2022). Recent changes in these environmental factors appear to contribute to the recent northward range expansion of squid into WEAs (Stewart et al., 2012, 2014). Given their ecological importance and the likelihood that spawning grounds overlap with nearshore cable landfall sites, cephalopods such as market squid were considered a high priority species group.

Plankton and Zooplankton

Plankton, including phytoplankton, zooplankton (e.g., krill and copepods), and meroplankton (eggs and larvae of many fish and early life history stages of many benthic invertebrates), are a high priority group because they form the foundation of the marine trophic pyramid (Fenchel, 1988). In the CCLME, the aggregation of these organisms into highly productive "hotspots" is driven by complex physical oceanographic and atmospheric processes. One concern related to OSW involves the alteration of surface winds. The extraction of kinetic energy by large-scale turbine arrays creates wind wakes, characterized by reduced wind speeds and heightened turbulence downwind of the rotors (Schultze et al., 2020). Monitoring these foundational communities will be essential, as any OSW induced modifications to water column turbulence, light attenuation, or DVM patterns would trigger cascading "bottom-up" effects. These shifts could alter energy availability for all high priority species, from forage fish to apex predators (Messié & Chavez, 2017).

Impacts to Demersal and Benthic Fishes

The IPF for benthic and demersal fish, during construction and operation, was infrastructure (Table 22). Anticipated impacts to demersal and benthic fishes from infrastructure include changes in distribution, shifts in demographic and community structure, changes in habitat use, and alterations to physiological condition (Bergström et al., 2013; Fowler et al., 2020; Gill et al., 2020; Langhamer, 2012; Melbourne-Thomas et al., 2021). OSW infrastructure would introduce hard artificial substrate into systems dominated by soft sediments, leading to colonization by encrusting organisms. Piers and pilings introduce hard substrate in intertidal and subtidal habitats where there will be substantial shading from light. The resulting habitat transformation and artificial reef effect may alter species composition, trophic dynamics, and benthic-pelagic coupling (Ajemian et al., 2015; Langhamer, 2012).

Species that benefit from increased structural complexity, including juvenile rockfishes, lingcod, and greenlings, may increase in local abundance offshore and nearshore in bays (Love et al., 2019; Porter et al., 2018; Schlosser, 2006). Addition of hard-structure habitat may enhance recruitment, growth rates, and fecundity, potentially yielding a positive impact on demersal fish populations (Fortune et al., 2024; Snodgrass et al., 2020).

The WEAs may function as de facto MPAs if fishing pressure is displaced or excluded. This reserve effect could bolster survival rates and shift demographic structure and abundance of resident species. It is unknown if adult populations protected from fishing at a de facto MPA WEA would show site fidelity to the area and benefit from protections from fishing mortality. The combined influences of artificial habitat creation and decreased fishing pressure may alter reproductive output and recruitment dynamics. WEAs could serve as a nursery for late-stage larvae or juveniles that colonize mid-water and surface infrastructure. Ultimately, these localized ecological shifts could provide a positive contribution to recruitment of broader benthic fish populations. Arguably, there are potentially negative impacts. Recruitment success to adult populations from offshore infrastructure sites may be lower than from natural habitats. However, populations might be negatively impacted if mortality rates at infrastructure sites are higher than in natural habitats. For example, a WEA could function as an ecological sink if offshore infrastructure is serving as nursery habitat for fishes (e.g., nearshore rockfishes), that are unable to successfully recruit to distant adult habitat (e.g., rocky reefs).

The net ecological impact will depend on the difference between habitat loss for soft sediment specialists and habitat gains for structure-oriented species. Demersal and benthic fish species that rely on soft sediment habitats for foraging, refuge, or reproduction are likely to be most negatively affected (Dernie et al., 2003; Thrush et al., 2001). Species with specialized associations to soft substrates (e.g., flatfishes, sanddabs, and some rockfishes during early life stages) may experience displacement and reduced habitat quality (Able & Joel Fodrie, 2014). Consequently, these species may decline in abundance and experience distribution shifts due to habitat loss, leading to altered community composition (Macdonald et al., 2012).

Port development and cable installation may have recurring short term and long term negative effects on benthic fish species, as continued maintenance dredging and cable maintenance activities cause seafloor disturbances (Gill et al., 2020). Port development, particularly in Humboldt Bay, is expected to alter physical and ecological conditions, with likely effects on demersal fish assemblages within and near the bay. Nearshore taxa, such as surfperch (Shiner, Pile, Striped), though ranked as low priority broadly, and juveniles of rockfishes and other coastal species are likely to be a greater concern in these port development areas due to considerable habitat changes and port activity. In addition, flatfishes such as California halibut and English sole will lose soft-bottom foraging areas and may be exposed to resuspended toxins (Airamé et al., 2003).

Impacts to Highly Migratory Pelagics and Forage Species

For highly migratory pelagic (e.g., tunas, billfishes, pelagic sharks) and forage fishes (e.g., sardines, anchovies, herring, market squid), infrastructure was identified as a IPF during construction for estuarine/bay dwelling species and operations (Table 23). Priority impacts include changes to abundance and distribution, habitat use, behavioral responses to structure, and changes to reproduction and recruitment.

OSW infrastructure may function as FADs, attracting prey species and creating foraging hotspots for predators, such as tuna and California yellowtail (*Seriola dorsalis*) (Dagorn et al., 2013). However, the extent and duration of habitat occupancy will likely vary by species, influenced by mobility and home range size. For highly mobile species like tunas, aggregations may be transient, reflecting brief foraging bouts rather than sustained residency. Offshore wind infrastructure could potentially create a more persistent ecosystem via an artificial reef effect. Depending on which species are repelled or attracted to infrastructure, these artificial reefs may serve to intensify spawning, which would result in increased production locally as well as regional larval supply and recruitment (Smith et al., 2016). Oceanographic impacts and changes in circulation patterns may also affect the retention of forage fish larvae.

If OSW infrastructure attracts predators to areas where prey is not sustainably produced, infrastructure could function as ecological sinks, concentrating fish in locations that ultimately offer lower foraging value or increased exposure to other stressors (e.g., vessel traffic and higher entanglement risk) (Dagorn et al., 2013; Nelson, 2003). There is a lack of knowledge of how construction may impact abundance and distribution of highly migratory pelagics and forage species (Table 24). Noise from construction may deter these species, but the scale of construction and its overlap with migratory pelagic and forage species remains unknown and is difficult to study based on the migratory nature of these species. The net balance between positive (enhanced foraging) and negative (ecological trap) outcomes remains unresolved (Snodgrass et al., 2020). Pacific herring also warrants explicit mention: California's commercial herring fishery is confined to four nearshore spawning bays (San Francisco, Tomales, Humboldt, and Crescent City) and does not directly overlap the WEAs, but adult herring forage in coastal waters that include WEA footprints, and cable-corridor disturbance along the routes between WEAs and spawning bays warrants monitoring. Additional OSW-specific concerns for the broader coastal pelagic/forage group — including market squid and the euphausiid krill (*Euphausia pacifica*, *Thysanoessa spinifera*) that underpin much of the CCE food web — include potential infrastructure-driven disruption of diel vertical migration and altered larval transport from localized hydrodynamic changes (Daewel et al., 2022).

Impacts to Demersal and Benthic Invertebrates

Infrastructure was identified as an IPF across all phases of OSW development for demersal and benthic invertebrates (Table 25). Anticipated effects include both positive and negative impacts on community composition, distribution, habitat use and behavior, and reproduction and recruitment (Dannheim et al., 2020; Lewis et al., 2002). Impacts from OSW infrastructure on demersal and benthic invertebrates are anticipated to occur at relatively small spatial scales, with potential population-level impacts generally limited to a regional scale. The introduction of hard substrate can fundamentally alter benthic habitats by changing the availability of settlement surfaces (Dannheim et al., 2020). Over time, the accumulation of invertebrates and other habitat forming species can create new complex habitats within soft-bottom environments, resulting in a potential shift from infaunal-dominated to epifaunal-dominated assemblages (Dannheim et al., 2020). Infaunal taxa (e.g., polychaetes, bivalves, burrowing crustaceans) that dominate soft sediments may decline in areas directly affected by turbine foundations and scour protection (Baeye & Fettweis, 2015) , while epifaunal filter-feeders (mussels, barnacles, tubeworms, tunicates) proliferate on hard surfaces (Hughes & Sayer, 2005). These changes may increase local biodiversity and habitat complexity but can also lead to greater competition as space on artificial structures becomes limited. Colonization dynamics during construction warrant particular attention, as early successional communities may differ from long-term stable assemblages. Shellfall from these novel invertebrate communities is also likely to create new benthic habitat and hard structure, which may facilitate colonization by more hard-bottom associated communities (Goddard & Love, 2010).

Cables, pipelines, and additional OSW associated port infrastructure will introduce hard substrate in coastal environments and may facilitate spread of non-native species into previously uncolonized areas (Glasby et al., 2007). Ballast water discharge from support vessels is another potential pathway for introducing non-indigenous invertebrates (Bailey, 2015). This infrastructure may facilitate the spread of non-indigenous invertebrates by functioning as stepping stones for larval dispersal and range expansion, enabling connectivity between coastal and offshore populations (Bulleri & Chapman, 2010; Simons et al., 2016).Introducing hard structures inside de facto MPAs in natural soft-bottom habitats drives the proliferation of invasive species by simultaneously providing an uncompetitive, optimal attachment surface for encrusting organisms and shielding them from both commercial fishing disturbances and native predators within the complex physical architecture (Page et al., 2006).

Finally, invertebrate recruitment and species distribution are strongly influenced by timing and physical oceanographic conditions (Menge et al., 2011). Seasonal upwelling and prevailing ocean currents influence larval transport pathways to and from offshore structures. Under typical northeasterly wind conditions, southward currents and enhanced offshore transport can directly enable invertebrate larvae to colonize far offshore platforms (Botsford, 2001; Parrish et al., 1981). This novel habitat may be beneficial for native species and increase habitat use, but there is also potential for nonnative and invasive species colonization.

Impacts to Plankton

Infrastructure and its associated hydrodynamic shifts were identified as the primary IPFs driving both positive and negative changes in plankton community structure (Table 26). Possible negative consequences are largely tied to the upwelling shadow effect, in which structures alter local surface circulation and reduce wind-driven mixing, creating a hydrodynamic shadow that suppresses natural upwelling processes immediately downstream (Raghukumar et al., 2023). This localized reduction in nutrient delivery could lower primary productivity, alter plankton community composition, and disrupt larval supply (Floeter et al., 2022). While pelagic holoplankton, ichthyoplankton, and zooplankton are most vulnerable to these effects, the overall impact on the broader CCLME is expected to be limited. However, the precise magnitude remains a significant knowledge gap, as residence time and spatial extent of these shadows are currently unconstrained by existing models (Dorrell et al., 2022).

Conversely, introduction of infrastructure may benefit plankton through several ecological pathways. Hard substrates provide abundant settlement surfaces for meroplanktonic larvae, potentially increasing local recruitment for structure-oriented species (Reeds et al., 2018). Attraction of migratory, schooling, and forage fishes to these structures (the FAD effect) may elevate localized spawning effort, enhancing larval supply to downstream habitats (Degraer et al., 2020). If OSW developments restrict fishing, the resulting increase in abundance of larger, older fish could lead to disproportionately higher per-capita production of high-quality eggs and larvae (Hixon et al., 2014).Ichthyoplankton and invertebrate zooplankton serve as a vital link to nearshore fish communities, anchoring the upper levels of the planktonic food chain.

Plankton are closely tied to oceanography, and it will be important to characterize both physical and biological oceanographic impacts from OSW in order to understand the potential impacts to plankton. Plankton are also largely influenced by natural seasonal and temporal variability (Hooff & Peterson, 2006), which will be important to distinguish from OSW induced impacts. Adaptive oceanographic modelling, new OSW WEA monitoring and continued region-wide surveying will be necessary to predict net gains or losses of plankton and to understand the cascading consequences for higher trophic levels.

8.3 Fish & Invertebrate Recommendations

Foundational Recommendations

Infrastructure is the primary IPF for fish and invertebrates, with potential impacts including altered abundance, community composition, habitat use, and recruitment. These effects are likely to be most extensive for demersal and benthic species, where the addition of hard substrate may trigger cascading community shifts, both positive and negative, via the reef effect. For plankton, the highest priority is infrastructure-driven community changes resulting from altered hydrodynamics. The following recommendations for fish and invertebrates should be prioritized:

- **Build On and Sustain California's Uniquely Comprehensive Marine Fishes and Invertebrate Monitoring Assets** Maintain and enhance California's fishes and invertebrate monitoring assets — including the 76-year CalCOFI time series and established fisheries-independent and ecological monitoring programs — by designing new OSW monitoring programs to explicitly integrate with, leverage, and conserve these legacy data streams. The dynamics of the California Current Ecosystem demand multi-decadal observational records to distinguish natural variability and secular trends from OSW-driven impacts.
- **Invest in Regionally Comprehensive, Multi-Year Pre-Construction Baseline Studies** Invest in pre-construction baseline studies of species composition, abundance, distribution, movement, and seafloor habitat, integrating traditional sampling with emerging tools (e.g., eDNA, acoustics, high-resolution imaging, and AUVs).
- **Expand Regional Oceanographic Monitoring** Expand oceanographic monitoring (temperature, current velocity, nutrient fluxes, plankton assemblages, and upwelling dynamics) to establish a robust pre-construction baseline of ecosystem processes within and outside OSW areas.
- **Develop Robust Species Distribution Models** Develop models that map current fish and invertebrate densities against existing natural habitat features and environmental covariates. Enhancing these predictive spatial models is

essential to forecast how the unprecedented introduction of novel, 3-dimensional structures into previously open-ocean or featureless soft-bottom environments will shift baseline habitat preferences and drive the attraction, displacement, or redistribution of local populations.

Impact-Specific Recommendation Tables

The following tables outline monitoring recommendations for impacts resulting from infrastructure and have been highlighted to address the associated impact topics and MQs (Tables 40-42). Priority species were identified for monitoring with each sensor in addition to a summary of key opportunities and limitations. The tables also present cost and effort assessments *relative* to other sensors used to monitor fish and invertebrates. West Coast monitoring programs employing these sensors were included where applicable to demonstrate their current application. Plankton-relevant monitoring is distributed across the four impact-topic tables rather than siloed, reflecting that plankton dynamics crosscut every OSW impact pathway.

MQ: How does the introduction of novel hard infrastructure alter the occurrence, abundance, demographic structure, and overall composition of local fish and invertebrate assemblages?
MQ: What are the physical and ecological impacts of upper-water-column epibiota sloughing off and accumulating on underlying seafloor habitats and benthic communities?
MQ: How does the addition of novel hard-bottom substrates influence recruitment dynamics and community composition in the adjacent natural soft-bottom environments?

Table 40. *Impact Topic: Physical habitat alteration & benthic ecology impacts*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Extractive + Non-Extractive Fishing Methods	Demersal groundfish Flatfishes Rockfishes Mobile crustaceans Cephalopods Benthic grazers & scavengers Coastal pelagics	Historical, time series data from long-term surveys. Fishing gear provides direct evidence of species presence, relative abundance, size structure, & condition; Ground-truth whether turbine-associated habitats are changing local fish & mobile invertebrate assemblages. Physical capture of individuals also allows for tissue sampling-based analysis (e.g. genetics, stable isotopes).	Methods are selective; can disturb habitat, may be impractical or undesirable around infrastructure or sensitive benthic areas. Catch rates can reflect gear bias; tools are better for targeted biological confirmation than for broad, non-invasive habitat-scale community assessment. Catch can induce injury or mortality. On water activities & angling expertise are required & must be managed.	Moderate to High Vessel time, gear deployment, personnel, permitting, & taxonomic processing can be substantial. Costs may be mitigated by cooperative fisheries research methods.	California Collaborative Fisheries Research Program, NOAA Shelf Rockfish Hook & Line Survey, NOAA U.S. West Coast Groundfish Bottom Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Fisheries-based sampling especially useful when management questions centers on fishery-relevant spp. or taxa that are difficult to identify reliably from imagery alone. Fisheries-based sampling can directly involve fishing communities in data collection.			
Imaging Systems - Camera/Video Surveys	Rockfishes, Flatfishes, Demersal groundfish, Coastal pelagic & forage fishes, Mobile crustaceans, Cephalopods, Benthic grazers & scavengers, Bivalves & sessile invertebrates	Can document turbine-related habitat change & show organisms & structure at same time. Detect shifts in fish use of foundations, hard-bottom colonization, shellfall, & changes along soft-to-hard substrate gradients, while creating an image archive that can be revisited as methods improve (e.g. AI classification, natural pattern mark recapture).	Detection is imperfect for cryptic, buried, nocturnal, or very small taxa. Taxonomic resolution can be limited for invertebrates without specimen confirmation. Strongly affected by turbidity, light, biofouling, field of view, currents, & platform stability; Seasonal water clarity can strongly influence data quality & comparability across	Moderate Cost-effective habitat-impact tools: non-destructive & information-rich, but cost rises with ROV time, repeated surveys, annotation burden, & image-management needs. Imaging at depth (~1000m) will likely require specialized & expensive cameras & deployment platforms.	None exist; camera surveys are likely going to be the best ways to survey fish & benthic communities post-construction

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
			surveys. Works best when paired with grab, settlement, or specimen-based methods.		
Visual Surveys	Rockfishes, Flatfishes, Demersal groundfish, Mobile crustaceans, Benthic grazers & scavengers, Bivalves & sessile invertebrates	Visual surveys document anemones, sponges, tunicates, sea stars, urchins, and fouling communities. SCUBA transect surveys provide direct visual census of fish & invertebrate abundance, size, & community composition at divable depths on & around floating structures & mooring lines, documenting habitat changes from new hard substrate. Divers quantify colonization, succession, & zonation on structures with high taxonomic resolution; Diver observations capture fine-scale behaviors &	Restricted to depths (typically <30 m), limiting assessment of deeper benthic infrastructure where much OSW occurs. Weather, currents, & visibility constrain sampling windows. Diver presence may alter fish behavior. Observer training & calibration needed for consistent data collection. Does not capture cryptic, buried, or nocturnal taxa well without complementary methods. Cannot directly sample infauna.	Moderate Among more cost-effective habitat-impact tools. SCUBA surveys require dive certification, safety equipment, & vessel support but avoid gear & specimen processing costs; Depth limitations reduce applicability in deep-water WEAs. Intertidal surveys among the most efficient methods, requiring only field personnel & basic equipment. Observer training essential for consistent data quality.	REEF (Reef Environmental Education Foundation) Survey Project, Reef Check, PISCO (intertidal & subtidal), CDFW diving surveys, MARINe Intertidal surveys

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		species interactions difficult to assess with other methods. Non-extractive surveys allow repeated sampling of same sites. Intertidal surveys document coastal habitat impacts at cable landfalls & port development areas.	Intertidal surveys restricted to tide windows & accessible shorelines.		
Active Acoustic Monitors	Coastal pelagic & forage fishes, Rockfishes, Demersal groundfish	Efficiently measure fish size frequencies, biomass, aggregation, & vertical distribution change around turbine foundations & adjacent habitats over broad spatial & temporal scales. Valuable when the question is whether infrastructure alters local fish use patterns beyond the narrow footprint visible in cameras or	Relative to imaging tools, active acoustics less informative for fish species enumeration, benthic invertebrates, attached communities, & fine-scale habitat condition. Species-level identification is limited without supporting sampling. Complex structures create acoustic	Moderate to High Can cover large areas efficiently, but specialized equipment, calibration, processing expertise, & interpretation effort make it more expensive than basic imaging & less direct for benthic community questions.	CalCOFI, NOAA Acoustic Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		grab samples. Side-scan sonar or similar acoustic methods are effective wide-area tools for monitoring benthic habitat.	shadowing & makes interpretation challenges near foundations & rough bottom.		
Environmental Sample collectors - Plankton Sampling/ Surveys	Plankton (phytoplankton, zooplankton)	Plankton sampling resolves phytoplankton (diatoms, dinoflagellates, HAB species) and zooplankton (copepods, euphausiids, larvaceans, pteropods) assemblages, and captures meroplanktonic larvae (veligers, megalopae, nauplii) and ichthyoplankton. Plankton sampling may reveal whether new hard structure alters larval supply, settlement potential, or local food-web pathways that ultimately affect fish & benthic invertebrate communities.	Taxonomic expertise is limited & processing can also be slow, & spatial & temporal variability is high. Highly sensitive to oceanography & seasonality. interpretation of data requires pairing with hydrography & circulation context, as well as broader spatial & time series context Cannot attribute local benthic community change to turbine effects without strong spatial & temporal design (i.e. nesting surveys within a	Moderate to High Field collection straightforward, but repeated sampling, sample processing, & sample storage raise total effort/cost; depending on frequency. Region-wide & long-term monitoring programs (CalCOFI) that provide context may require future funding to maintain region-side survey design goals.	CalCOFI

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		Specimen collection builds an archive of biological samples that support additional monitoring questions (e.g. genetics, toxins). Useful when efforts are made to connect observed benthic change to recruitment dynamics or water-column transport processes.	region wide survey effort like CalCOFI).		

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Genetic + Tissue sampling	Rockfishes, Flatfishes, Demersal groundfish, Elasmobranchs, Mobile crustaceans, Cephalopods, Bivalves & sessile invertebrates, Benthic grazers & scavengers, Plankton (phytoplankton, zooplankton)	Used to confirm species ID, resolve cryptic taxa, detect early colonizers, & linking turbine-associated communities to source populations or recruitment pathways; Added value as a verification layer to grabs, settlement plates, or imagery. Genetics approaches to population assessment hold great promise; eDNA sampling & "ecosystem assessment in a bottle" using meta-barcoding & other emerging molecular techniques allow for broad-spectrum presence/absence & (more recently) relative abundance/biomass.	Usually do not provide straightforward abundance, biomass, or habitat-use metrics on their own, & interpretation can be difficult without conventional ecological sampling. Significant ground-truthing is needed for each environment/habitat sampled. Lab workflows, contamination control, & reference-library limitations can constrain consistency & comparability.	Moderate Field collection is straightforward; lab processing, QA/QC, & bioinformatics can make total effort substantial Costs highly variable depending on genomic protocols. Sample preservation requires investment in long term sample curation & storage.	CalCOFI, NOAA Rockfish Recruitment & Ecosystem Assessment Survey, California Collaborative Fisheries Research Program, NOAA U.S. West Coast Groundfish Bottom Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Tagging	Rockfishes, Demersal groundfish, Elasmobranchs	Clearest way to test turbine infrastructure changes residency, attraction, movement corridors, or habitat connectivity for individual fishes. Useful when managers need behavioral evidence that observed community changes reflect altered habitat use rather than just local aggregation visible in a survey snapshot.	Capture, handling, permitting, receiver recovery, & infrastructure interference can all complicate implementation, making it a targeted rather than screening-level tool. Poorly suited for most benthic invertebrates & broad community characterization, & sample sizes are often limited to a few focal species. Deep-water receiver deployments/recoveries are difficult & may require specialize equipment.	High Intricate planning, permitting, field logistics, & data-management burdens; best reserved for, high-priority species.	N-PAcT
Environmental Sample Collectors - Settlement Surveys	Bivalves & sessile invertebrates, Benthic grazers & scavengers, Mobile crustaceans, Plankton (phytoplankton, zooplankton)	Settlement plates and ARMS capture meroplanktonic larvae and early colonizers including barnacles, mussels, bryozoans, tunicates, and crabs. Highly effective for	These tools use a uniform, man-made surface that doesn't capture full variety of natural seafloor. Because of this, what we find on the sampler may not accurately reflect	Low to Moderate Among more cost-efficient tools for turbine colonization questions; Materials & deployment can be	Smithsonian ARMS

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		measuring novel hard substrate changes colonization, recruitment, & early community development on & near turbine structures. Directly addresses questions about hard-bottom creation, shellfall/ sloughing effects, & community assembly in a standardized way that is easy to compare through time & among sites.	actual communities living in surrounding mud or sand. Underrepresents mobile fishes & larger invertebrates, need complementary imagery or grabs sampler for full ecosystem picture. Deployment & recovery in deep water presents a logistical challenge. Performance & interpretation depend on flow, sedimentation, fouling rates, temperature, & seasonal recruitment pulses. Placement depth & exposure matters.	relatively simple (shallow water), though repeated retrievals & taxonomic processing still require steady effort.	

MQ: How will OSW-driven alterations to physical oceanography (e.g., wind wake, upwelling transport, and circulation) influence primary productivity, plankton distributions, and trophic transfer to forage fishes and benthic communities?
MQ: How might the release of chemical contaminants and biohazards during port development, construction, and operation impact local bioaccumulation and the health of plankton, fish, and invertebrate communities?

Table 41. *Impact Topic: Indirect ecosystem alteration via biogeochemical & physical oceanographic drivers*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Extractive + Non-Extractive Fishing Methods	Demersal groundfish, Flatfishes, Rockfishes Mobile crustaceans, Cephalopods Benthic grazers & scavengers	Fishing gears provide direct evidence of changes in fish & invertebrate abundance, size structure, body condition, & species composition from altered oceanography, contamination, or port development. Specimen collection allows for tissue analysis for contaminants (heavy metals, microplastics, organic pollutants) to assess bioaccumulation in highly migratory species & invertebrates. Trawls document soft-bottom community changes from dredging or sedimentation.	Methods are selective & may not capture all affected taxa; Catch rates reflect gear efficiency as much as ecological change. Cannot detect phytoplankton or nutrient changes directly. Separation of upwelling, circulation, or pollution effects from other drivers requires careful BACI design & long time series. Tissue contamination analysis is expensive. Fishing may be restricted near infrastructure or in areas impacted by port development.	Moderate to High Costs include vessel time, gear, crew, permitting, specimen processing, & taxonomic identification. Oceanographic instrumentation (CTD, nutrient analysis) adds expense. Tissue contaminant analysis (mass spectrometry, chromatography) is costly. Long-term monitoring needed to detect trends against natural variability.	California Collaborative Fisheries Research Program, NOAA Shelf Rockfish Hook & Line Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Imaging Systems - Camera/Video Surveys	Coastal pelagic & forage fishes, Rockfishes, Flatfishes, Demersal groundfish, Mobile crustaceans, Benthic grazers & scavengers, Bivalves & sessile invertebrates, Plankton (phytoplankton, zooplankton)	Imaging documents zooplankton aggregations, planktonic invertebrate larvae, anemones, sponges, tunicates, sea stars, urchins, and forage fish schools. Document fish & invertebrate distribution, behavior, & community structure changes from altered oceanography, contamination, or habitat disturbance. High-resolution cameras identify invertebrate species composition in soft-bottom habitats. Videos can reveal particle flux, plankton aggregations, & forage fish schools indicating productivity changes. Imaging detects shifts in fish behavior or invertebrate activity signaling contamination	Limited quantitative data on nutrients, contaminants, or sediment chemistry. Taxonomic identification of small invertebrates or larvae from video is challenging. Cryptic, buried, or nocturnal taxa underrepresented. Image annotation is labor-intensive. Cannot directly measure bioaccumulation or physiological stress. Turbidity from circulation changes or dredging reduces image quality. Cost increases with depth & low visibility.	Moderate ROV or camera deployments require vessel support & skilled operators. Annotation & species identification requires expertise & time. Repeated surveys across seasons needed to capture oceanographic cycles & track disturbance recovery.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		stress. Time-series imaging documents benthic recovery following port dredging. Non-extractive, allowing repeated sampling.			
Visual Surveys	Coastal pelagic & forage fishes, Plankton (phytoplankton, zooplankton)	Vessel/aerial visual surveys detect surface forage fish schools (anchovies, sardines, herring), phytoplankton blooms, jellyfish swarms, and surface contamination signatures. Detect large-scale changes in surface fish distributions & productivity patterns from circulation or upwelling alterations. Surface forage fish schools indicate prey availability & trophic conditions. Phytoplankton blooms	Only detect surface manifestations; miss subsurface fish distributions & benthic invertebrates; Provides presence/absence or relative abundance but not quantitative biomass. Limited species identification, especially for invertebrates. Weather & sea state constrain timing. Detection varies with fish behavior & water clarity.	Low to Moderate Vessel-based visual surveys are among the most cost-effective broad-scale tools, requiring only trained observers & vessel time. Aerial surveys cover larger areas but cost more. Does not require specimen collection or specialized equipment. Useful for rapid assessment & directing intensive sampling.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		suggest productivity changes. Observations detect surface contamination (oil sheens, discoloration, debris) & turbidity plumes from port dredging. Provide rapid, cost-effective broad-scale coverage to identify areas for intensive sampling.			
Environmental Sample collectors - Plankton Sampling/ Surveys	Plankton (phytoplankton, zooplankton)	Plankton sampling resolves phytoplankton (diatoms, dinoflagellates, HAB species) and zooplankton (copepods, euphausiids, larvaceans, pteropods, gelatinous zooplankton) assemblages, and captures ichthyoplankton and meroplanktonic larvae (crab megalopae, barnacle nauplii, bivalve veligers). Most direct measurement of food web base changes	Labor-intensive, requiring taxonomic expertise or molecular processing Sampling is spatially patchy. Net avoidance can bias abundance. Plankton dynamics are highly variable, requiring extensive baselines & long time series to detect changes against natural variability.	Moderate to High Field collection requires specialized nets & deployment systems. Major costs in sample preservation, microscopy, taxonomic identification, or molecular sequencing. Nutrient analysis & productivity measurements add expense.	CalCOFI, NOAA Acoustic Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		driving trophic transfer to fish & benthic invertebrates; Net tows & water samples quantify abundance, biomass, size structure, & community composition. Paired with nutrient & chlorophyll data, can test whether upwelling or circulation affects productivity; Community shifts may signal eutrophication from port runoff. Larval sampling reveals recruitment dynamics & dispersal impacts. Phytoplankton & zooplankton are sensitive to contaminants & can be analyzed for bioaccumulation.	Preservation & processing are time-consuming & expensive. Provide indirect information about adult fish & invertebrate populations.	Ichthyoplankton & larvae require specialist taxonomists. Sample processing is a major bottleneck.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Genetic + Tissue sampling	Plankton (phytoplankton, zooplankton), Rockfishes, Flatfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Mobile crustaceans, Bivalves & sessile invertebrates, Benthic grazers & scavengers	Metabarcoding & eDNA can comprehensively characterize plankton & fish communities including morphologically difficult taxa and non-native/invasive taxa. Microbial metagenomics can reveal nutrient cycling changes affecting productivity. Tissue analysis can quantify bioaccumulation of heavy metals, persistent organic pollutants, microplastics, & antifouling compounds. Stable isotopes & fatty acids trace trophic pathways & detect food web changes. Genetic barcoding can identify non-native invertebrates from port ballast water or hull	Provides presence/absence & relative abundance but less quantitative for biomass than traditional counts. Cannot directly measure productivity rates. Sequencing & bioinformatic analysis are expensive & require specialized expertise; Reference databases are incomplete for many invertebrates. Tissue analysis requires substantial sample material. Results may lag field collection by weeks to months. eDNA cannot distinguish live from dead organisms.	Moderate to High Water & tissue collection is inexpensive, but sequencing, bioinformatics, & database curation are costly. Tissue contaminant analysis & stable isotope/fatty acid analyses require mass spectrometry. Costs decrease with throughput & automation. Processing time is a consideration for time-sensitive decisions.	CalCOFI

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		fouling. Population genetics can detect fragmentation or reduced diversity from port activities.			
Environmental Sample Collectors - Settlement Surveys	Plankton (phytoplankton, zooplankton), Bivalves & sessile invertebrates, Benthic grazers & scavengers, Mobile crustaceans, Rockfishes, Flatfishes	Settlement plates and ARMS capture meroplanktonic larvae and early colonizers (barnacles, mussels, bryozoans, tunicates, crab megalopae, sea urchin larvae) and recruiting surfperch and rockfish and can detect non-native/invasive taxa. Settlement collectors detect whether altered oceanography affects larval supply & recruitment. Upwelling & circulation changes alter larval transport, retention, &	Represent artificial surfaces & may not reflect natural habitat recruitment; Focuses on early life stages delays detection of population-level effects. Larval supply is affected by many factors beyond local oceanography (distant spawning, large-scale circulation, predation). Cannot directly measure upwelling, circulation, nutrients, or contaminants.	Low to Moderate Settlement plates & collectors are among the most cost-effective recruitment tools. Main costs are repeated site visits, processing & identifying settlers, & sustaining long-term programs. ARMS add molecular sequencing costs & processing time but provide comprehensive diversity data.	CalCOFI, NOAA Rockfish Recruitment & Ecosystem Assessment Survey, California Collaborative Fisheries Research Program

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		delivery to settlement habitats. Seasonal timing can reflect upwelling-driven productivity & favorable oceanographic windows. Can track benthic recolonization following dredging & detect non-native species from ballast water or hull fouling.	Requires deployment before spawning/settlement seasons.		

MQ: Will the 3-dimensional infrastructure act as a barrier or a facilitator (corridor) for the dispersal and movement of larvae, juveniles, and adults between populations?
MQ: Will wind farms cause Fish Aggregating Device (FAD) attraction/avoidance behaviors, and how will this alter localized predator-prey dynamics and trophic interactions?
MQ: How will the presence of infrastructure and altered oceanography impact the diel vertical migration (DVM) and foraging behavior of pelagic fishes and zooplankton?
MQ: How does physical habitat disruption and EMF from buried/surface power cables alter the spatial connectivity and movement of demersal and benthic species?

Table 42. *Impact Topic: Behavioral ecology & spatial connectivity changes*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Extractive + Non-Extractive Fishing Methods	Rockfishes, Flatfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Eulachon, Mobile crustaceans, Cephalopods, Benthic grazers & scavengers	Fishing gears retain squid, lobsters, crabs, and epibenthic species along cable routes; Provides direct evidence of how fish & mobile invertebrates distributions, abundance, & community composition respond to infrastructure as barriers or attractants. Catch data from inside, outside, & adjacent to WEAs would reveal FAD-like aggregation effects & avoidance behavior. Stratified sampling along	Selective for target species & sizes; may miss cryptic or small-bodied taxa, key to connectivity questions. Cannot resolve fine-scale movement or behavior around structures without telemetry complement. Impractical around active infrastructure & cables. Demersal gears poorly sample the mid-water column (important for vertical migration). Spatial coverage limited	Moderate to High Costs include vessel time, multiple gear types, crew, permitting, & specimen processing. Stratified designs across structures & distances increase effort. Diel sampling roughly doubles ship time. Long-term monitoring needed to detect connectivity changes against natural variability.	U.S. West Coast Groundfish Bottom Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		cable routes & at varying distances would document habitat disruption from buried cables. Diel sampling (day/night catches) can detect vertical migration shifts for pelagic species. Mark-recapture survey with traditional tagging complement electronic telemetry for connectivity assessment.	by vessel time & permits.		
Imaging Systems - Camera/Video Surveys	Rockfishes, Flatfishes, Demersal groundfish, Coastal pelagic & forage fishes, Elasmobranchs, Mobile crustaceans, Cephalopods, Bivalves & sessile invertebrates, Benthic grazers & scavengers	Imaging systems (BRUVs, ROVs, towed cameras, stationary video) directly document fish & invertebrate behavior around infrastructure, including attraction, avoidance, aggregation, & habitat use. Video captures fine-scale behavioral responses to	Detection is imperfect for cryptic, nocturnal, or small taxa, & species ID from video can be limited. Turbidity, light conditions, & currents reduce image quality. Cameras observe finite areas & miss broader-scale movements.	Moderate Among the more cost-effective behavioral assessment tools, particularly BRUVs & stationary video. ROV operations are more expensive. Annotation & species ID add labor costs.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		structures difficult to measure with other methods; Time-lapse & 24-hour video reveal diel patterns in vertical distribution & activity. Imaging survey transects across cable routes could document habitat disruption & recovery. Imaging pairs well with tagging & acoustics to interpret behavioral context.	Pelagic surveys typically sample narrow depth ranges & may miss DVM extent. Annotation is labor-intensive. Baited cameras can bias aggregation estimates.	Repeated deployments across seasons & infrastructure components (turbines, cables, scour protection) increase effort.	
Visual Surveys	Rockfishes, Flatfishes, Demersal groundfish, Coastal pelagic & forage fishes, Mobile crustaceans, Benthic grazers & scavengers, Bivalves & sessile invertebrates	Visual surveys document anemones, sponges, tunicates, sea stars, urchins, lobsters, crabs, and fouling communities on floating structures and in intertidal habitat near cable landings. SCUBA transect surveys provide direct visual census of fish & invertebrate abundance, size, & behavior at divable	Restricted to divable depths (typically <30 m), limiting assessment of deeper demersal & pelagic communities where much OSW infrastructure occurs. Weather, currents, & visibility constrain survey timing. Diver presence may alter fish behavior.	Low to Moderate SCUBA surveys require certification, safety equipment, & vessel support but avoid gear & specimen processing costs. Intertidal surveys are among the most cost-effective methods. Observer training &	REEF, Reef Check, PISCO, CDFW diving surveys

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		depths on & around floating structures, documenting attraction/avoidance & community assembly. Surveys along & across cable routes at divable depths can assess habitat disruption & recovery. Diver observations capture fine-scale behaviors (territoriality, feeding, schooling) that inform connectivity & aggregation questions. Intertidal surveys can document coastal effects where cables make landfall or port development occurs.	Observer training & calibration needed. Intertidal surveys limited to tide windows & accessible shorelines.	calibration required for consistent data. Depth limitations reduce applicability in deep-water WEAs.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Active Acoustic Monitoring	Coastal pelagic & forage fishes, Rockfishes, Demersal groundfish, Plankton (phytoplankton, zooplankton), Eulachon	Multi-frequency echosounders resolve forage fish schools, zooplankton scattering layers, and diel vertical migrations of plankton and pelagic prey. Maps fish density, biomass, aggregation size, & vertical distribution around OSW infrastructure across large areas & full water column. Multi-frequency echosounders resolve fish schools, forage fish layers, & zooplankton concentrations, directly addressing FAD-like aggregation & DVM questions. Repeated transects across WEAs & reference sites quantify attraction/avoidance. Continuous bottom-	Less informative for species identification; requires ground-truthing. Near-field backscatter from structures can create acoustic shadows & data gaps. Limited information on benthic invertebrates or cryptic species. Interpretation of aggregations requires calibration against net samples or video. Specialized equipment & analytical expertise needed.	Moderate to High Covers large areas efficiently but requires specialized echosounders, calibration, & analytical expertise. Ground-truthing with net tows or imaging adds cost. Continuous bottom-mounted systems require deployment & retrieval infrastructure.	NOAA Acoustic Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		mounted acoustics capture diel & tidal patterns in vertical distribution & abundance.			
Environmental Sample collectors - Plankton Sampling/ Surveys	Plankton (phytoplankton, zooplankton)	Plankton sampling resolves ichthyoplankton, meroplanktonic larvae (crab megalopae, bivalve veligers, barnacle nauplii), and zooplankton (copepods, euphausiids, gelatinous zooplankton) relevant to connectivity. Plankton sampling addresses connectivity through the lens of larval supply & dispersal, testing whether infrastructure affects larval transport between populations. Ichthyoplankton & invertebrate larval surveys upstream &	Sampling is patchy & misses fine-scale structure. Preservation & processing are expensive & slow. Larval identification requires specialist taxonomists or molecular methods. High natural variability requires extensive baselines & long time series.	Moderate to High Field collection is straightforward but sample processing (microscopy, molecular ID) is time consuming. Stratified vertical sampling adds complexity & expense. CalCOFI-style programs demonstrate feasibility.	CalCOFI

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		downstream of WEAs can document whether structures alter larval delivery. Larval distributions & concentrations at varying distances from cables can assess dispersal effects. Vertical stratification of plankton tows can reveal how DVM of larvae & prey intersects with turbine infrastructure.			
Environmental Sample collectors - Genetic + Tissue sampling	Rockfishes, Flatfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Mobile crustaceans, Cephalopods, Bivalves & sessile invertebrates, Benthic grazers & scavengers, Plankton (phytoplankton, zooplankton), Chinook salmon, Chum salmon, Coho salmon, Steelhead	Tissue/eDNA workflows additionally target cryptic taxa and resolve larvae and early life stages across fishes and invertebrates. Directly address connectivity through population structure & parentage analyses, testing whether infrastructure fragments populations or alters gene flow between	Genetic methods provide relative information about connectivity & population structure but are less quantitative for abundance or biomass; Cannot directly measure movement rates or behavior. Bioinformatics & reference databases are incomplete for many	Moderate to High Sample collection is relatively inexpensive, but sequencing, bioinformatics, & stable isotope analyses are costly. Population genomics requires large sample sizes. Costs decrease with	CalCOFI, NOAA Rockfish Recruitment & Ecosystem Assessment Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
	trout, Green sturgeon, Eulachon	areas. Population genomics & kinship methods identify source-sink dynamics across WEAs & reference sites. eDNA sampling at multiple depths reveals vertical distributions of cryptic species difficult to detect with other methods. Stable isotopes & fatty acid analysis characterize trophic interactions & FAD-like foraging shifts near structures.	invertebrates. Population genetics require large sample sizes & multiple life stages. Results lag field collection by weeks to months.	sequencing technology improvements.	
Tagging	Rockfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Mobile crustaceans, Cephalopods, Chinook salmon, Chum salmon, Coho salmon, Steelhead	Tag deployments target larger demersal and pelagic fishes (sharks, sablefish, lingcod), lobsters, large crabs, and squid. Most direct approach for quantifying individual fish &	Poorly suited for most benthic invertebrates & small-bodied species; Tag attachment may affect behavior & survival. Acoustic arrays have limited detection range &	High Tagging has the highest per-unit costs due to tag prices, surgical implantation or attachment, array infrastructure, data management, & long-	NPACT

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
	trout, Green sturgeon, Elasmobranchs	invertebrate movement, residency, & connectivity among habitats. Acoustic telemetry with arrays inside & outside WEAs directly tests barrier/facilitator hypotheses & FAD-like residency. Pop-up & archival tags record depth & temperature, directly addressing DVM & vertical distribution questions. Cable-crossing experiments with tagged fish quantify avoidance of buried infrastructure. Multi-year tagging reveals connectivity among populations.	require infrastructure. Detection probability varies with environmental conditions. Sample sizes limited by cost & handling constraints. Inference depends on tagged animal representativeness.	term monitoring. Satellite tags for HMS are particularly expensive. Returns scale with study duration.	

MQ: Will WEAs function as de facto Marine Protected Areas (MPAs) due to excluded activities, and how will that impact fish abundance, size structure, mortality rates, and reproductive output?
MQ: What is the risk of OSW infrastructure facilitating the recruitment and persistence of non-native/invasive invertebrate species, acting as steppingstones for range expansion?
MQ: How do the assemblages of fish and invertebrates recruiting directly to offshore infrastructure differ from those in natural habitats, and does this artificial recruitment ultimately sink or subsidize natural populations?

Table 43. *Impact Topic: Impacts to population dynamics (dispersal, recruitment, and demographics)*

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Environmental Sample collectors - Extractive + Non-Extractive Fishing Methods	Rockfishes, Flatfishes, Demersal groundfish, Coastal pelagic & forage fishes, Eulachon, Elasmobranchs, Mobile crustaceans, Benthic grazers & scavengers	Fishing methods sample commercially targeted rockfishes, flatfishes, groundfish, crabs, lobsters, and shrimp. Provides direct evidence of population-level changes including abundance, size structure, age composition, & reproductive condition (GSI, fecundity, spawning stage) inside versus outside WEAs. Catch data test de facto MPA effects by comparing population metrics before & after construction & among zones with different	Selective methods may miss affected species or life stages. Fishing is typically restricted within WEAs, creating sampling asymmetry; Catch rates confound biological change with gear efficiency & local behavior. Age & reproductive assessments require specialized lab processing. Long time series needed to detect MPA-like benefits against natural variability & fishing	Moderate to High Costs include vessel time, gear, permitting, specimen processing, aging, & reproductive analyses. BACI designs require replicated pre- & post-construction sampling. Long-term monitoring (5-10+ years) necessary to detect MPA effects.	U.S. West Coast Groundfish Bottom Trawl Survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		fishing access. Specimen collection can enable aging (otoliths, statoliths) & reproductive biology assessments. Trawls can detect non-native invertebrates establishing in surrounding soft-bottom habitats.	history.		
Imaging Systems - Camera/Video Surveys	Rockfishes, Demersal groundfish, Flatfishes, Coastal pelagic & forage fishes, Mobile crustaceans, Cephalopods, Bivalves & sessile invertebrates, Benthic grazers & scavengers	Imaging captures size-structured populations of rockfishes and other long-lived fishes, and documents sessile and mobile invertebrate colonizers including non-native species. Imaging systems (BRUVs, ROVs, towed cameras) provide non-extractive assessment of fish abundance, size structure, & community composition, critical for areas where fishing is	Size estimation accuracy depends on camera calibration & viewing geometry; stereo systems improve but add complexity. Detection is imperfect for cryptic taxa. Cannot collect specimens for aging, diet, or reproductive condition. Species ID from video has taxonomic limits; Non-native species ID often requires specimen confirmation.	Moderate One of the more cost-effective population assessment tools for restricted-access areas. Stereo-camera systems add cost but improve size estimation. Annotation is labor-intensive. Repeated surveys across years needed to detect population trajectories.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		restricted. Video surveys can document size distributions using stereo-camera systems or laser calipers, testing whether WEAs protect larger/older fish. Imaging can detect non-native sessile & mobile invertebrates on structures, including cryptic colonizers. Repeated surveys can track population trajectories across construction phases.	Turbidity & light constrain data quality.		
Visual Surveys	Rockfishes, Flatfishes, Demersal groundfish, Coastal pelagic & forage fishes, Mobile crustaceans, Benthic grazers & scavengers, Bivalves & sessile invertebrates	Visual surveys document anemones, sponges, tunicates, sea stars, urchins, fouling communities on floating structures, and intertidal communities near cable landfalls. SCUBA transect surveys provide	Restricted to divable depths, limiting assessment of deeper populations. Size estimation accuracy depends on diver training. Weather & visibility	Moderate Cost-effective method requiring dive certification & basic equipment. Observer training essential.	REEF, Reef Check, PISCO, CDFW diving survey

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		direct non-extractive assessment of fish & invertebrate abundance, size, & community composition at divable depths on floating structures. Visual census can detect non-native invertebrates on structures & in coastal areas near ports & cable landfalls. Size estimation by trained divers contributes to population assessments in fishing-restricted areas. Intertidal surveys document coastal impacts from construction & cable landings.	constrain sampling. Observer presence may alter fish behavior. Non-native species ID requires expertise & often specimen collection. Does not capture full population age or reproductive structure.	Intertidal surveys among the most efficient for coastal impact monitoring.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
Active Acoustic Monitoring	Coastal pelagic & forage fishes, Eulachon, Rockfishes, Demersal groundfish, Plankton (phytoplankton, zooplankton)	Echosounders resolve forage fish schools, vertically distributed populations, and zooplankton scattering layers relevant to spawning/feeding aggregations. Quantifies fish biomass & aggregation size across WEAs, testing de facto MPA effects through time; Repeated acoustic surveys inside & outside WEAs document population-level abundance changes across construction phases. Echo-integration provides quantitative biomass estimates for pelagic & semi-pelagic species. Long-term acoustic monitoring detects trajectory differences between protected &	Species identification limited; requires ground-truthing with nets or imaging. Does not resolve size structure well. Near-field backscatter from structures creates data gaps. Poorly suited for benthic invertebrates or cryptic species. Not useful for non-native species detection or reproductive status.	Moderate to High Efficient for broad-scale surveys but requires specialized equipment & analytical expertise. Ground-truthing adds cost. Continuous deployments require infrastructure for power & data.	

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		accessible areas.			
Environmental Sample collectors - Plankton Sampling/ Surveys	Plankton (phytoplankton, zooplankton)	Plankton sampling resolves ichthyoplankton (fish eggs and larvae), meroplanktonic invertebrate larvae, and zooplankton (copepods, euphausiids), and can detect non-native larval arrivals. Plankton sampling can address population-level reproductive output by quantifying egg & larval production in & around WEAs, directly testing whether de facto MPA effects translate to enhanced reproductive output. Ichthyoplankton abundance, species	Indirect measure of adult population status. Larval abundance reflects both spawning output & survival. Sampling is patchy; Species ID requires expertise; molecular methods help. Natural variability in larval supply is high, requiring long time series. Cannot distinguish WEA effects from source population changes without additional data.	Moderate to High Field collection is straightforward, but processing is a major bottleneck. Molecular identification reduces some expertise requirements. Long time series necessary.	CalCOFI

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		composition, & spatial patterns reveal spawning activity. Larval invertebrate sampling detects reproductive success. Plankton surveys near ports detect non-native larvae arriving via ballast water. Construction-phase sampling can document impacts on larval survival.			
Environmental Sample collectors - Genetic + Tissue sampling	Rockfishes, Flatfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Mobile crustaceans, Cephalopods, Bivalves & sessile invertebrates, Benthic grazers & scavengers, Plankton (phytoplankton, zooplankton), Chinook salmon, Coho salmon, Steelhead trout, Green	eDNA, tissue, and reproductive biology sampling targets all life stages across the listed functional groups. Genetic approaches directly address population-level questions through effective population size estimation, parentage analysis of recruits, & detection of non-native	Provides relative abundance & structure but less quantitative for absolute biomass. Close-kin methods require large sample sizes. Bioinformatics expertise & reference databases needed. Reproductive biomarker interpretation requires species-specific	Moderate to High Sample collection inexpensive; sequencing & analysis costly; Requires substantial sample sizes. Reproductive hormone assays specialized. Costs decreasing with technology improvements.	CalCOFI, Rockfish Recruitment Survey, CalCOFI larval rockfish DNA time series

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
	sturgeon, Eulachon	species via barcoding & eDNA. Close-kin mark-recapture quantifies adult abundance without extensive tagging. Reproductive biology (vitellogenin, sex hormones) in tissue samples assesses reproductive output. Stable isotopes reveal whether WEA populations have distinct trophic signatures.	calibration. eDNA cannot distinguish live from dead organisms. Results lag field collection.		
Tagging	Rockfishes, Demersal groundfish, Elasmobranchs, Coastal pelagic & forage fishes, Mobile crustaceans	Tagging enables mark-recapture estimation of population size, survival, & growth inside & outside WEAs, directly testing de facto MPA predictions of increased abundance & size. Acoustic telemetry quantifies residency & survival of tagged	Poorly suited for most benthic invertebrates & small-bodied species. Tag effects on behavior, growth, & survival possible. Array maintenance requirements around infrastructure. Sample	High Tag costs, surgery, array infrastructure, & data management substantial. Long-term commitment required for meaningful population-level inference.	NPACT

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		individuals across construction phases. Tagging during construction documents immediate displacement (emigration) & return (immigration) behavior. Long-term tagging reveals changes in spatial ecology & reproductive behaviors.	sizes limited. Cannot detect non-native species. Reproductive behavior inference requires additional observations.		
Environmental Sample Collectors - Settlement Cores/ Traps	Plankton (phytoplankton, zooplankton), Bivalves & sessile invertebrates, Benthic grazers & scavengers, Mobile crustaceans, Rockfishes	Settlement plates, ARMS, and sediment cores capture meroplanktonic larvae and early colonizers (barnacles, mussels, bryozoans, tunicates, crab megalopae, urchin larvae) and recruiting rockfishes/surfperch, including detection of non-native taxa. Settlement collectors & sediment cores directly measure recruitment & colonization at WEAs,	Artificial surfaces may not fully represent natural habitat recruitment. Delayed detection of adult population effects. Cannot distinguish local recruitment from imported larvae without genetic analysis. Limited temporal resolution between retrievals. Cores represent small	Low to Moderate Settlement plates & cores are among the most cost-effective recruitment tools. ARMS monitoring program add molecular processing costs but provide comprehensive diversity data. Deployment, retrieval, & processing straightforward.	Smithsonian ARMS

Sensors/ Data Collectors	Species	Opportunities	Limitations	Cost Effort	Example Monitoring Programs & Projects
		testing whether infrastructure enhances or disrupts early life stages. Settlement rates on plates at turbines versus reference sites quantify recruit supply & reveal MPA-like benefits. Standardized collectors particularly effective for detecting non-native invertebrate establishment & tracking spread from ports & vessel routes. Sediment cores document soft-bottom recruitment in construction footprints.	areas; high replication needed.		

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Appendix

Appendix A. Permitting Section Authority Tables

The permitting tables in this appendix are based on the California Energy Commission's AB 525 Offshore Wind Environmental Permitting Roadmap[37] identified authorities that are closely tied to environmental monitoring in the marine environment. To develop these tables, interviews were conducted with relevant state and federal agencies. These tables did not undergo full final review by all federal agencies involved and can be considered preliminary. The content reflects permitting requirements, processes, and timelines as understood in Fall 2025, and subsequent shifts in federal policies or procedures may not be captured here. These are select statutes and requirements that are not a comprehensive description of all the laws applicable.

Energy Policy Act of 2005 (EPAct), Outer Continental Shelf Lands Act (OCSLA)

Lead: Bureau of Ocean and Energy Management (BOEM)
Consulting: None Required

OCSLA authorizes the government to lease offshore areas for energy uses, including for wind projects. The Interior Secretary has delegated leasing authority to the BOEM. In that capacity, BOEM promulgated regulations for offshore wind development under authority provided to the Interior Secretary in the EPAct[38]. EPAct requires that BOEM coordinate with relevant Federal agencies and affected state and local governments, obtain fair return for leases and grants issued, and ensure that renewable energy development takes place in a safe and environmentally responsible manner.

[37] https://www.energy.ca.gov/data-reports/reports/ab-525-reports-offshore-renewable-energy
[38] https://www.boem.gov/newsroom/hr6textconfreptpdf

Table A1. *Outer Continental Shelf Lands Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Leasing	BOEM designates areas for offshore wind development, holds lease sales.		BOEM[39] may prepare an environmental assessment for lease issuance and site assessment activities.
Site Assessment	Regulatory Approval; submittal and approval of a **Site Assessment Plan (SAP)** is sometimes required if BOEM determines that proposed site assessment facility is complex or significant. BOEM must approve of SAP prior to initiating proposed site assessment activities requiring such approval. 30 CFR § 585.605[40]	**SAP to include:** Project information, site assessment description and design information; survey reports characterizing site conditions. 30 CFR § 585.610[41]	Hazard and site condition data, water quality data, biological resource data, location and bathymetric data. 30 CFR Part 585 Subpart G - Site Assessment Plan [42]

[39] https://www.boem.gov/sites/default/files/documents/about-boem/Wind-Energy-Comm-Leasing-Process-FS-01242017Text-052121Branding.pdf
[40] https://www.ecfr.gov/current/title-30/section-585.605
[41] https://www.ecfr.gov/current/title-30/section-585.610
[42] https://www.ecfr.gov/current/title-30/chapter-V/subchapter-B/part-585/subpart-G?toc=1

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Site Assessment	Regulatory Approval; submittal and approval of a **General Activities Plan (GAP)** may be needed for any pre-wind farm construction activities**.** BOEM must approve of GAP prior to initiating proposed activities on lease or permit.	GAP to include: proposed construction, activities, facilities, and conceptual decommissioning for all planned facilities. [30 CFR § 585.640[43]]	Facility siting and design both onshore and offshore, geological, geotechnical, biological, benthic, archaeological, meteorological, oceanographic data to support proposed activities. [30 CFR Part 585 Subpart G - General Activities Plan[44]]
Site Assessment	Development of a **Marine Site Investigation Report (MSIR)** is needed for submission of a COP. Including geological, geophysical, and geotechnical data to assess hazards for a proposed project.	MSIR submitted within a COP to include: results of high-resolution geophysical surveys, and geotechnical investigations. [Geo Guidelines[45]]	High Resolution Geophysical survey & Geotechnical investigations [pg. 9-14 Guidelines[46]] [Submitted per BOEM/ BSEE data standards[47]]
Site Assessment	Regulatory Approval; results from **Benthic Survey and Sediment Surveys** and supporting data are submitted with COP .	**Benthic Habitat Survey & Sediment Scour survey** and data/analysis elements. [Benthic Survey Guidelines[48]]	Benthic Community Composition Survey & Sediment Scour survey and/ or Deposition Survey. [Benthic Survey Guidelines[49]]

[43] https://www.ecfr.gov/current/title-30/section-585.640
[44] https://www.ecfr.gov/current/title-30/part-585/subject-group-ECFR3db90fcc2159352
[45] https://www.boem.gov/sites/default/files/documents/about-boem/Renewable%20Energy%20Geohazard%20Guidelines_0.pdf
[46] https://www.boem.gov/sites/default/files/documents/about-boem/Renewable%20Energy%20Geohazard%20Guidelines_0.pdf
[47] https://www.boem.gov/sites/default/files/documents/newsroom/BSEE-BOEM-Renewable-Energy-Geospatial-Data-NTL.pdf
[48] Benthic Survey Guidelines

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Site Assessment	Regulatory Approval; results from **Avian Survey** and supporting data are submitted to support COP.	Quarterly and Annual Progress Report for **Avian Surveys** to describe species and habitat within impact area documenting species presence, establish pre-construction baseline abundance and distribution, and methods for detecting changes associated with project activities. [Avian Survey Guidelines[49]]	Avian Surveys for two annual cycles with more if needed to determine spatial temporal distribution and abundance from boat-based, aerial, or high-resolution digital aerial surveys, including: spatially explicit density estimates, seasonal patterns, and species-specific flight height distributions. [Avian Survey Guidelines[50]]
Site Assessment	Regulatory Approval; a lessee should complete and submit results of a **Fisheries Survey** with its COP.	Lessee should develop a **Fisheries Survey plan** in consultation with potentially affected fishing groups; describing objectives, survey design, methods, analytical approach, and quality control measures, developed in consultation with potentially affected fishing groups. [pg. 3-17, Fisheries Guidelines[50]] BOEM then coordinates with agencies to ensure the data and analysis proposed in the fisheries survey meets regulatory requirements, and will receive the survey results of the report in the appropriate plan.	Lessee should submit results of fisheries survey to BOEM which include: Fisheries and habitat data on seasonal presence/ absence, abundance, and distribution of ESA-listed species, commercially and recreationally important species, prey resources, habitats important to life history of present species (including EFH per benthic habitat survey guidelines), and migration corridors. [pg. 19, Fisheries Guidelines[51]]

[49] https://www.boem.gov/sites/default/files/documents/newsroom/Avian%20Survey%20Guidelines.pdf
[50] https://www.boem.gov/sites/default/files/documents/about-boem/Fishery-Survey-Guidelines.pdf

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Site Assessment	Regulatory Approval; a lessee must complete site characterization studies and submit results with COP including **Marine Mammal and Sea Turtle Surveys**.	**Marine Mammal and Sea Turtle Survey** plan should include sufficient information for BOEM to assess and monitor the level of impact anticipated to occur at any phase. Including geographic study area and issues under study, survey methods, analytical approach, quality control, and Protected Species Observers (PSO) qualifications, BOEM recommends the lessee provide quarterly and annual progress reports. [pg. 4, 11, Marine Mammal Sea Turtle Guidance[51]] BOEM recommends that survey specifications be submitted to BOEM prior to the pre-survey meeting in the form of a pre-survey plan. BOEM may seek advice from relevant natural resource agencies to ensure that data and analyses are adequate to meet regulatory requirements.	Marine mammal and sea turtle distribution and abundance data derived from line transect vessel with NMFS-approved PSO and aerial based surveys passive acoustic monitoring, including species-specific density estimates, seasonal presence, spatial use, detectability metrics, and ambient noise characterization. [Marine Mammal Sea Turtle Guidelines[52]]

[51] https://www.boem.gov/sites/default/files/renewable-energy-program/Regulatory-Information/BOEM-Marine-Mammals-and-Sea-Turtles-Guidelines.pdf

[52] https://www.boem.gov/sites/default/files/renewable-energy-program/Regulatory-Information/BOEM-Marine-Mammals-and-Sea-Turtles-Guidelines.pdf

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Site Assessment	Regulatory Approval; development of a **Marine Site Investigation Report (MSIR)** is needed for submission of a COP. Including geologic, geophysical, and geotechnical hazard assessments for a proposed project.	MSIR submitted within a COP to include: results of High-resolution Geophysical Surveys and Geotechnical Investigations. [Geo Guidelines[46]]	High-resolution Geophysical Survey [pg. 9-13 of the Geo Guidelines.[47]] Geotechnical Investigations [pg. 14, Geo Guidelines[48]] Submitted per [BOEM/ BSEE data standards[53]]
COP Review	Regulatory Approval; submittal and approval of a **Construction and Operations Plan (COP).** BOEM must approve COP prior to initiating approved lease activities. [30 CFR § 585.620[54]]	COP to be submitted 6 months prior to the completed site assessment term, and should describe resources, conditions, and activities that may be affected by proposed activities. [COP Guidelines[55]] Project should be discussed with BOEM at pre-survey meetings to determine specific surveys and environmental data that should be acquired [pg. 8 COP Guidelines[56]] BOEM drafts an EIS in consultation with developer, government and public to determine whether to approve lessees COP.	Site assessment and characterization data used to develop COP. [COP Guidelines[56]] [30 CFR Part 585 Subpart G - General Activities Plan Requirements for Limited Leases[56]]

[53] https://www.boem.gov/sites/default/files/documents/newsroom/BSEE-BOEM-Renewable-Energy-Geospatial-Data-NTL.pdf
[54] https://www.ecfr.gov/current/title-30/chapter-V/subchapter-B/part-585/subpart-G/subject-group-ECFRb5c16c9fda33f7c/section-585.620
[55] https://d23h0vhsm26o6d.cloudfront.net/1a.-Selected-BOEM-guidelines.pdf
[56] https://www.ecfr.gov/current/title-30/part-585/subject-group-ECFR3db90fcc2159352

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	Regulatory Approval; a lessee should submit a **Fisheries Survey plan** with its COP.	Lessee should develop a **Fisheries Survey plan** in consultation with potentially affected fishing groups; describing objectives, survey design, methods, analytical approach, and quality control measures, developed in consultation with potentially affected fishing groups. [pg. 7-17, Fisheries Guidelines[51]] BOEM then coordinates with agencies to ensure the data and analysis proposed in the fisheries survey meets regulatory requirements, and will receive the survey results of the report in the appropriate plan.	Lessee should submit results of fisheries survey to BOEM which include: Fisheries and habitat data on seasonal presence/ absence, abundance, and distribution of ESA-listed species, commercially and recreationally important species; prey resources, habitats important to life history of present species (including EFH per benthic habitat survey guidelines), and migration corridors. [pg. 19, Fisheries Guidelines[51]]
COP Review	Regulatory Approval; results from **Benthic Survey and Sediment Surveys** and supporting data are submitted with COP.	**Benthic Habitat Survey & Sediment Scour survey** and data/analysis elements. [Benthic Survey Guidelines[49]]	Benthic Community Composition Survey & Sediment Scour survey and/ or Deposition Survey. [Benthic Survey Guidelines[49]]

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	Regulatory Approval; results from **Avian Survey** and supporting data are submitted to support.	Quarterly and Annual Progress Report for **Avian Surveys** to describe species and habitat within impact area documenting species presence, baseline abundance and distribution, and methods for detecting changes associated with project activities. [Avian Survey Guidelines[50]]	Avian Surveys for two annual cycles with more if needed to determine spatial temporal distribution and abundance from boat-based, aerial, or high-resolution digital aerial surveys, including: spatially explicit density estimates, seasonal patterns, and species-specific flight height distributions. [Avian Survey Guidelines[50]]
COP Review	Regulatory Approval; Lessee must complete sight characterization studies in accordance with COP including **Marine Mammal and Sea Turtle Surveys.**	**Marine Mammal and Sea Turtle Survey plan** should include sufficient information for BOEM to assess and monitor the level of impact anticipated to occur at any phase of lease development. Including geographic study area and issues under study, survey methods, analytical approach, quality control, and Protected Species Observers (PSO) qualifications, BOEM recommends the lessee provide quarterly and annual progress reports. [pg. 4, 11, Marine Mammal Sea Turtle Guidance[52]]	Marine mammal and sea turtle distribution and abundance data derived from line transect vessel with NMFS-approved PSO and aerial based surveys passive acoustic monitoring, including species-specific density estimates, seasonal presence, spatial use, detectability metrics, and ambient noise characterization. [pg. 5-11, Marine Mammal Sea Turtle Guidelines[53]]

National Environmental Policy Act (NEPA) (40 Code of Federal Regulations, Parts 1500-1508)

Lead Agency: BOEM
Consulting Agency: If formal NEPA consultation process with National Marine Fisheries Service (NMFS) and United States Fish and Wildlife Service (USFWS)

NEPA, enacted in 1970, requires federal agencies to assess the environmental effects of proposed major actions—such as infrastructure projects or land management—prior to implementation. It mandates informed decision-making, public involvement, and the preparation of Environmental Impact Statements (EIS) for actions that may have significant impacts.

Table A2. *National Environmental Policy Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Leasing	BOEM may prepare NEPA analysis, likely an **Environmental Assessment (EA),** to determine whether a full Environmental Impact Statement is required prior to issuing a lease.	BOEM will compile a description of the affected environment and environmental impacts encompassing geology, air quality, water quality, marine and coastal habitats and associated biotic assemblages, marine mammals and sea turtles, coastal and marine birds, commercial fishing, recreation and tourism, socioeconomics, historic properties, environmental justice, and tribes and tribal resources. [Morro Bay EA[57]]	A compilation of existing data on the affected biological and physical resources. [Morro Bay EA[58]]
COP Review	BOEM prepares NEPA analysis, likely an **Environmental Impact Statement (EIS)** informing COP approval decision.	Developer required to engage with BOEM to inform preparation of an EIS. Developer submits a NOI to prepare a	Supporting data types for physical and biological resources, including data types from the BOEM Survey Guidelines;

57 https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/2022-MorroBay-FinalEA.pdf

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
	[BOEM Timeline[58]] NEPA requires a Notice of Intent (NOI) to prepare a COP, BOEM provides a checklist of information needed [NOI checklist[59]] A Programmatic EIS may be developed but is not binding. A joint EIS / EIR with the State is also possible, but not required.	COP. Environmental data needed for the NOI includes: [NOI checklist[60]] As lead agency, BOEM leads consultations and development of the EIS which includes at a minimum [EIS Format & Content Process[60]]	Including environmental impact analysis, such as identification of IPFs and analysis of their impacts to biological and physical resources, mitigation measures, and other assessments of impacts. [CA Draft PEIS[61]] [BOEM EIS Process[62]]

[58] https://www.boem.gov/renewable-energy/construction-operations
[59] https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM%20NOI%20Checklist.pdf
[60] https://www.boem.gov/environment/environmental-assessment/environmental-impact-statement-eis-format-and-content-process
[61] https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/2024_1021_CA_PEIS_Vol_I_508c_0.pdf
[62] https://www.boem.gov/environment/environmental-assessment/eis-format-and-content-process

California Environmental Quality Act (CEQA) lead. Pub. Res. Code § 21000 et seq. (14 California Code of Regulations (CCR) §§ 15250-53.).

Lead Agency: California State Lands Commission (CSLC)
Consulting Agency: Responsible Agencies (state and local agencies with discretionary approval for the project); Trustee Agencies (includes CDFW; defined in 14 CCR § 15386(a)–(d)).
Consultation with Trustee Agencies and Responsible Agencies is required at specified stages of the CEQA process, including scoping and drafting of CEQA documents. (See, e.g., Pub. Res. Code §§ §21080.3, 21080.4 (a), 21104, 21104.2, 21153; 14 CCR §§ 15082, 15086, 15375.) Additionally, Responsible Agencies are legally required to review CEQA documents and reach their own independent determinations for their respective Project approvals.

CEQA is California's primary law requiring state and local agencies to evaluate and disclose the environmental impacts of projects that require discretionary government approval. For California offshore wind development, CEQA applies to project components in State waters. However, and depending upon the specifics of the project, the analysis may need to extend to components of the project, and/or impacts generated, in federal waters (14 CCR §§ 15277, 15378). CEQA ensures a California agency considers the effect a project will have on the environment as well as any feasible alternatives prior to deciding whether to approve the project.

Table A3. *California Environmental Quality Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	State Lands Commission will serve as the CEQA lead.	Developers must submit a [lease application[63]] for the proposed use of state lands, including a project description required from the developer to initiate review under CEQA.	CEQA Guidelines Appendix G contains environmental resource areas that the CEQA lead agency should consider when assessing impacts. Examples include: aesthetics, air quality, biological resources, cultural resources, geology/soils, greenhouse gas emissions, and tribal cultural resources. However, this list is not exhaustive of potential studies that could be required (i.e. coastal processes).
Decommissioning	Not a permit; State Lands Commission will likely serve as the CEQA lead for decommissioning activities.	Developers must submit a [lease application[64]] for the proposed use of state lands, including a project description required from the developer to initiate review under CEQA.	CEQA Guidelines Appendix G contains environmental resource areas that the CEQA lead agency should consider when assessing impacts. Examples include: aesthetics, air quality, biological resources, cultural resources, geology/soils, greenhouse gas emissions, and tribal cultural resources. However, this list is not exhaustive of potential studies that could be required (i.e. coastal processes).

[63] https://slcprdwordpressstorage.blob.core.windows.net/wordpressdata/2019/10/SLC-702.pdf

Federal Consistency Review for Consistency under Coastal Zone Management Act (CZMA)

Section §307, 15 CFR 930.39; Coastal Act of 1976

Lead Agency: California Coastal Commission (CCC)
Consulting Agency: Not required but consulting with state and federal partners is expected

CZMA gives state coastal management agencies federal consistency review authority, pursuant to NOAA's CZMA federal consistency regulations at 15 CFR Part 930 over proposed federal activities and federally licensed, permitted or financially assisted activities, wherever they may occur (i.e., landward or seaward of the respective coastal zone boundaries fixed under state law) if the activity affects coastal uses or resources.

Table A4. *Federal Consistency Review by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Leasing	Not a permit but **Consistency Concurrence** for Federal Agency Activities.	BOEM submits a Consistency Determination (CD) to CCC demonstrating BOEM's proposed federal action is consistent with California's enforceable policies under its approved Coastal Zone Management Plan, including a detailed activity description and analysis of coastal effects. [15 CFR 930.39[64]]	Proposed lease area, lease exploration, impact analysis, lease development activities, future lease development impacts, biological assessment. [Humboldt CD[65]]

[64] https://www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-B/part-930/subpart-C/section-930.39
[65] https://documents.coastal.ca.gov/assets/upcoming-projects/offshore-wind/Th8a-4-2022%20adopted%20findings.pdf

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	Regulatory Approval; **Federal Consistency Concurrence for COP approval**.	Developers submit Consistency Certification (CC) demonstrating project consistency with California Coastal Zone Management Plan (CCMP) enforceable policies, including impact analysis, federal permit materials, project description, supporting technical information, and findings on coastal effects. [15 CFR 930.57-58[66]]	Data and information necessary to assess the consistency of federal license or permit activities (15 CFR 930.58). Project description and coastal effects data addressing public access, recreation, marine and terrestrial resources, development and industrial uses, and sea level rise, sufficient to evaluate consistency with enforceable of the CCMP [15 CFR 930.58[67]] [Coastal Act Chapter 3[68]]
Decommissioning	Regulatory Approval; **Federal Consistency Certification (CC) for** decommissioning	Developers submit CC demonstrating decommissioning's consistency with California Coastal Management Program (CCMP) policies, including impact analysis, federal permit materials, project description, supporting technical information, and findings on coastal effects.	Data and information necessary to assess the consistency of federal license or permit activities (15 CFR 930.58). Project description and coastal effects data addressing public access, recreation, marine and terrestrial resources, development and industrial uses, and sea level rise, sufficient to evaluate consistency with enforceable of the CCMP

[66] https://www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-B/part-930
[67] https://www.law.cornell.edu/cfr/text/15/930.58
[68] https://www.coastal.ca.gov/fedcd/cach3.pdf

Coastal Development Permits (CDPs) under California Coastal Act, Public Resources Code §30000.

Lead Agency: CCC
Consulting Agency: None Required
Under the Coastal Act, the CCC regulates the use of land and water in the coastal zone. Development activities, which are broadly defined by the Coastal Act, generally require a coastal development permit (CDP). CDP regulates development within the state's coastal zone, extending 3 nm from shore to the Coastal Zone boundary. CDP applications need to provide a comprehensive assessment of the project's potential impacts on coastal resources. This assessment often includes the environmental documentation prepared under CEQA.

Table A5. *Coastal Development Permit by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Triggered by action not by phase.	Key Permit; **Coastal Development Permit,** issued by CCC in coordination with local authorities under [SB 286[69]]	**Coastal Development Permit** application including technical analyses, coastal resource impact studies, environmental review documents (CEQA/NEPA), and project plans and maps.	Technical analysis or coastal resources studies. [CDP Instructions, CA Coastal Act[70]]

[69] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB286
[70] https://coastal.ca.gov/cdp/cdp-forms.html

State Tidelands Leases, Pub. Res. Code, § 6301 et seq. Cal. Code Regs. Tit.2, § 2000 et seq.

Lead Agency: CSLC
Consulting Agency: None required

Within state waters, any renewable energy project must obtain a lease for the use of state sovereign lands. Applies to ungranted tidelands, submerged lands, beds of navigable lakes and waterways from mean high tide to approximately 3 geographic miles. Includes structures both floating on the water (e.g., wind turbines) and affixed to the ocean floor (e.g., anchoring systems). Does not apply on legislatively granted lands (e.g. ports and other areas). Considerations for lease issuance include conformance with the Public Trust Doctrine, whether the project is in the best interest of the State, and conformance with the CSLC Tribal Consultation and Environmental Justice Policies.

Table A6. *State Tidelands Lease by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Leasing of State Tidelands, not lease of Federal WEA's	State Tidelands Lease	CSLC evaluates the potential for environmental impacts from the proposed activity or use, consistent with the [California Environmental Quality Act[71]]. CSLC also examines potential impacts from [climate change and sea level rise[72]] on the proposed use. [Application for Use of State Lands, Supplemental M-1[73]]	

[71] https://www.slc.ca.gov/ceqa/
[72] https://www.slc.ca.gov/sea-level-rise/
[73] https://slcprdwordpressstorage.blob.core.windows.net/wordpressdata/2019/10/SLC-702.pdf

Geophysical Survey Permit program. Pub. Res. Code § 6212.3 & 6826. Cal. Code Regs. Tit.2, § 2100.02 et seq.

Lead Agency: CSLC
Consulting Agency: None Required
State marine waters including those on legislatively granted lands and inland waters within the jurisdiction of the Commission.

Table A7. *Geophysical Survey Permit by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Triggered by action not by phase.	Permit; **Geophysical Survey Permit**	**Geophysical Survey Permit** Requires: Marine Wildlife Contingency Plan (MWCP); Vessel Transit Plans near marine mammals; Oil Spill Contingency Plan; Verification of Equipment Service and/or Maintenance and Sound Output. [Application for Use of State Lands, Supplemental M-1[74]]	MWCP including acoustic safety zones, noise reduction measures, marine wildlife monitor protocols, vessel operation constraints near protected species, identification of sensitive sites, and impact observation and reporting procedures. [MWCP Guidance[74]]

[74] https://www.slc.ca.gov/leases-permits/geological/#required

Endangered Species Act (ESA) § 7 Endangered Species Act (ESA) Consultation

Leads: USFWS and NMFS (also known as NOAA Fisheries).
Consulting: BOEM consults on listed species
Enacted in 1973, the Endangered Species Act (ESA) is the primary U.S. law protecting threatened and endangered plants, animals, and their habitats from extinction. It mandates listing imperiled species, designates critical habitats, prohibits unauthorized "taking" (The term "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct; may include significant habitat modification or degradation if it kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering.) of species, and guides federal agencies to avoid jeopardizing listed species' existence or having adverse impacts on critical habitat. Take Permit (issued to agency permitting action that would result in take) if consultation finds a project would result in take.

Table A8. *Endangered Species Act Consultation by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Leasing	Consultation, not a permit. No permit required unless surveys are likely to result in the "take" of ESA-listed species beyond authorized levels, in which case an **Incidental Take Permit** required**.** The consulting agency (NMFS or USFWS) advises the action agency (BOEM) on potential effects to listed species and their critical habitats by providing regulatory, policy, and biological info as needed, and helps determine measures to reduce or avoid effects on ESA species or habitat.	BOEM may prepare a BA to both USFWS and NMFS for review. Including project description, biological assessment, environmental baseline data, mitigation and monitoring plans, listed threatened and endangered species that occur in the area, analysis of the potential effects of the proposed action on listed species and their critical habitat information, cumulative effects analysis, and relevant environmental and biological analyses based on the best available scientific and commercial data. [Endangered Species Consultation Handbook[75]]	Requires sufficient information to determine that actions they authorize are not likely to jeopardize the continued existence of any threatened or endangered species or result in the destruction or adverse modification of habitat of such species. [NOAA slides[76]] To include: data underlying BA, and environmental review data to determine if a proposed action is likely to adversely affect species status or designated critical habitat adversely. [USFWS ESA section 7 Consultation[77]] [Endangered Species Consultation Handbook[76]]

[75] https://www.fws.gov/sites/default/files/documents/endangered-species-consultation-handbook.pdf
[76] https://www.boem.gov/sites/default/files/renewable-energy-program/Day-1-Morning_Crocker_ESA.pdf
[77] https://www.fws.gov/service/esa-section-7-consultation

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	No permit required unless surveys are likely to result in the "take" of ESA-listed species beyond authorized levels, in which case an **Incidental Take Permit** required**.** The consulting agency (NMFS and USFWS) advises the action agency (BOEM) on potential effects to listed species and their critical habitats by providing regulatory, policy, and biological info as needed, and helps determine measures to reduce or avoid effects on ESA species or habitat.	BOEM will prepare a BA to both USFWS and NMFS for review. Including project description, biological assessment, environmental baseline data, mitigation and monitoring plans, listed threatened and endangered species that occur in the area, analysis of the potential effects of the proposed action on listed species and their critical habitat information, cumulative effects analysis, and relevant environmental and biological analyses based on the best available scientific and commercial data. [Endangered Species Consultation Handbook[76]]	Requires sufficient information to determine that actions they authorize are not likely to jeopardize the continued existence of any threatened or endangered species or result in the destruction or adverse modification of habitat of such species. [NOAA slides[77]] To include: data underlying BA, and environmental review data to determine if a proposed action is likely to adversely affect species status or designated critical habitat adversely. [USFWS ESA section 7 Consultation[78]] [Endangered Species Consultation Handbook[76]]
Decommissioning	ESA Consultation required.		

California Endangered Species Act (CESA) California, Fish and Game Code § 2080 & 2081 and Scientific Collecting Permit (SCP), Fish and Game Code § 1002 &1003

Lead Agency: CDFW
Consulting Agency: None Required

CESA conserves and protects state-listed native plant and animal species by prohibiting unauthorized take and requiring projects to fully mitigate impacts. SCPs are permits issued by CDFW to authorize take of native wildlife for research or educational purposes. CESA MOUs are permits issued by CDFW to authorize take of state-listed species for research, educational, or management purposes.

Table A9. *California Endangered Species Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Triggered by action not by phase.	Permit; **Scientific Collecting Permit (SCP).** Any development stage where developers may conduct research, surveys, and monitoring to assess environmental impacts that involves scientific collection of biological samples or may involve the incidental take of wildlife.	**Scientific Collecting Permit** application describing proposed work and methods, target and potential species with permitted methods, measures to minimize wildlife impacts, relevant environmental documentation, and applicant qualifications and authorizations. [SCP General Use Application[78]]	[CDFW Scientific Collecting Permit[79]]

[78] https://wildlife.ca.gov/Licensing/Scientific-Collecting

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Triggered by action not by phase.	Permit; **CESA Memorandum of Understanding (MOU)** [FGC § 2081(a)[79]]: Any development stage where developers may conduct research, surveys, and/or monitoring that may involve the incidental take of state endangered, threatened, or candidate species.	SCP application materials are generally referenced for issuing CESA MOUs.	
Triggered by action not by phase.	**Consistency Determination** (sec. 2080.1) Consistency Determinations may only be issued for species that are listed under both the federal Endangered Species Act and CESA.	Submittal of the federal ESA incidental take statement or permit, with a written request for CDFW to determine consistency with CESA. [CDFW CD[80]]	Analysis of take and effects for each covered species; take minimization and mitigation measures; jeopardy analysis evaluating population viability and cumulative effects. [CDFW ITP[81]]
Triggered by action not by phase.	Permit; **Incidental Take Permit** FGC § 2081(b)	**Incidental Take Permit** application identifying covered species and CESA status, project description, analysis of expected take and impacts, jeopardy analysis, proposed minimization and mitigation measures, monitoring plan, description of funding sources to implement minimization and mitigation	Analysis of take and effects for each covered species; take minimization and mitigation measures; jeopardy analysis evaluating population viability and cumulative effects. [CDFW ITP[82]]

[79] https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=FGC&sectionNum=2081.
[80] https://wildlife.ca.gov/Conservation/CESA/Permitting/Consistency-Determinations#499951519-how-do-i-apply-for-a-consistency-determination
[81] https://wildlife.ca.gov/Conservation/CESA/Permitting/Incidental-Take-Permits

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
		measures, and CEQA compliance documentation. [CDFW ITP[82]]	

Marine Mammal Protection Act (MMPA). 16 U.S. Code 1361-1407.

Lead: NMFS, USFWS (sea otters)

Authorizations: by NMFS and USFWS requested by developers

MMPA prohibits "taking" marine mammals, which includes harming, harassing, or killing them. Requires determination of negligible impact on and small numbers of affected species, and mitigatable effects on subsistence uses. Often requires mitigation / monitoring requirements to minimize harm.

Table A10. *Marine Mammal Protection Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Triggered by action not by phase.	MMPA **Incidental Take Authorization** (ITA) is issued directly to developers by NMFS, required only if project activities are expected to result in take of marine mammals.	**MMPA ITA Application** describing proposed activities and geographic regions, affected marine mammal species and stock status, describing take types and estimates, species status and seasonal distribution, and stock-level impacts. [MMPA ITA[82]] NMFS evaluates based on: 1) The developer's authorization application. 2) Monitoring reports for previous, similar activities. 3) NEPA documents. 4) ESA consultation (when required). 5) Additional literature or scientific input.	Examples include: Baseline species data, acoustic environment data, PSO surveys, PAM, Acoustic Sound Field Verification Surveys, environmental conditions data, bubble curtain performance etc. [NOAA MMPA authorization website16 U.S.C. §§ 1361 et seq[83]] [MMPA ITA[83]]

[82] https://www.fisheries.noaa.gov/national/marine-mammal-protection/apply-incidental-take-authorization

[83] https://www.ecfr.gov/current/title-50/chapter-II/subchapter-C/part-216

Magnuson-Stevens Fishery Conservation and Management Act (MSA) - Essential Fish Habitat (EFH)

Lead Agency: NMFS
Consulting Agency: Consultation by BOEM (lead) with NMFS to conserve EFH

A consultation with NOAA Fisheries is required whenever a federal agency, including the military, works in an area that will adversely affect essential fish habitat. Together, the agency and NOAA determine how best to conduct coastal development while supporting fish habitat and minimizing or avoiding environmental damage. Active within the US Exclusive Economic Zone. NMFS EFH conservation recommendations are not binding.

Table A11. *Magnuson-Stevens Fishery Conservation and Management Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	Consultation, not a permit; for fulfillment of consultation requirements of section 305(b)(3) and 305(b)(4) of the MSA.	Interagency consultation process; developers do not provide direct documentation to NMFS. Other federal agencies might ask for information on EFH that may be used in the consultation process. [pg. 7, OSW BA for Central and Northern CA[84]]	EFH and Habitat Areas of Particular Concern overlapping proposed activities. List of fish species occurrence within or near the area and that are managed or monitored by Pacific Fishery Management Council, description of IPFs, discussion of cumulative effects from non-OSW sources, conservation recommendations and mitigation. [pg. 90, OSW BA for Central and Northern CA[85]]

[84] https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Final%20CA%20Ren%20lease%20issuance%20BA_EFH_07222022_Clean_508%20compliant%20Final.pdf

Fish and Wildlife Coordination Act (FWCA)

Lead Agency: USFWS
Consulting Agency: NMFS and state wildlife agency recommendations are incorporated into BOEM and other permitting decisions.

The act requires that all federal agencies consult with NOAA Fisheries, U.S. Fish and Wildlife Service, and state wildlife agencies when proposed actions might result in modification of a natural stream or body of water.

Table A12. *Fish and Wildlife Coordination Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	Consultation process, not a direct permit authority	Requires that BOEM consults with USFWS, NMFS on potential impacts of proposed projects on fish and wildlife resources. USFWS will make reports and recommendations, to assess impacts to identify avoidance, minimization, and conservation measures. [16 USC 662 Section 2(b)[85]]	Given the FWCA consultation process is often integrated with NEPA, the environmental surveys conducted by developers for their SAP, COP, or GAP under NEPA may be used for FWCA consultation. [USFWS Fish and Wildlife Coordination Act webpage[86]] [16 USC 661-666[87]]

[85] https://www.govinfo.gov/content/pkg/COMPS-3003/pdf/COMPS-3003.pdf
[86] https://www.fws.gov/law/fish-and-wildlife-coordination-act#:~:text=The%20Fish%20and%20Wildlife%20Coordination,or%20other%20body%20of%20water
[87] https://www.govinfo.gov/content/pkg/COMPS-3003/pdf/COMPS-3003.pdf

Bald and Golden Eagle Protect Act

Lead: USFWS
Permit: Internal USFWS consultation when ESA species involved, informal consultation with BOEM.

Prohibits the take, possession, sale, purchase, barter, or transport of bald and golden eagles, including their parts (feathers), nests, or eggs, without a permit. It protects both species from harm, including disturbance, with severe criminal and civil penalties. If a project could cause incidental eagle take, the developer may need an Eagle Incidental Take Permit (EITP) from the USFWS.

Table A13. *Bald and Golden Eagle Protection Act by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
COP Review	**Eagle Take Permit** authorizing incidental or disturbance take of eagles, where applicable to project activities.	Developers must submit Application Form 3-200-71, which has information on the project scope and location, a description of eagle activity in the area, historical data, and avoidance and mitigation measures. An Eagle Conservation Plan may be included for longer-term or higher risk projects. [3-200-71: Eagle Incidental Take General Permit[88]] USFWS recommended 2 years of developer monitoring for ESA species.	Multi-year pre-construction baseline monitoring to characterize seasonal eagle habitat use, including migratory pathways, breeding activity, and communal roosting or wintering areas. Leverage established USFWS protocols and regional monitoring initiatives to ensure data comparability and statistical rigor. [USFWS Bald and Golden Eagle Protection Act webpage[89]] [50 CFR 22[90]] [USFWS Eagle Take Permit Website[91]] [3-200-71: Eagle Incidental Take General Permit[89]]

[88] https://www.fws.gov/service/3-200-71-eagle-incidental-take-general-permit
[89] https://www.fws.gov/law/bald-and-golden-eagle-protection-act#:~:text=The%20Act%20provides%20criminal%20penalties,nest%2C%20or%20egg%20thereof.%22
[90] https://www.ecfr.gov/current/title-50/chapter-I/subchapter-B/part-22
[91] https://www.fws.gov/program/eagle-management/eagle-incidental-disturbance-and-nest-take-permits#:~:text=There%20are%20regulations%20that,criteria%20and%20conditions%20are%20met.

30 CFR 285

Lead: Bureau of Safety and Environmental Enforcement (BSEE)
Consulting: None Required
Safety and environmental oversight, compliance, and enforcement of regulations for the Offshore Renewable Energy Program in OCS Federal Waters.

Table A14. *Safety and environmental oversight by Project Phase*

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Construction	Regulatory Approval; Lessee must submit to BSEE a **Facility Design Report (FDR)** and **Fabrication and Installation Report (FIR)** prior to construction. [30 CFR 235 § 285.700[92]]	FDR must document proposed facility location, engineering design, environmental and geotechnical data, and safety systems. [30 CFR § 285.701[93]] FIR must describe how facilities will be fabricated, installation, quality assurance, permitting, and commissioning procedures. [30 CRF § 285.702[94]]	Environmental data used for design (extreme weather, metocean conditions, seafloor and water depth). Engineering design data (structural and foundation parameters, materials, fatigue and stability). Project specific studies used in facility design or installation (oceanographic and soil reports). Geotechnical reports and supporting data (site investigations, soil properties, and design parameters) supporting facility design and installation. [Code of Federal Regulations (CFR) 30, Part 285[95]]

[92] https://www.ecfr.gov/current/title-30/chapter-II/subchapter-B/part-285

[93] https://www.law.cornell.edu/cfr/text/30/285.701

[94] https://www.ecfr.gov/current/title-30/chapter-II/subchapter-B/part-285/subpart-G/subject-group-ECFR403549b6e9ffa23/section-285.702

[95] https://www.ecfr.gov/current/title-30/chapter-II/subchapter-B/part-285

Phase	Key Permit or Regulatory Approval	Developer or Lead Agency Required Documentation	Supporting Data Types
Operations	Enforcing operational safety and environmental protection through data analysis, safety management system oversight and audits, inspections, and incident reporting. Enforcing compliance with laws, regulations, and lease and permit terms and conditions.	Reviews of industry plans to ensure they promote safe operations, includes robust safety management systems, and will comply with applicable regulations, lease stipulations, and other terms and conditions of BOEM's plan approval.	[Code of Federal Regulations (CFR) 30, Part 285[96]]
Decommissioning	Regulatory Approval; BSEE review and approval of a decommissioning application, followed by BSEE oversight of decommissioning activities. [BSEE OSW development diagram[97]]	**Decommissioning application** describing schedule, removal methods, transportation/disposal plans, and potential impacts If approved, must submit pre-decommissioning notice with recent biological survey results and mitigation measures; and post-removal compliance report within 60 days of removing the facility. [30 CRF 285.903[98]]	

96 https://www.ecfr.gov/current/title-30/chapter-II/subchapter-B/part-285
97 https://www.bsee.gov/about-bsee/renewable-energy
98 https://www.ecfr.gov/current/title-30/chapter-II/subchapter-B/part-285

Appendix B. Methodologies

Informing a Precautionary and Adaptive Path Forward

Relying on expert opinion is a cornerstone of precautionary and adaptive management (Kriebel et al. 2001). California's approach is rooted in neutrality, transparency, collaboration, and science-based decision making (De Santo, 2010). Expert opinion does not replace data collection, but guides it efficiently, ensuring that limited resources are directed toward assessing the most pressing potential offshore environmental impacts. As real-world data are gathered from initial development phases, this Framework can be iteratively refined, creating a dynamic and responsive monitoring system that evolves with growing understanding of this new industry's effects.

Institutions and Roles

Institutions involved in creating the Framework include:

The California Marine Sanctuary Foundation (CMSF) – CMSF is a California-based non-governmental organization (NGO) with 30 years of experience integrating best available science into conservation policy. As project leader, CMSF organized and collaborated with the scientific WGs and Coordination Team[99] to develop the Framework. Selected functions were:

- Organizing workshops.
- Conducting initial research on data and science gaps.
- Organizing communications and facilitation amongst the Coordination Team, project funder, and WGs.
- Supporting WGs with data, facilitation coordination, synthesis, and preparation of materials and other resources as needed.
- Authoring the Framework

Ocean Protection Council (OPC) – Ocean Protection Council is a state body that works jointly with state and federal agencies, NGOs, tribes, and the public to ensure California maintains healthy, resilient, and productive ocean and coastal ecosystems. Ocean Protection Council funded CMSF to develop the Framework, and have mutually supported achieving milestones and goals toward completion of the Framework, while serving on the coordination team.

California Department of Fish and Wildlife (CDFW) – CDFW is California's trustee agency for fish and wildlife resources, and has jurisdiction over conservation, protection,

[99] The Coordination Team was composed of three institutions: CMSF, Cal Poly, OPC, and CDFW.

and management of California’s diverse fish, wildlife, native plant species, and habitats necessary for biologically sustainable populations of those species. CDFW staff provided scientific consultation and expert input.

California Polytechnic State University, San Luis Obispo (Cal Poly) – The Center for Coastal Marine Sciences at Cal Poly collaborated with CMSF, providing scientific and coordination support. Cal Poly:

- Conducted initial literature review and compiled/organized references,
- Researched and compiled database and GIS map of monitoring programs,
- Contributed to data synthesis, organization, and elicitation, communications, workshops, facilitation, preparation of materials, writing, review and scientific expertise.

Ocean Science Trust (OST) – Created by state legislation, OST supports and brings world-class science and innovation together with state and federal policymakers to accelerate progress toward a healthy and resilient coast and ocean. OST staff contributed the initial analysis and facilitated agency review of the data and science needs for permitting (Appendix A).

Environmental Monitoring Framework Working Structure

The Framework was a collaborative process between CMSF and the Coordination Team, scientific experts, and contributor groups to execute and synthesize expert opinion results.

Coordination Team

The Coordination Team (consisting of CMSF, Cal Poly, OPC, and CDFW) was responsible for providing the overarching strategic direction and ensuring the Framework’s scope, content, and focus remained aligned with its core purpose. California Marine Sanctuary Foundation, with support from scientific experts and the Coordination Team, developed and led the scientific approach for collecting and synthesizing results (Figure B1).

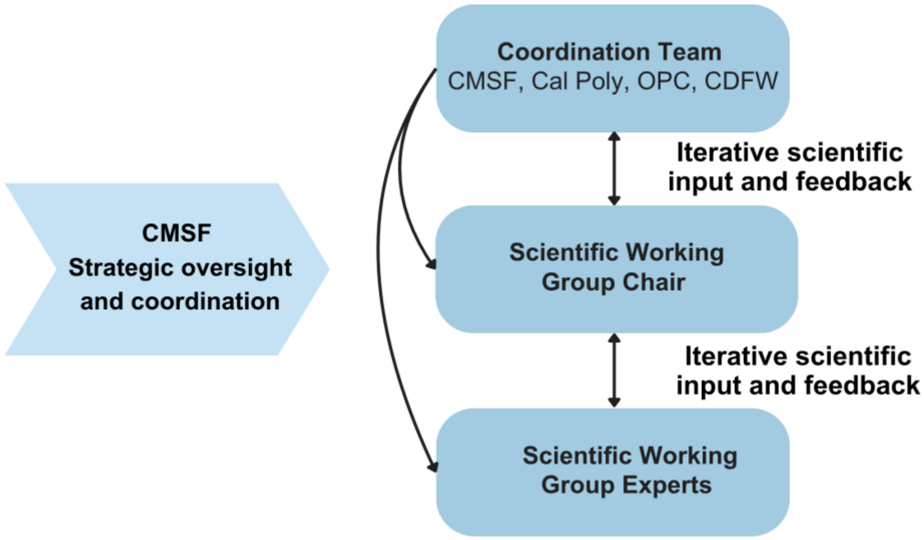

Figure B1. *Organizational structure showing connections between the Coordination Team, each Scientific WG Chair, and WG experts*

Scientific Working Groups

A total of six WGs were led by CMSF in conjunction with the respective scientific chairs to execute the expert input (Figure B2). The WGs were organized by ecological and technical expertise. The ecological WGs included: Marine Mammals and Sea Turtles, Fish and Invertebrates, Marine Birds and Bats, Habitats and Ecosystems, and Oceanography. A Data and Technology Integration WG worked across WGs. Ecological WGs were further divided into subgroups based on ecological and/or functional groups to ensure differences in focal habitats or specific life histories were captured. Working Groups provided expert opinion to evaluate potential OSW impacts, highlight and address key monitoring questions, and review CMSF's scientific synthesis.

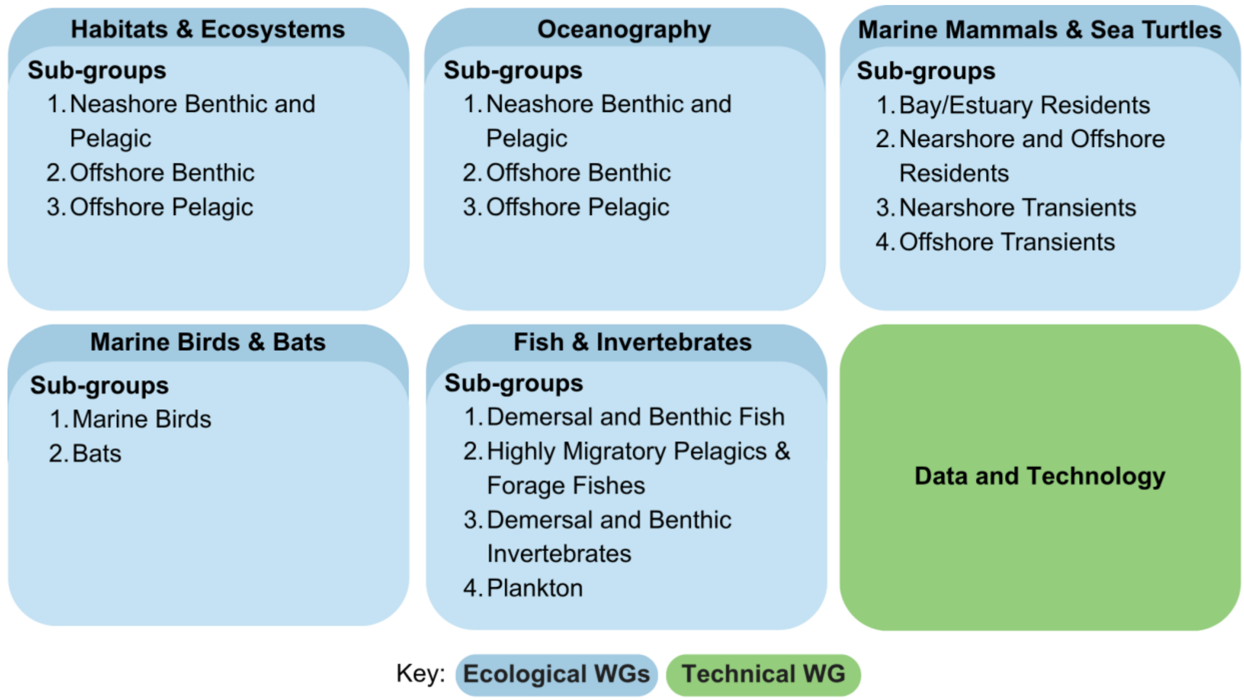

Figure B2. *Breakdown of the six scientific WGs into ecological and technical WGs and their subgroups*

WGs produced the information that guided monitoring recommendations and provided review and feedback on results, thereby contributing to several segments of the final deliverable.

WG experts were identified through CMSF partner and collaborator networks, extensive research on lead scientists in the field, and by referrals. In the first few months, CMSF focused on active outreach and informational meetings, inviting over 450 experts. The starting WG rosters contained over 270 experts. As a consequence of policy shifts at the federal level, WG participation fluctuated over the course of the project. CMSF adapted to changes in participation by filling any expertise gaps that emerged with expert scientists. Working Group members:

- Provided scientific expert insights.
- Fulfilled follow-up tasks or reviews identified during WG meetings
- Kept partners well-informed about current and pertinent advancements within the sector.

Chairs

Scientific WG Chairs were appointed based on their proven ability to lead collaborative workshops and deep scientific expertise in their fields. This dual qualification was essential for effective deliberation. By anchoring discussions in robust evidence, accurately weighing technical trade-offs, and identifying priority knowledge gaps, Chairs steered their groups toward scientifically sound and defensible recommendations. Chairs:

- Aiding Coordination Team in preparing materials to facilitate and summarize discussions
- Facilitating meetings
- Leading execution of tasks and assignments
- Contributing to WG assignments
- Resolving discrepancies between WG expert opinions.

Scientific WG Meetings

All scientific WG meetings were held virtually, with durations ranging from 1 to 3 hours. Each WG had access to a shared folder containing references, resources, and materials. At least six meetings were held for each ecological WG, and five meetings were held with the Data and Technology Integration WG, in addition to numerous one-on-one conversations with the Chairs or WG experts. Each WG meeting was followed by review periods when experts completed assignments started in WG meetings.

Agencies

Resource management agencies were strategically engaged to ensure the Framework aligned with existing legal frameworks and scientific mandates. These agencies included:

- Bureau of Ocean Energy Management
- U.S. Fish and Wildlife Service
- National Marine Fisheries Service (NOAA Fisheries)
- U.S. Coast Guard
- California Department of Fish and Wildlife
- California Coastal Commission
- California State Lands Commission
- California Ocean Protection Council
- California Energy Commission (CEC) (in its resource assessment capacity)

Community Outreach

A leading principle in developing the Framework was the incorporation of broad perspectives from its earliest stages. Input was solicited from a wide net of those with interests in marine ecosystems and OSW development. The engagement strategy was designed to be inclusive, iterative, and transparent, emphasizing the neutral, scientific purpose of the document.

The phased outreach involved:

1. **Early and direct outreach.** Contact was initiated through direct, one-on-one conversations including representatives from federal and state agencies, California Native American tribes, the fishing community, environmental NGOs, and developers. Initial discussions introduced the purpose and scope and explained the Framework's role as a scientific, not advocacy or regulatory, document.
2. **Targeted collaborative sessions.** CMSF hosted a series of dedicated webinars for each stakeholder group in the fall of 2024. These sessions provided a platform to present the goals, scope, monitoring challenges, and information needs unique to each group. The core solicitation was for input on key species, habitats, and concerns for environmental monitoring of OSW impacts.
3. **Sharing of interim materials.** An interim technical memo100 was widely shared in another series of dedicated webinars during the spring of 2025.

While outreach provided helpful insight into scientific concerns of our outreach groups, the final Framework reflects only the guidance of our scientific experts and State agencies. Additional outreach by California State Agencies to solicit tribal and community perspectives, in conjunction with the Framework, will ultimately guide California's OSW monitoring program.

Fishing Community

The Coordination Team recognized the commercial and recreational fishing communities as a valuable local knowledge base, whose dependence on marine resources was key to developing a practical and effective Framework. The multi-stage engagement strategy above was implemented to engage with the community and relay their scientific concerns to the WGs. This approach ensured that concerns of California's fishing communities were reviewed by scientific experts and incorporated, when appropriate, into the Framework.

NGOs

Engagement with NGOs active in OSW policy, conservation, and environmental advocacy was conducted throughout the development of the Framework to solicit issue identification and relevant scientific data. Regular communication was maintained to gather emerging information from the NGO community and provide project updates; however, all final content, revisions, and scientific determinations were managed exclusively to ensure independent oversight.

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[100] Interim Memo - Environmental Monitoring Framework

OSW Developers

To ground the work in real-world application, CMSF actively engaged OSW developers from the outset, forming a group of California leaseholder representatives. This collaboration was instrumental in clarifying industry capabilities, identifying monitoring opportunities and obstacles, and vetting practical methods. Despite changes in the group's membership, regular communication ensured that developer input was integrated, where appropriate scientifically, into the Framework.

Across all outreach groups, input was evaluated and only incorporated into the Framework deliverables if it was within the project's scientific scope.

Literature Review

A literature synthesis and meta-analysis[101] of global research on environmental impacts of OSW development was created at the beginning of the project, serving as a foundation for scientific understanding.

Literature Review Executive Summary

A total of 144 studies were identified through searches of Tethys, BOEM, Google Scholar, and through expert submissions. Studies were categorized by ecological subgroup, impact producing factor, study type, turbine foundation type, and geographic region. Impact producing factors are defined as a specific activity or physical stressor associated with an OSW project that has the potential to cause a change in the environment or an affected resource. Ecological subgroups include marine mammals and sea turtles, marine birds and bats, fish and invertebrates, habitats and ecosystems, and oceanography.

Across all taxa and habitats, infrastructure is the most frequently examined stressor, in addition to other IPFs, such as noise, vessel traffic, EMFs, lighting, and environmental pollutants. Main concerns for each ecological WG are listed below.

- **Marine mammals and Sea Turtles:** Research focuses on behavioral responses to noise, changes in habitat use, vessel strike risk, and potential attraction or displacement around OSW infrastructure.
- **Marine Birds and Bats**: Studies emphasize collision risk, avoidance and displacement behavior, and attraction to lighting or turbine platforms.
- **Fish and Invertebrates:** Findings center on artificial reef effects, changes to benthic and pelagic communities, noise-related impacts, and responses to EMFs.

[101] Winds of Change: Evaluating the Environmental Impacts of Floating Offshore Wind Through Literature Synthesis

- **Habitats and Ecosystems:** Research documents sediment disturbance, changes to benthic communities, potential stepping-stone effects for non-native species, and array-scale alterations (cumulative environmental change caused by an array of OSW turbines rather than the impact of a single turbine) to physical and biological processes.

Of the 144 studies reviewed, 56% focused on fixed bottom foundations, 16% focused on floating platforms, 13% examined both floating and fixed systems, and 15% did not specify foundation type. This limits the direct applicability to California's unique offshore environment. Floating OSW introduces new technologies and stressors at scales not yet studied empirically, especially within upwelling ecosystems like the CCLME (Raghukumar et al., 2023; Rockwood et al., 2024; Watson et al., 2024). As such, the most important outcome of this review is not only identifying known impacts, but highlighting knowledge gaps where data are lacking. Filling these gaps through targeted pre-construction baseline studies, monitoring, and research will be essential for understanding and mitigating ecological implications of OSW development off California's coast.

This synthesis created a defensible, evidence-based starting point for the Framework. It provides Communities, Government, and Developers with a shared understanding of the foundational science around OSW platforms, ensuring that the resulting monitoring framework is relevant to the dynamic, deep water conditions of the CCLME.

Framework Procedure

Expert Elicitation Approach

The Framework utilized scientific expert opinion as its foundational methodology to acquire California-specific insights. This approach is necessary due to the absence of direct, local empirical evidence from existing floating OSW installations (Mangano & Sarà, 2017). The use of a formal, structured, collaborative elicitation process that engaged multiple experts across relevant disciplines strengthened the integrity of results (Hemming et al., 2018; O'Hagan, 2019; Singh et al., 2017). Experts were organized into WGs based on subject-matter expertise. They participated through a structured, iterative elicitation approach with multiple opportunities for providing input, comments, and revisions to collect the best expert opinion and understanding (Donovan et al., 2016; Singh et al., 2017). Experts were provided with structured tools and frameworks, such as decision trees and prioritization criteria, to ensure objective and consistent knowledge extraction and decision-making. In regular, facilitated workshop meetings, experts were encouraged to challenge each other, reconcile discrepancies, and reduce biases to improve defensibility (Hemming et al., 2018; O'Hagan, 2019). This collaborative, taxon and habitat-specific approach was designed to leverage diverse expertise, identify the most relevant impacts, evaluate monitoring methods, and provide prioritized OSW impact monitoring recommendations.

Impact Matrices

Potential OSW environmental impacts were organized into specialized "Impact Matrices" tailored to each scientific WG. These matrices structured analysis by impact-producing factors (IPFs; e.g., noise, vessel traffic) and associated impacts (e.g., changes in abundance, habitat use). The IPFs and impacts differed between WGs, but were consistent for all subgroups in a WG (Table B1).

Table B1. *Impact Producing Factors and Associated Impacts by WG*

Working Group	IPFs	Associated Impacts
Habitats and Ecosystems	Infrastructure[102] Environmental Pollutants Vessel Traffic EMF	Physical Oceanographic Processes Biological Oceanographic Processes Habitat Degradation Habitat Creation
Oceanography	Infrastructure Environmental Pollutants Vessel Traffic EMF	Physical Oceanographic Processes Biological Oceanographic Processes
Marine Mammals and Sea Turtles	Infrastructure Vessel Traffic Noise EMF	Entanglement Injury/Mortality Alteration of habitat Spatial Avoidance
Marine Birds and Bats	Infrastructure Vessel Traffic Noise Lighting	Injury/Mortality Energy Cost Resource Access Resource Quality
Fish and Invertebrates	Infrastructure Vessel Traffic Noise EMF Once-Through Cooling	Abundance/Occurrence Demographic Changes Community Changes Habitat Use & Behavior Changes Larval Dispersal & Recruitment Change Physiology & Condition Change

[102] Throughout this document, the term infrastructure refers to all components of the turbine and platform, mooring and anchoring systems and the electrical transmission network.

Stoplight Assessment

A stoplight assessment is a semi-quantitative risk assessment and decision-support tool used to synthesize expert judgment, characterized by a visual, color-coded framework—green (low impacts), yellow (moderate), and red (high impact) (Foden et al., 2008).

Working Group (WG) members utilized a "stoplight assessment" to evaluate the intensity, probability and directionality (positive or negative) of IPFs and their associated impacts (e.g., noise and spatial avoidance) (Table B2). Impacts were assessed for the different development phases (e.g., construction, operations, maintenance) and considered temporal and spatial scale of impacts, mitigation effectiveness, and confidence in assessment. Following established scoring frameworks (Hargrave, 2002; Schalm et al., 2019), experts assessed impacts separately for the construction and operations phases based on collective expertise, scientific literature, and regional data. During these evaluations, experts identified taxonomic groups of special concern or "outliers," which directly informed species prioritization. This iterative process was conducted at the subgroup level and underwent multiple rounds of review by WG members, Chairs, and the CMSF to ensure a systematic identification of high-priority and unknown impacts.

Table B2. *Impact category definitions and scoring options*

Category	Definition	Options
Intensity	Relative significance of impacts. It describes the magnitude of an impact on the environment. It gauges how substantial the elicited change is.	**Negligible** - The impact is so small or transient that it results in no measurable or observable change **Minimal** - The impact leads to minor changes that do not significantly alter original function or state. Effects may be detectable but for example, remain within natural variation **Moderate** - The impact causes noticeable changes; **Major** - The impact is substantial enough to cause fundamental changes; **Unknown** - There is insufficient evidence or data to determine the magnitude **N/A** - Non-applicable
Probability	The qualitative probability that the impact will affect the population. While a few or all individuals in an area can be affected, there will be no	**Almost certain** – is expected to occur in most circumstances **Likely** – Will probably occur in most circumstances **Possible** – Might occur at some time

Category	Definition	Options
	population level effect. Based on whether the species will definitely occur in the area, OR if the species may pass through the area	**Unlikely** – Could occur at some time **Rare** – May occur only in exceptional circumstances **Unknown** - There is insufficient evidence or data to determine probability of occurrence
Impact Directionality	Refers to whether impact has a beneficial (positive) or harmful (negative) effect.	**Positive** - The impact enhances or improves condition of monitored aspect, **Unknown** - There is insufficient evidence or data to determine directionally **Negative** - The impact degrades condition of monitored aspect **Both** - Can either degrade or enhance condition depending on context **N/A** - Non-applicable or insignificant impact
OSW development Phase	What phase of OSW development does the impact occur?	Construction Operation/Maintenance
Temporal Scale	Relative time scale that describes the persistence of an impact on the biological relevance and generation time. Definitions of options will depend on the biological relevance of time for each impacted factor.	Short-term (days) Medium-term (weeks to 1 year) Long-term (> 1 year)
Spatial Scale	Approximate spatial range from the source of the impact in which effects were documented	Meters (m) Kilometers (km) 100s of kilometers
Mitigation Effectiveness	In case mitigation measures exist, how well do they reduce, offset, or prevent impact.	**High** - Mitigation measures are very likely to significantly reduce, eliminate, or offset negative impacts, to near-negligible levels **Moderate** - Mitigation measures partially reduce the severity of impacts. Residual effects remain but are substantially less than if unmitigated; **Low** - Mitigation measures offer limited or uncertain reduction of impacts. Significant residual effects may persist despite efforts; **Unknown** - Experts are not aware of mitigation measures **N/A** - Mitigation measures are not available

Category	Definition	Options
		(unfeasible or not possible).
Confidence	The level of confidence in the expert assessment	High Medium Low

A binning key was developed to rank each IPF-impact intersection for every stoplight assessment (Figure B3). This binning process considered the intensity and probability stoplight rankings of each IPF and impact, resulting in outputs of high, medium, low, and negligible priorities. Any IPF-impact with unknown intensity or probability was considered a knowledge gap. The WG Chairs determined if knowledge gaps were high or low monitoring priorities based on their expertise. **Only IPFs and associated impacts and knowledge gaps ranked as high priority were presented in the results section and considered in developing monitoring questions and recommendations.** See Appendix C for the results of the priority binning.

Intensity/ Probability	Almost Certain	Likely	Possible	Unlikely	Rare	Unknown
Major	High Priority	High Priority	High Priority	Medium Priority	Medium Priority	Knowledge Gap
Moderate	High Priority	Medium Priority	Low Priority	Low Priority	Low Priority	Knowledge Gap
Minimal	Low Priority	Low Priority	Low Priority	Low Priority	Low Priority	Knowledge Gap
Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Knowledge Gap
Unknown	Knowledge Gap	Knowledge Gap	Knowledge Gap	Knowledge Gap	Knowledge Gap	Knowledge Gap

Figure B3. *Stoplight assessment binning key*

Monitoring Questions

Monitoring questions were written by the WGs based on the high priority impacts and knowledge gaps. The monitoring questions captured additional context relevant to the IPFs and impacts and ensured that the subsequent monitoring recommendations were actionable based on availability of baseline data, accessibility of physical data, and current technology.

Species Prioritization

A list of taxa potentially sensitive to impacts from OSW was compiled based on recommendations from the Scientific Chairs, the CMSF OSW literature review, WG expert stoplight assessments, and existing priority or protected species identified by State and Federal agencies. Chairs evaluated each identified species using a decision tree (Figure B4) and recorded justifications for each answer in a companion table (Appendix D). Species prioritization results were classified as high, medium, or low priority, not a feasible monitoring priority, or likely not exposed to impacts. Although the decision tree nodes are binary, context and species-specific answers were not always yes or no. In these instances, Chairs classified species based on a conservative decision and their best expert opinion and provided context in their rationale. Finalization of species ranking integrated feedback from WG members.

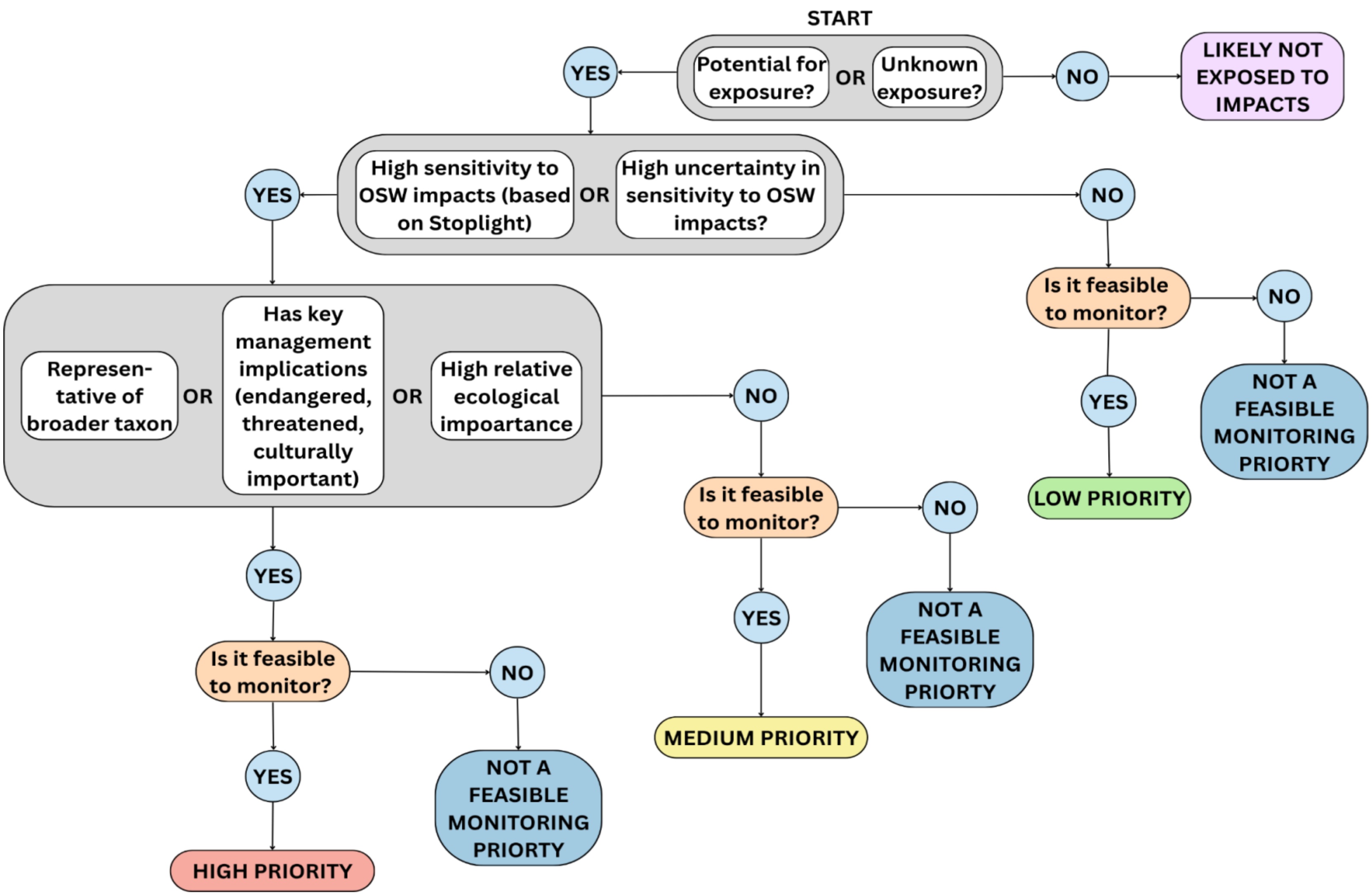

Figure B4. *Species prioritization decision tree framework*

Habitat and Ecosystem Prioritization

Habitat prioritization was essential for aligning monitoring technologies with the Framework's monitoring recommendations. In ecological WGs, priority habitats were assigned based on key life-stage requirements of priority species. In the Habitats and Ecosystems and Oceanography WGs, priority habitats were determined by probability and intensity of impacts by the WG Chairs in collaboration with the other taxonomic WG Chairs. Additional habitats were designated directly by WG Chairs to address specific, site-based monitoring questions, such as assessing impacts near development zones or filling key data gaps.

Monitoring Programs

A review of existing California ocean monitoring programs was developed to assess existing data, methods and technologies that can be leveraged for OSW environmental monitoring (Appendix E).

Appendix C. Results of Priority Binning

Table C1. *Habitat, Ecosystems and Oceanography descending order IPF x Impact by OSW development Phase: Nearshore Benthic and Pelagic*

IPF	Impact	Phase	Priority
Infrastructure	Biological Oceanographic Processes	Construction, Operation	High Priority
Infrastructure	Habitat Degradation	Construction	High Priority
Environmental Pollutants	Habitat Degradation	Construction	High Priority
Vessel Traffic	Habitat Degradation	Construction	High Priority
Infrastructure	Habitat Degradation	Operation	Low Priority
Infrastructure	Physical Oceanographic Processes	Construction, Operation	Low Priority
EMF	Habitat Degradation	Construction, Operation	Low Priority
Environmental Pollutants	Habitat Degradation	Operation	Low Priority
Environmental Pollutants	Biological Oceanographic Processes	Construction, Operation	Low Priority
Vessel Traffic	Habitat Degradation	Operation	Low Priority
Vessel Traffic	Biological Oceanographic Processes	Construction, Operation	Low Priority
Infrastructure	Habitat creation	Construction, Operation	High Priority Knowledge Gap

Table C2. *Habitat, Ecosystems and Oceanography descending order IPF x Impact by OSW development Phase: Offshore Benthic*

IPF	Impact	Phase	Priority
Infrastructure	Habitat Degradation	Construction	High Priority
Infrastructure	Habitat Creation	Operation	High Priority
Infrastructure	Habitat Degradation	Operation	High Priority
Infrastructure	Physical Oceanographic Processes	Construction	High Priority
Infrastructure	Habitat Creation	Construction	Low Priority
Infrastructure	Biological Oceanographic Processes	Operation	Low Priority
Vessel Traffic	Biological Oceanographic Processes	Construction, Operation	Low Priority
Infrastructure	Biological Oceanographic Processes	Operation	High Priority Knowledge Gap

Table C3. *Habitat, Ecosystems and Oceanography descending order IPF x Impact by OSW development Phase: Offshore Pelagic*

IPF	Impact	Phase	Priority
Infrastructure	Biological Oceanographic Processes	Operation	High Priority
Infrastructure	Physical Oceanographic Processes	Operation	High Priority
Infrastructure	Habitat Degradation	Construction, Operation	Low Priority
EMF	Habitat Degradation	Construction, Operation	Low Priority
Environmental Pollutants	Habitat Degradation	Construction, Operation	Low Priority
Vessel Traffic	Habitat Degradation	Construction, Operation	Low Priority
Environmental Pollutants	Biological Oceanographic Processes	Construction, Operation	Low Priority
Infrastructure	Habitat Creation	Construction, Operation	High Priority Knowledge

IPF	Impact	Phase	Priority
			Gap

***Table C4**. Marine Mammals and Sea Turtles descending order IPF x Impact by OSW development Phase: Bay and Estuary*

IPF	Impact	Phase	Priority
Noise	Alteration of Habitat	Construction	High Priority
Physical Structure	Alteration of Habitat	Construction	High Priority
Vessel Traffic	Injury/mortality	Construction, Operation	High Priority
Vessel Traffic	Alteration of Habitat	Construction	High Priority
Vessel Traffic	Spatial Avoidance	Construction	High Priority
Noise	Injury/Mortality	Operation	High Priority
Physical Structure	Entanglement	Construction	High Priority
Physical Structure	Alteration of Habitat	Operation	High Priority
Physical Structure	Spatial Avoidance	Construction	High Priority
Vessel Traffic	Alteration of Habitat	Operation	High Priority
Noise	Injury/Mortality	Construction	Medium Priority
Noise	Alteration of Habitat	Operation	Medium Priority
Noise	Spatial Avoidance	Construction	Medium Priority
Physical Structure	Injury/Mortality	Construction, Operation	Medium Priority
Vessel Traffic	Spatial Avoidance	Operation	Medium Priority
Noise	Entanglement	Construction, Operation	Low Priority
Noise	Spatial Avoidance	Operation	Low Priority
Physical Structure	Entanglement	Operation	Low Priority
Physical Structure	Spatial Avoidance	Operation	Low Priority
Vessel Traffic	Entanglement	Construction, Operation	Low Priority
EMF	Entanglement	Construction, Operation	Low Priority Knowledge Gap
EMF	Injury/Mortality	Construction, Operation	Low Priority

IPF	Impact	Phase	Priority
			Knowledge Gap
EMF	Alteration of Habitat	Construction, Operation	Low Priority Knowledge Gap
EMF	Spatial Avoidance	Construction, Operation	Low Priority Knowledge Gap

Table C5*. Marine Mammals and Sea Turtles descending order IPF x Impact by OSW development Phase: Bay and Estuary: Resident Species (Nearshore and Offshore)*

IPF	Impact	Phase	Priority
Noise	Injury/mortality	Construction	High Priority
Physical Structure	Entanglement	Construction, Operation	High Priority
Noise	Entanglement	Construction, Operation	Medium Priority
Noise	Injury/mortality	Operation	Medium Priority
Noise	Alteration of Habitat	Construction, Operation	Medium Priority
Noise	Spatial Avoidance	Construction	Medium Priority
Physical Structure	Injury/mortality	Construction, Operation	Medium Priority
Physical Structure	Alteration of Habitat	Construction, Operation	Medium Priority
Vessel Traffic	Injury/mortality	Construction, Operation	Medium Priority
Noise	Spatial Avoidance	Operation	Low Priority
Physical Structure	Spatial Avoidance	Construction, Operation	Low Priority
Vessel Traffic	Entanglement	Construction, Operation	Low Priority
Vessel Traffic	Alteration of Habitat	Construction, Operation	Low Priority
Vessel Traffic	Spatial Avoidance	Construction	Low Priority
Vessel Traffic	Spatial Avoidance	Operation	Low Priority
EMF	Entanglement	Construction, Operation	Low Priority Knowledge Gap
EMF	Injury/mortality	Construction, Operation	Low Priority Knowledge Gap

IPF	Impact	Phase	Priority
EMF	alteration of Habitat	Construction, Operation	Low Priority Knowledge Gap
EMF	Spatial Avoidance	Construction, Operation	Low Priority Knowledge Gap

***Table C6**. Marine Mammals and Sea Turtles descending order IPF x Impact by OSW development Phase: Bay and Estuary: Nearshore Transient*

IPF	Impact	Phase	Priority
Physical Structure	Entanglement	Construction, Operation	High Priority
Vessel Traffic	Injury/mortality	Construction, Operation	High Priority
Physical Structure	Injury/mortality	Construction, Operation	Medium Priority
Vessel Traffic	Entanglement	Construction, Operation	Medium Priority
Noise	Entanglement	Construction, Operation	Low Priority
Noise	Injury/mortality	Construction, Operation	Low Priority
Noise	Alteration of habitat	Construction, Operation	Low Priority
Noise	Spatial avoidance	Construction, Operation	Low Priority
Physical Structure	Alteration of habitat	Construction, Operation	Low Priority
Physical Structure	Spatial avoidance	Construction	Low Priority
Vessel Traffic	Alteration of habitat	Construction, Operation	Low Priority
Vessel Traffic	Spatial avoidance	Construction, Operation	Low Priority
EMF	Alteration of habitat	Construction, Operation	High Priority Knowledge Gap
EMF	Spatial avoidance	Construction, Operation	High Priority Knowledge Gap
EMF	entanglement	Construction, Operation	Low Priority Knowledge Gap
EMF	Injury/mortality	Construction, Operation	Low Priority Knowledge Gap

***Table C7**. Marine Mammals and Sea Turtles descending order IPF x Impact by OSW development Phase: Offshore transient*

IPF	Impact	Phase	Priority
Physical	Injury/mortality	Construction, Operation	High Priority

IPF	Impact	Phase	Priority
Structure			
Vessel Traffic	Injury/mortality	Construction, Operation	High Priority
Noise	Injury/mortality	Construction, Operation	Medium Priority
Noise	Alteration of habitat	Construction	Medium Priority
Noise	Spatial Avoidance	Construction	Medium Priority
Noise	Spatial Avoidance	Operation	Low Priority
Noise	Alteration of habitat	Operation	Low Priority
Physical Structure	Alteration of habitat	Construction, Operation	Low Priority
Physical Structure	Spatial Avoidance	Construction, Operation	Low Priority
Vessel Traffic	Alteration of habitat	Construction, Operation	Low Priority
Vessel Traffic	Spatial Avoidance	Construction, Operation	Low Priority
Noise	Entanglement	Construction, Operation	High Priority Knowledge Gap
EMF	Alteration of habitat	Construction, Operation	High Priority Knowledge Gap
EMF	Spatial Avoidance	Construction, Operation	High Priority Knowledge Gap
Physical Structure	Entanglement	Construction, Operation	High Priority Knowledge Gap
EMF	Entanglement	Construction, Operation	Low Priority Knowledge Gap
EMF	Injury/mortality	Construction, Operation	Low Priority Knowledge Gap
Vessel Traffic	Entanglement	Construction, Operation	Low Priority Knowledge Gap

Table C8. *Marine Birds and Bats descending order IPF x Impact by OSW development Phase: Marine Birds*

IPF	Impact	Phase	Priority
Physical Structure	Injury/mortality	Operation	High Priority
Physical Structure	Injury/mortality	Construction	Low Priority
Vessel Traffic	Injury/mortality	Construction, Operation	Low Priority

IPF	Impact	Phase	Priority
Vessel Traffic	Energy Cost	Construction, Operation	Low Priority
Vessel Traffic	Resource Access	Construction, Operation	Low Priority
Lighting	Injury/mortality	Construction, Operation	Low Priority
Lighting	Energy Cost	Construction, Operation	Low Priority
Physical Structure	Energy Cost	Operation	High Priority Knowledge Gap
Physical Structure	Resource Access	Operation	High Priority Knowledge Gap
Physical Structure	Energy Cost	Construction	Low Priority Knowledge Gap
Physical Structure	Resource Access	Construction	Low Priority Knowledge Gap
Physical Structure	Resource Quality	Construction, Operation	Low Priority Knowledge Gap
Noise	Energy Cost	Construction, Operation	Low Priority Knowledge Gap
Noise	Resource Access	Construction	Low Priority Knowledge Gap

Table C9. *Marine Birds and Bats descending order IPF x Impact by OSW development Phase: Bats*

IPF	Impact	Phase	Priority
Physical Structure	Resource Access	Operation	Low Priority
Physical Structure	Resource Quality	Construction, Operation	Low Priority
Noise	Energy Cost	Construction, Operation	Low Priority
Noise	Resource Access	Construction, Operation	Low Priority
Noise	Resource Quality	Construction, Operation	Low Priority
Lighting	Energy Cost	Construction	Low Priority
Lighting	Resource Access	Construction, Operation	Low Priority
Lighting	Resource Quality	Construction, Operation	Low Priority
Physical Structure	Injury/Mortality	Operation	High Priority Knowledge Gap
Physical Structure	Energy Cost	Operation	High Priority Knowledge Gap

IPF	Impact	Phase	Priority
Physical Structure	Resource Access	Operation	High Priority Knowledge Gap
Noise	Energy Cost	Operation	High Priority Knowledge Gap
Lighting	Energy Cost	Operation	High Priority Knowledge Gap
Physical Structure	Resource Quality	Construction, Operation	Low Priority Knowledge Gap
Vessel Traffic	Energy Cost	Construction, Operation	Low Priority Knowledge Gap
Noise	Energy Cost	Construction	Low Priority Knowledge Gap

***Table C10**. Fish and Invertebrates descending order IPF x Impact by OSW development Phase: Demersal and Benthic Fishes*

IPF	Impact	Phase	Priority
Infrastructure	Abundance/Occurrence	Construction, Operation	High Priority
Infrastructure	Demographic Changes	Construction, Operation	High Priority
Infrastructure	Community Changes	Construction, Operation	High Priority
Infrastructure	Habitat Use and Behavior Changes	Construction, Operation	High Priority
Infrastructure	Larval Dispersal and recruitment Change	Construction, Operation	High Priority
Infrastructure	Physiology & Condition Change	Construction	High Priority
Infrastructure	Physiology & Condition Change	Operation	Medium Priority
Noise	Abundance/ Occurrence	Construction, Operation	Low Priority
Noise	Community Changes	Construction, Operation	Low Priority
Noise	Habitat Use and Behavior Changes	Construction, Operation	Low Priority
Noise	Larval Dispersal and recruitment Change	Construction, Operation	Low Priority
EMF	Abundance/Occurrence	Operation	Low Priority
EMF	Community Changes	Operation	Low Priority
EMF	Habitat Use and Behavior Changes	Operation	Low Priority
Once-Through	Physiology & Condition Change	Operation	Low Priority

IPF	Impact	Phase	Priority
Cooling			

Table C11. *Fish and Invertebrates descending order IPF x Impact by OSW development Phase: Demersal and Benthic Invertebrates*

IPF	Impact	Phase	Priority
Infrastructure	Abundance/ Occurrence	Construction, Operation	High Priority
Infrastructure	Community Changes	Construction, Operation	High Priority
Infrastructure	Habitat Use and Behavior Changes	Construction, Operation	High Priority
Infrastructure	Reproduction recruitment	Construction, Operation	High Priority
Infrastructure	Demographic Changes	Construction, Operation	Low Priority
EMF	Abundance/Occurrence	Operation	Low Priority
Once-Through Cooling	Habitat Use and Behavior Changes	Operation	Low Priority
Once-Through Cooling	Reproduction recruitment	Operation	Low Priority

Table C12. *Fish and Invertebrates descending order IPF x Impact by OSW development Phase: Highly Migratory Pelagic and Foraging Fish*

IPF	Impact	Phase	Priority
Infrastructure	Abundance/ Occurrence	Operation	High Priority
Infrastructure	Habitat Use	Operation	High Priority
Infrastructure	Behavior Change	Operation	High Priority
Infrastructure	Reproduction recruitment	Operation	High Priority
Infrastructure	Reproduction recruitment	Construction	Medium Priority
Noise	Abundance/ Occurrence	Construction, Operation	Low Priority
Noise	Community Changes	Construction, Operation	Low Priority
Noise	Habitat Use	Construction, Operation	Low Priority
Noise	Behavior Change	Construction, Operation	Low Priority

IPF	Impact	Phase	Priority
EMF	Abundance Occurrence	Operation	Low Priority
EMF	Habitat Use	Operation	Low Priority
EMF	Behavior Change	Operation	Low Priority
Infrastructure	Demographic Change	Operation	Low Priority
Infrastructure	Community Change	Operation	Low Priority
Once-Through Cooling	Habitat Use	Operation	Low Priority
Once-Through Cooling	Behavior Change	Operation	Low Priority
Infrastructure	Abundance Occurrence	Construction	High Priority Knowledge Gap
Noise	Reproduction recruitment	Construction	Low Priority Knowledge Gap
EMF	Community Change	Operation	Low Priority Knowledge Gap

Table C13. *Fish and Invertebrates descending order IPF x Impact by OSW development Phase: Plankton*

IPF	Impact	Phase	Priority
Infrastructure	Community Change	Operation	High Priority
Infrastructure	Abundance/Occurrence	Operation	Medium Priority
Infrastructure	Demographic Changes	Operation	Medium Priority
Infrastructure	Reproduction recruitment	Operation	Medium Priority
EMF	Abundance/Occurrence	Operation	Low Priority
Infrastructure	Habitat Use	Operation	Low Priority
Infrastructure	Behavior Change	Construction, Operation	Low Priority
Once-Through Cooling	Abundance/Occurrence	Operation	Low Priority
Once-Through Cooling	Demographic Changes	Operation	Low Priority
Once-Through Cooling	Community Change	Operation	Low Priority

Appendix D. Species Prioritization Decision Tree Results

Table D1. *Marine Mammals and Sea Turtles Species Prioritization*

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
Baird's beaked whale	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Representative	Yes. Feasible to monitor	High priority
Blainville's beaked whale	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Representative	Yes. Feasible to monitor	High priority
Blue whale	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications, Yes. High relative ecological importance, Yes. Representative	Yes. Feasible to monitor	High priority
Bottlenose dolphin	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Medium priority
Bryde's Whale	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Not feasible to monitor	Not a feasible monitoring priority
California Sea Lion	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Medium priority
Cuvier's/Goose Beaked Whale	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Representative	Yes. Feasible to monitor	High priority
Dall's Porpoise	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	Medium priority
Dwarf sperm whale	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Fin Whale	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Representative, Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Gray whale	Yes. Potential	Yes. High	Yes. Key management	Yes. Feasible to	High priority

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
	for exposure	sensitivity to impacts	implications, Yes. High relative ecological importance	monitor	
Guadalupe Fur Seal	No	Yes. High uncertainty of sensitivity	Yes. Key management implications	Not feasible to monitor	Not likely to be exposed to impacts
Harbor porpoise	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Harbor Seal	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Humpback whale	Yes. Potential for exposure	No	Yes. Key management implications, No	Yes. Feasible to monitor	Medium priority
Killer whale	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	Yes. High relative ecological importance, Yes. Key management implications	Yes. Feasible to monitor	High priority
Long-beaked common dolphin	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Minke Whale	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Northern Elephant Seal	No	No	No	Yes. Feasible to monitor	Low priority
Northern Fur Seal	No	No	No	Yes. Feasible to monitor	Low priority
North pacific right whale	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Not feasible to monitor	Not a feasible monitoring priority
Pacific white sided dolphin	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Risso’s dolphin	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Sei whale	Yes. Uncertainty for	Yes. High uncertainty of	Yes. Key management implications	Not feasible to monitor	Not a feasible monitoring

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
	exposure	sensitivity			priority
Short-beaked common dolphin	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Short-finned pilot whale	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low priority
Steller Sea Lion	No	No	No	Yes. Feasible to monitor	Low priority
Sperm Whale	Yes. Potential for exposure	No	Yes. Key management implications	Yes. Feasible to monitor	Low priority
Leatherback Sea Turtle	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications, Yes. High relative ecological importance, Yes. Representative	Yes. Feasible to monitor	High priority
Loggerhead Sea Turtle	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Representative, Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Green Sea Turtle	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Representative, Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Olive Ridley Sea Turtle	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Representative, Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Sea Otter	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Representative, Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority

Table D2. *Marine Birds and Bats Species Prioritization*

Species	**Answer to Q1: Exposure**	**Answer to Q2: Sensitivity**	**Answer to Q3: Representative/ Management/ Ecological Importance**	**Is it feasible to monitor?**	Final Rating
Marbled Murrelet	No	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	Not likely to be exposed to impacts
Scripps's Murrelet	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Guadalupe Murrelet	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Ancient Murrelet	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Rhinoceros Auklet	Yes. Potential for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Parakeet Auklet	No	Yes. High sensitivity to impacts		Yes. Feasible to monitor	Not likely to be exposed to impacts
Pigeon Guillemot	Yes. Potential for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Low priority
Common Murre	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Tufted puffin	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Horned Puffin	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Cassin's Auklet	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority

Species	**Answer to Q1: Exposure**	**Answer to Q2: Sensitivity**	**Answer to Q3: Representative/ Management/ Ecological Importance**	**Is it feasible to monitor?**	Final Rating
Craveri's Murrelet	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Brant	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No		Medium priority
Black Scoter	No	Yes. High sensitivity to impacts	Yes. Representative	Yes. Feasible to monitor	Not likely to be exposed to impacts
Common Merganser	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Harlequin duck	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Long-tailed Duck	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Red-breasted Merganser	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Surf scoter	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
White-winged Scoter	No	Yes. High sensitivity to impacts	No		Not likely to be exposed to impacts
Hoary Bat	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High Priority
Mexican free-tailed bats	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High Priority
Western Red Bat	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High Priority

Species	**Answer to Q1: Exposure**	**Answer to Q2: Sensitivity**	**Answer to Q3: Representative/ Management/ Ecological Importance**	**Is it feasible to monitor?**	Final Rating
Townsend's big-eared bat	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Silver-haired bat	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High Priority
Yuma myotis	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
California myotis	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Western mastiff bat	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium Priority
Western yellow bat	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium Priority
Fringed myotis	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Big brown bat	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium Priority
Little brown bat	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Pallid bat	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Canyon bat	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low Priority
Short-tailed Albatross	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Black-footed Albatross	Yes. Potential for exposure	No	Yes. Key management implications	Yes. Feasible to monitor	Low priority
Laysan Albatross	No	No	Yes. Representative	Yes. Feasible to monitor	Not likely to be exposed to impacts

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
Pacific Loon	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Yellow-billed Loon	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Common Loon	Yes. Potential for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Red-throated Loon	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Ashy Storm-petrel	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Leach's Storm-petrel	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Black Storm-Petrel	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium priority
Fork-tailed Storm-petrel	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Wilson's Storm-Petrel	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Townsend's Storm-Petrel	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Least Storm-Petrel	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
California Gull	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. High relative ecological importance	Yes. Feasible to monitor	Medium priority

Species	**Answer to Q1: Exposure**	**Answer to Q2: Sensitivity**	**Answer to Q3: Representative/ Management/ Ecological Importance**	**Is it feasible to monitor?**	Final Rating
Western Gull	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Elegant Tern	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Glaucous-winged Gull	Yes. Potential for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Heermann's Gull	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Herring Gull	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium priority
Iceland Gull	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium priority
Bonaparte's Gull	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Sabine's Gull	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Black Skimmer	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Black Tern	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Caspian Tern	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Common Tern	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
Forster's Tern	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Gull-billed Tern	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Least Tern	No	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	Not likely to be exposed to impacts
Ring-billed Gull	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Royal Tern	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Short-billed Gull	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium priority
Arctic Tern	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Black-legged Kittiwake	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
American White Pelican	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Brown Pelican	No	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Red-billed Tropicbird	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Double-crested Cormorant	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
Pelagic Cormorant	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Brandt's Cormorant	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Red-necked Grebe	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Clark's Grebe	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Eared Grebe	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Horned Grebe	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Western Grebe	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Northern Fulmar	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Hawaiian Petrel	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Cook's Petrel	No	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	Not likely to be exposed to impacts
Murphy's Petrel	No	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Mottled Petrel	No				Not likely to be exposed to impacts

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
Sooty Shearwater	Yes. Potential for exposure	No	Yes. High relative ecological importance	Yes. Feasible to monitor	Medium priority
Black-vented Shearwater	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Pink-footed Shearwater	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Flesh-footed Shearwater	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Manx Shearwater	No	No	No	Yes. Feasible to monitor	Not likely to be exposed to impacts
Short-tailed Shearwater	No				Not likely to be exposed to impacts
Buller's Shearwater	Yes. Potential for exposure	No	Yes. High relative ecological importance	Yes. Feasible to monitor	Low priority
Red Phalarope	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Representative	Yes. Feasible to monitor	High priority
Red-necked Phalarope	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Representative	Yes. Feasible to monitor	High priority
Wilson's Phalarope	No	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	Not likely to be exposed to impacts
Long-tailed Jaeger	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low priority
Parasitic Jaeger	Yes. Uncertainty for exposure	No	No	Yes. Feasible to monitor	Low priority
Pomarine Jaeger	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority

Species	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/ Management/ Ecological Importance	Is it feasible to monitor?	Final Rating
South Polar Skua	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Blue-footed Booby	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Cocos Booby	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Masked Booby	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Nazca Booby	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority
Red-footed Booby	Yes. Uncertainty for exposure	Yes. High sensitivity to impacts	No	Yes. Feasible to monitor	Medium priority

Table D3. *Fish and Invertebrates Species Prioritization*

Species/ Taxonomic Group	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/Management/Ecological Importance	Is it feasible to monitor?	Final Rating
Rockfishes	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Demersal Groundfish	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Jacks & Barracuda	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Elasmobranchs	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. High relative ecological importance, Yes. Key management implications	Yes. Feasible to monitor	High priority
Flatfishes	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Salmonids	Yes. Potential for exposure	No	Yes. Key management implications	Yes. Feasible to monitor	Low priority
Tunas & Billfishes (HMS)	Yes. Potential for exposure	No	Yes. High relative ecological importance	Yes. Feasible to monitor	Low priority
Coastal Pelagic & Forage Fishes	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Croakers & Drums (Sciaenids)	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Surfperches	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Deepwater Slope Specialists	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Nearshore Reef Residents	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority

Species/ Taxonomic Group	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/Management/Ecological Importance	Is it feasible to monitor?	Final Rating
Sturgeons	Yes. Potential for exposure	No	No	Yes. Feasible to monitor	Low priority
Cephalopods	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Benthic Grazers & Scavengers	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Crustaceans (Mobile)	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. Key management implications	Yes. Feasible to monitor	High priority
Bivalves & Sessile Invertebrates	Yes. Potential for exposure	Yes. High sensitivity to impacts	Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Plankton	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications, Yes. High relative ecological importance	Yes. Feasible to monitor	High priority
Chinook Salmon	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Chum Salmon	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Coho Salmon	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Eulachon	Yes. Uncertainty for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Green Sturgeon	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority

Species/ Taxonomic Group	Answer to Q1: Exposure	Answer to Q2: Sensitivity	Answer to Q3: Representative/Management/Ecological Importance	Is it feasible to monitor?	Final Rating
Oceanic whitetip shark	No				Not likely to be exposed to impacts
Scalloped hammerhead shark	No				Not likely to be exposed to impacts
Shortfin mako shark	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	No	Yes. Feasible to monitor	Medium priority
Sockeye salmon	No	No			Not likely to be exposed to impacts
Steelhead trout	Yes. Potential for exposure	Yes. High uncertainty of sensitivity	Yes. Key management implications	Yes. Feasible to monitor	High priority
Tope shark	Yes. Uncertainty for exposure	No		Yes. Feasible to monitor	Low priority
Yelloweye rockfish	Yes. Uncertainty for exposure	No		Yes. Feasible to monitor	Low priority

Appendix E. Existing California Monitoring Initiatives

The Existing California Monitoring Programs and Initiatives spreadsheet is a review of California ocean monitoring programs as of May 22, 2026.

Appendix F. California Fish and Invertebrate Groupings

Rockfishes (Genus Sebastes) The most speciose group. They share strong site fidelity to hard structure habitat, generally shallower than 500m.

Species: Black rockfish, Black-and-Yellow Rockfish, Blue Rockfish, Boccaccio Rockfish, Brown Rockfish, Calico Rockfish, Canary Rockfish, Chilipepper Rockfish, China Rockfish, Copper Rockfish, Cowcod, Flag Rockfish, Gopher Rockfish, Grass Rockfish, Greenblotched Rockfish, Greenspotted Rockfish, Greenstriped Rockfish, Halfbanded Rockfish, Kelp Rockfish, Olive Rockfish, Pacific ocean perch, Quillback Rockfish, Redstripe Rockfish, Rosethorn Rockfish, Rosy Rockfish, Speckled Rockfish, Squarespot Rockfish, Starry Rockfish, Stripetail Rockfish, Tiger Rockfish, Tree Fish, Vermilion/ Sunset Rockfish, Widow rockfish, Yelloweye rockfish, Yellowtail rockfish.

Demersal Groundfish (Non-Rockfish) A broad group of benthic structure- and hard-bottom-associated predators.

Species: Barred sand bass, Cabezon, California Scorpionfish, Giant Sea Bass, Kelp Bass, Kelp Greenling, Lingcod, Monkeyface Prickleback, Ocean whitefish, Pacific Cod, Rock greenling, Spotted sand bass, Striped Bass.

Jacks & Barracuda High-speed, semi-pelagic predators often found in the water column near structure or kelp lines.

Species: Almaco Jack, Pacific Barracuda, Yellowtail.

Elasmobranchs (Sharks, Rays & Skates) Cartilaginous fishes sensitive to Electromagnetic Fields (EMF) from cables. They exhibit "K-selected" life histories (slow growth, late maturity).

Species: Bat Ray, Blue Shark, Bonnethead Shark, Broadnose Sevengill Shark, Brown smoothhound shark (listed twice), Common Thresher Shark, Horn shark, Leopard Shark, Oceanic whitetip shark, Pacific angle shark, Pacific common thresher shark, Pacific spiny dogfish, Round Stingray, Salmon Shark, Scalloped hammerhead shark, Shortfin mako shark, Shovelnose Guitarfish, Soupfin Shark, Swell Shark, Thornback, Tope shark, White shark.

Flatfishes Strictly benthic fishes on soft sediment. Key stressors are seabed disturbance (cable burial, anchoring) and habitat conversion.

Species: Arrowtooth Flounder, California halibut, Diamond Turbot, Dover Sole, English Sole, Flathead Sole, Pacific halibut, Pacific sanddab, Petrale sole, Rex sole, Rock sole, Sand Sole, Starry Flounder.

Salmonids Anadromous species migrating through the ocean. They are surface-oriented, sensitive to EMF (navigation), and many are ESA-listed.

Species: Chinook Salmon, Chum Salmon, Coho Salmon, Pink Salmon, Sockeye salmon, Steelhead trout.

Tunas & Billfishes (Highly Migratory Species) Large, highly migratory pelagic predators. Exposure is primarily related to collision risk and displacement/barrier effects. Attraction to prey on structure.

Species: North Pacific Swordfish, Opah, Pacific Albacore Tuna, Pacific Bigeye tuna, Pacific bluefin tuna, Pacific bonito, Pacific mahi mahi, Pacific skipjack tuna, Pacific wahoo, Pacific yellowfin tuna, Striped marlin.

Coastal Pelagic & Forage Fishes Schooling fishes that support the food web. They are sensitive to acoustic particle motion and schooling disruption.

Species: California Grunion, Eulachon, Jack Mackerel, Jack Smelt, Night smelt, Northern Anchovy, Pacific Butterfish, Pacific herring, Pacific mackerel, Pacific sardine, Smallhead Flyingfish, Surf Smelt, Topsmelt.

Croakers & Drums (Sciaenids) Demersal fish that are "soniferous" (produce sound for communication), making them uniquely vulnerable to acoustic masking. Generally shallow water species.

Species: Black Croaker, California corbina, Queenfish, Sargo, Spotfin Croaker, White croaker, White seabass, Yellowfin Croaker.

Surfperches Live-bearing (viviparous) nearshore residents with very limited dispersal, making populations sensitive to localized construction impacts only in nearshore areas.

Species: Barred surfperch, Black Perch, Calico Surfperch, Pile Perch, Rainbow Seaperch, Redtail surfperch, Rubberlip Seaperch, Shiner seaperch, Silver Surfperch, Striped Seaperch, Walleye Surfperch.

Deepwater Slope Specialists Species found in deep continental slope waters, exposed mainly to transmission cables and deep-sea anchoring.

Species: Pacific hagfish, Pacific whiting (hake), Sablefish, Shortspine thornyhead.

Nearshore Reef Residents Highly resident small fishes (e.g. Wrasses, Damsels) with high site fidelity to specific reef features, associated with hard structure and kelp.

Species: Blacksmith, California Moray Eel, California Sheephead, Garibaldi, Halfmoon, Opaleye, Rock Wrasse, Senorita.

Sturgeons Benthic, anadromous, armored fish with electro-sensitivity. Ocean habitat generally shallow water and migratory.

Species: Green Sturgeon, White Sturgeon.

Cephalopods Intelligent invertebrates with complex sensory systems (statocysts) and short lifespans. Attracted to structure and lighting effects.

Species: California market squid, CA Two-Spot Octopus, Market squid.

Benthic Grazers & Scavengers Slow-moving or sessile invertebrates (Echinoderms, Gastropods) vulnerable to crushing and sedimentation.

Species: Black abalone, Giant pink sea star, Giant red sea cucumber, Green abalone, Kellet's whelk, Pink abalone, Pinto abalone, Red abalone, Red sea urchin, Sunflower sea star, Warty sea cucumber, White abalone.

Crustaceans (Mobile) Mobile arthropods (Crabs, Lobsters, Shrimp). Vulnerable to EMF and often subject to commercial trap fisheries. May benefit from deepwater habitat.

Species: Bay Shrimp, Brown rock crab, CA spiny lobster, Dungeness crab, Ocean (pink) shrimp, Red rock crab, Ridgeback prawn, Rock Crabs, Sheep Crab, Spot prawn.

Bivalves & Sessile Invertebrates Filter feeders attached to substrate or buried. Highly sensitive to turbidity plumes and smothering. May benefit from deepwater habitat.

Species: Blue mussel, CA mussel, Geoduck clam, Giant rock scallop, Pacific Gaper clam /Flat Gaper Clam, Pacific Geoduck Clam, Pacific oyster, Pacific Razor Clam, Pismo clam, Sponges, Washington clam and butter.

Plankton Drifting organisms at the base of the food chain.

Species: Plankton.

Appendix G. Analysis of sensors used to collect different data categories

Table G. *A list of sensors/data collectors are assessed for which data types or categories they can collect*

Data Types / Categories	Passive acoustic monitors	Active acoustic monitors	Tags	Environmental sample collectors	Vibration sensors	Light/ heat sensors	Radar	Metocean condition sensors	Nets, traps, and other items for organism collection	Imaging systems	Biological/ physiological samplers/ monitors
Abundance and population dynamics	x	x	x	x			x	x	x	x	x
Behavior and behavioral response (short- and long-term)	x	x	x	x			x	x	x	x	x
Biodiversity/biomass/species richness	x	x	x	x			x	x	x	x	x
Demography and life history/life stages	x	x	x	x		x	x	x		x	
Habitat composition/recovery				x		x				x	
Injury/Mortality				x						x	
Oceanographic			x						x	x	x
Physiological health and growth	x		x	x			x		x	x	
Presence/distribution/use pattern/seasonality		x		x						x	
Productivity/upwelling				x							
Sediment composition, movement, and toxicity				x						x	
Trophic relationships			x						x	x	x
Water quality		x			x		x			x	

Appendix H. Analysis of platforms that can be used to deploy different sensors/data collectors

Table H. *Mobile and fixed platforms are assessed for what sensors/data collectors can be affixed to them*

		Mobile Platforms						***Fixed Platforms***			
Sensors/Data Collectors	**Examples**	**crewed water-based vessels**	**autonomous water-based vessels**	**crewed aerial vessels**	**autonomous aerial vessels**	**Animals**	**Satellites**	**Buoys**	**Offshore wind infrastructure**	**Subsea moored platforms**	**Other infrastructure**
Passive acoustic monitors	hydrophones ultrasonic recorders	x	x			x		x		x	x
Active acoustic monitors	sonar pingers	x	x					x		x	x
Tags	bird/bat bands satellite tags radio tags passive integrated transponders Motus tags global position system tags suction-cup or penetrating depth/acoustic tags					x					
Environmental sample collectors	water samplers eDNA samplers box grabs sediment corers conductivity/temperature/depth sampler dissolved oxygen sampler nutrient sampler	x	x	x	x			x		x	x
Vibration sensors	vibration detector								x		
Light/heat sensors	light detector temperature detector							x	x		x
Radar	radar							x	x		x
Metocean condition sensors	LiDAR FLiDAR acoustic doppler current profiler	x	x	x	x			x		x	x

		Mobile Platforms						***Fixed Platforms***			
Sensors/Data Collectors	**Examples**	**crewed water-based vessels**	**autonomous water-based vessels**	**crewed aerial vessels**	**autonomous aerial vessels**	**Animals**	**Satellites**	**Buoys**	**Offshore wind infrastructure**	**Subsea moored platforms**	**Other infrastructure**
Nets, traps, and other items for organism collection	plankton tow systems fish tow/trawl systems fish pots mist nets seines	x	x	x	x						
Imaging systems	digital cameras infrared cameras thermal imagers night vision devices sediment profile imagers side scan sonar multibeam echosounders video satellite imaging systems	x	x	x	x	x	x	x	x	x	x
Biological/physiological samplers/monitors	biopsy samplers blood samplers whale blow samplers	x	x	x	x						

Appendix I. General limitations and opportunities for sensors

Table I. *Sensors and data collectors are assessed for general limitations and opportunities and potential platforms*

Sensors/Data Collectors	***Examples***	***Limitations***	***Opportunities***	***Platforms***
General	**Specific Types**	**General limitations on:** **Power** **Data storage and transfer** **Cybersecurity** **Clear standards and benchmarks for approval of new and modified technologies** **Autonomy** **Ability to integrate into infrastructure and typical operations of windfarms**	**General opportunities to:** **Scale up** **Supplement and draw from existing studies and technologies** **Address noted limitations** **Improve integration with multi-sensor platforms and concurrent observational and environmental studies** **Decrease costs with further commercialization and competition** **Improve analytics** **Improve models, identify most important predictive variables** **Improve timing of planning relative to engineering, procurement, and financial milestones**	**Full list:** **Mobile -** **Crewed water-based vessels** **Autonomous water-based vessels** **Crewed aerial vessels** **Autonomous aerial vessels** **Animals** **Satellites** **Fixed -** **Buoys** **Offshore wind infrastructure** **Subsea moored platforms** **Other infrastructure**
Passive acoustic monitors	Hydrophones Ultrasonic recorders	Limited distance to detection as frequencies increase Can be expensive to deploy at scale Commercially available but may be limited supply at the required scale Lack of calibration data for classification of some taxa to species, lack of verified data to train and test AI for some species Cannot detect animals not making noise or without a noise producing tag Lack of calibration data to understand cue rates for translating to prediction of densities or abundances Difficult to detect high-frequency animals at long ranges (attenuation of sound)	Likely less expensive at scale than vessel or aerial surveys Published studies on collection of data from acoustically tagged fish AI and algorithms are starting to be developed for detection and classification Systems are becoming more available and improving general issues with power, redundancy, autonomy, etc. Some published studies on detection ranges, error rates, and other calibration of metrics for some species Ability to collect data at times and in conditions when surveys are unsafe or difficult and to collect data at relatively short intervals over long duration compared to vessel and aerial surveys	Crewed or autonomous water-based vessels Animals Buoys Subsea moored platforms Other infrastructure
Active acoustic monitors	Sonar Pingers	Create noise in the environment that can have impacts and sometimes requires authorizations Some systems can be expensive, lack robustness to ocean conditions, Lack of calibration to classify to lower	Can detect animals not vocalizing and without a noise producing tag Published studies on detection ranges and classification of birds and bats	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels Buoys Subsea moored platforms Other infrastructure

Sensors/Data Collectors	***Examples***	***Limitations***	***Opportunities***	***Platforms***
		taxonomic levels		
Tags	Bird/bat bands Satellite tags Radio tags Passive integrated transponders Motus tags Global position system tags Suction-cup or penetrating depth/acoustic tags	Requires invasive capture or other attachment of tags Requires sufficient sample size of individuals tagged - the act of tagging is a limiting factor Can require permits for some types of tagging and some taxa Generally require receivers deployed broadly and maintained over time Some types of tags are expensive Some types of tags are not easily commercially available and can be inconsistent in quality and technical support Some types of tags are short-duration or not durable to long deployments or can be easily lost or removed by animals Some tags require animal in close range of a detector (e.g., Motus, fish nanotag detector, radio tag) Bands and marks (e.g. brands) must be re-observed and require good communications for re-sighting confirmation Satellite tags can have poor constellations at some times of day or year, reducing data quality Tags for deepwater species must tolerate high pressure and can be more expensive Some tags require retrieval to obtain data Small animals can be difficult to tag due to necessary tag size Tags can change animals' typical behavior or affect health	Potential to collect concurrent observational and environmental data Some types of tags can be long-duration Some types of tags have long ranges (e.g. satellite tags, GPS tags) Bands and marks can be observed over long periods of time and in wide geographic range Some tags can remotely send data, not requiring retrieval of tags, which can be difficult	Animals Receivers can be on any appropriate platform
Environmental sample collectors	Water samplers eDNA samplers Box grabs Sediment corers Conductivity/temperature/depth sampler Dissolved oxygen sampler Nutrient sampler	Integration of environmental sample collectors into autonomous platforms is in early stages for some collectors Collection of environmental samples can be difficult to achieve at spatiotemporal scales sufficient for robust data analyses Collectors can take up significant space to store samples in autonomous systems New and modified collectors lack calibration and validation data eDNA is a newer technology which is still	Most environmental samplers are long-standing technologies with publications and well established methodologies New autonomous platforms should ultimately increase sampling ability and decrease cost of sampling	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels Buoys Subsea moored platforms Other infrastructure

Sensors/Data Collectors	***Examples***	***Limitations***	***Opportunities***	***Platforms***
		under development as a tool for study Generally water and sediment sampling requires an expensive platform like a ship		
Vibration sensors	Vibration detector	Would need to be integrated into offshore wind infrastructure, which is an engineering and procurement issue There is poor information on calibrating error rates for identification of source of vibration (i.e. if source is an animal or something else) Without concurrent imagery, vibration sensors cannot identify an animal species	Ability to detect direct interactions of animals, marine debris, and other items with infrastructure May be less expensive and easier to integrate at scale than camera systems; cameras are also hard to use on underwater infrastructure beyond short distances Possibly could be adapted from existing sensors for detecting infrastructure integrity issues Could potentially be calibrated and tested on land for birds and bats, reducing cost of initial calibration and validation compared to offshore	Offshore wind infrastructure
Light/heat sensors	Light detector Heat detector	Would need to be integrated into offshore wind infrastructure, which is an engineering and procurement issue There is poor information on calibrating error rates for correlating light and heat with species attraction or repulsion in ocean environments	Some predictions can be made regarding species attraction or repulsion relative to light and heat signatures There are publications available on some bat and bird species and response to light and heat Better understanding of bird and bat responses to light and heat can inform adaptive mitigation	buoys offshore wind infrastructure other infrastructure
Radar	Radar	When integrated into offshore wind infrastructure, it is an engineering and procurement issue Radar is not as good for distinguishing species as visual observation or cameras There are field-of-view issues depending on location of radar Radar accuracy is reduced as size of target is reduced, so small-bodied animals are less reliably detectable Radar is limited to use in air Radar requires a relatively stable platform or stabilizing technologies that exist but are still not ideal for best data collection	Radar can be good for detecting birds and bats and can define shapes sufficiently to distinguish individuals and identify potential taxa to high levels Radar can be deployed for extended periods of time and is well tested in marine environments Radar can potentially have better range than camera systems	Buoys Offshore wind infrastructure Other infrastructure

Sensors/Data Collectors	***Examples***	***Limitations***	***Opportunities***	***Platforms***
Metocean condition sensors	LiDAR FLiDAR Acoustic doppler current profiler	Metocean condition data are commercially sensitive to developers with leases, creating some concerns around public availability Fixed platforms for metocean sensors are limited in space, and mobile platforms tend to be limited in power and data storage/transfer capabilities Systems can be expensive and more work is needed to improve autonomy and reduce frequency of maintenance of sensors and platforms and increase sampling rates and areas Metocean data tend to be mainly collected near the surface; in deepwater, platforms and sensors with higher pressure tolerance are needed	Metocean conditions that are connected in time and space to observational data are very important for better understanding drivers of animal behavior, distribution, and use patterns Metocean platform technology has improved to reduce the need for towers and now operates well on easier to deploy buoy systems Metocean sensors can be deployed for extended periods of time and is well tested in marine environments Metocean sensors have been added to mobile, autonomous platforms successfully, allowing increased range of data collection Quality metocean data are important for wind developers and the deployment of platforms with these sensors is an opportunity to also incorporate other sensors for other priority questions Good models exist for applying metocean data to predictive questions about upwelling, wind regimes, larval transport, etc.	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels Buoys Subsea moored platforms Other infrastructure
Nets, traps, and other items for organism collection	Plankton tow systems Fish tow/trawl systems Fish pots Mist nets (birds/bats) Seines (in water)	Requires invasive capture, disruption, potential habitat damage, potential bycatch Can require permits for some types of collection Injury to animals can result Limited in time and space for individual deployments At sea, usually requires ship for deployment and retrieval which is expensive	Direct counting and health assessment of individuals Can be deployed anywhere in water column and on bottom (or terrestrially for organisms that spend time on land for less expensive collection) Allows for physiological sample collection such as blood, fat, genetic samples Direct in situ productivity sampling Could potentially collaborate with fisheries research	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels

Sensors/Data Collectors	***Examples***	***Limitations***	***Opportunities***	***Platforms***
Imaging systems	Digital cameras Infrared cameras Thermal imagers Night vision devices Sediment profile imagers Side scan sonar Multibeam echosounders Video Satellite imaging systems	Some systems for imaging use sound that can have impacts and sometimes requires authorizations Field-of-view can be limited for some systems Some systems are limited in poor weather or darkness Calibration of systems and development of algorithms for detection and classification and AI systems is still nascent for some imaging technologies Imaging datasets and files are very large and hard to transfer, store, QA/QC, and analyze Some types of cameras are better at identifying species than radar or vibration/heat/light sensors Thermal systems can have less precision for classification than other systems Visual satellite imagery has some issues with national security that can be limiting Use of ships or aircraft for studies is expensive Can be used at depth, dependent on pressure and platform constraints Can record data at geographic scale including more individuals than tagging or capture studies	Sensors like side scan sonar and multibeam echosounders (sound producing) can produce good resolution to delineate some habitats and bottom topography Some imaging systems can operate at night and in poor weather conditions Video and digital imagery can be easier to verify than visual observer data Imaging systems can be less invasive than tagging and direct collection of organisms Imaging systems are improving and algorithms and AI are in development to leverage them better Satellite imagery for productivity proxies light sea surface temperature and chlorophyll a are readily available in public portals There are publications on use of satellite imagery for whale detection There are well established standards for some types of habitat classifications and productivity measures Some systems can be deployed on autonomous technologies, reducing cost and reaching more locations than traditional ships and aircraft	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels Animals Satellites Buoys Offshore wind infrastructure Subsea moored platforms Other infrastructure
Biological/physiological samplers/monitors	Biopsy samplers Blood samplers Whale blow samplers	Some systems require invasive capture or sampling methods Requires sufficient sample size of individuals sampled - the act of sampling is a limiting factor Can require permits for some types of sampling and some taxa At sea, usually requires ship for deployment and retrieval which is expensive	Can provide insight into physiological responses and health Are useful for informing population consequences of disturbance models New technologies are being developed that reduce invasiveness as possible Some types of samples need to be stored in complicated ways for at sea research or autonomous platforms (e.g. freezing or chemical storage) Can provide information about diet of organisms Can provide information about genetic relationships and diversity	Crewed or autonomous water-based vessels Crewed or autonomous aerial vessels

Appendix J. General limitations and opportunities for platforms

Table J1. *Mobile platforms are assessed for general limitations and opportunities*

Mobile Platforms	***Examples***	***Limitations***	***Opportunities***
General	**Specific Types**	**General limitations on:** **Power** **Data storage and transfer** **Cybersecurity** **Clear standards and benchmarks for approval of new and modified technologies** **Health and safety risks** **Expense** **Operable weather and ocean conditions** **Size and weight of payloads** **Field-of-view** **Depth/pressure constraints** **Stable platforms for sensors that need stability**	**General opportunities to:** **Scale up and integrate across platforms** **Adapt existing technologies** **Address noted limitations** **Decrease costs with further commercialization and competition** **Improve alignment of engineering, procurement, and expectations around use of infrastructure as a platform** **Continue technology development to improve capabilities of mobile, autonomous platforms** **Develop standards and benchmarks for platforms to create more consistency for designing sensors that can be easily installed, maintained, and configured on platforms**
Crewed water-based vessels	Ships Zodiacs Remote Operated Vessels (tethered systems)	Expensive Safety risks to people on vessels Whale collision risk Limited operations in some weather and ocean conditions	Can undertake large-scale, long-term studies at sea Carry larger payloads and can store more samples than autonomous vessels Can carry large equipment and towed systems People on vessels can troubleshoot and address unexpected issues Well established platforms with known methods, sensors, and capabilities
Autonomous water-based vessels	Autonomous underwater vessels Autonomous surface vessels Gliders	Less capable of carrying large payloads or storing large numbers of samples than crewed vessels Generally cannot carry large equipment like boomers and sparkers Still developing technologies so lack testing, validation, and standards in some cases Depth/pressure limitations May be slower or less adaptable/flexible to address unexpected conditions than crewed vessels Limitations on power, data storage/transfer, duration of mission without maintenance	Likely less expensive than crewed vessels for same purposes More maneuverable than larger crewed vessels Reduced risk of whale collision/serious injury Reduced safety risk to people than crewed vessels Can operate in areas and conditions that crewed vessels cannot

Mobile Platforms	***Examples***	***Limitations***	***Opportunities***
Crewed aerial vessels	Planes Helicopters	Very expensive High safety risks to people on some types of aircraft Bird collision risk Aviation interaction risk (low) Very limited in weather conditions and distance from shore	Can potentially operate longer, higher, and in larger areas than uncrewed vessels Carry larger payloads than autonomous vessels People on vessels can troubleshoot and address unexpected issues Well established platforms with known methods, sensors, and capabilities
Autonomous aerial vessels	Drones	Less capable of carrying large payloads than crewed vessels Still developing technologies so lack testing, validation, and standards in some cases Line-of-sight limitations (regulatory requirements) Distance limitations relative to crewed vessels Many require crewed water-based vessels for deployment (see limitations above) Limitations on power, data storage/transfer, duration of mission without maintenance Bird collision risk Aviation interaction risk Limited in use in poor weather	Likely less expensive than crewed vessels for same purposes More maneuverable than larger crewed vessels Reduced risk of bird collision Reduced safety risk to people than crewed vessels Can operate in areas and conditions that crewed vessels cannot Can potentially operate farther from shore than crewed aerial vessels (transported by ships) Likely very low risk of bird collision and aviation interaction
Animals	Organisms as platforms for tags	Hard to find some species of animals Tagging can be challenging for some species Obtaining a sufficient sample size for statistically robust results can be difficult Placement of receivers for active tags can be challenging Tags can be expensive Tags fail and are lost relatively often for some species and tag types Power and data storage/transfer can be limited Small animals may not be feasible to tag without smaller, less invasive tag development	Tags can provide movement data over time of individual animals that is more comprehensive in time and space than single observations of individuals Tags can be used for mark-recapture studies and better assessing population dynamics Tag data are helpful for assessing behavior and response under different conditions A single receiver can log many tags from many animals Tags can provide a useful complement to ocean condition data for understanding animal movement and use pattern drivers
Satellites	Argos, Starlink	Need permission to use images from satellites - can incur national security risks Satellites do not collect data deep into the water column or on the bottom Satellite images can be low-resolution relative to data collected closer to the sea surface or bottom Need improved algorithms and AI for better target detection, classification, and analyses/models	Satellite data on ocean parameters, like sea surface temperature and chlorophyll a are easily accessible in public portals Satellite data on ocean parameters can serve as useful proxies for models of animal distribution and use when drivers are understood New use of satellite images for observing animals at the surface is developing as satellite imagery improves (e.g. whale observations)

Table J2. *Fixed platforms are assessed for general limitations and opportunities*

Fixed Platforms	***Examples***	***Limitations***	***Opportunities***
General	**Specific Types**	**General limitations on:** **Power** **Data storage and transfer** **Cybersecurity** **Clear standards and benchmarks for approval of new and modified technologies** **Health and safety risks** **Expense** **Operable weather and ocean conditions** **Size and weight of payloads** **Field-of-view** **Depth/pressure constraints** **Stable platforms for sensors that need stability**	**General opportunities to:** **Scale up and integrate across platforms** **Adapt existing technologies** **Address noted limitations** **Decrease costs with further commercialization and competition** **Improve alignment of engineering, procurement, and expectations around use of infrastructure as a platform** **Continue technology development to improve capabilities of mobile, autonomous platforms** **Develop standards and benchmarks for platforms to create more consistency for designing sensors that can be easily installed, maintained, and configured on platforms**
Buoys	Moored systems with surface floats	Limited range relative to mobile platforms Need improvements in duration of deployment of sensors on buoys without maintenance Limitations of power and data storage and transfer Can be dislodged and damaged or lost during studies Limited space for sensors Require redundancy to address lost, failure, and damage Can be a navigational hazard (though are marked and permitted) Birds, bats, sea lions, and seals can potentially get onto these platforms and be injured or damage the platform or sensors Causes minor damage to bottom where anchored Significant environmental compliance requirements have been implemented for offshore wind-related buoys Debris can attach to moorings and be a hazard to wildlife	Less expensive than vessels at sea for similar time periods, though they need deployment, maintenance, and retrieval using vessels Can be deployed long-term (years) Can transfer data via satellite or internet, including in near real-time Can use deterrents to reduce wildlife interactions with buoys Cause less sound and emissions than most mobile platforms Cause very minimal adverse effects to seafloor and wildlife and can be retrieved after use

Fixed Platforms	***Examples***	***Limitations***	***Opportunities***
Offshore wind infrastructure	Blades Nacelles Cables Moorings	In some cases, sensors on offshore wind infrastructure would collect data that cannot be collected on separate infrastructure (e.g. vibration sensor data for collision detection)Limited space for sensors Addition of sensors requires changes to design and engineering Warranties can be voided on equipment if external sensors are added Insurance can be affected by addition of external sensors Field-of-view can be limited on the infrastructure depending on sensor location Could compromise the ability of the infrastructure to function as intended for energy capture and transfer Potential cybersecurity issues for data transfer Inaccessibility of sensors - human health and safety risks Need improvements in integration of sensors during design and engineering of infrastructure Need improved autonomy, redundancy, and remote operations of sensors There is currently no plug-and-play ability to design sensors to be compatible with installation in and on infrastructure	Cables can serve as data transfer mechanism Significant extent of infrastructure could allow for substantial long-term data collection Some sensors for infrastructure integrity could potentially be adapted to also monitoring environmental and wildlife parameters Collaborative opportunity to design infrastructure that includes sensors or specific locations on infrastructure minimal where sensors can be added resolving some of the limitations noted Some sensors require deployment on infrastructure (e.g. vibration sensors) There is a significant body of literature on sensors used on terrestrial wind infrastructure and calibration and testing of those sensors to inform use on offshore wind infrastructure
Subsea moored platforms	Moored housing for fish video	Subsea platforms are limited to collecting data under the surface Limited range relative to mobile platforms Need improvements in duration of deployment of sensors on buoys without maintenance Limitations of power and data storage Data transfer would be limited to archival retrieval unless a transmitter were above the surface Can be dislodged and damaged or lost during studies Limited space for sensors Require redundancy to address lost, failure, and damage Can be a navigational hazard (though are marked on maps and permitted) Wildlife can potentially interact with these platforms and be injured or damage the platform or sensors Causes minor damage to bottom where anchored Significant environmental compliance requirements have been implemented for offshore wind-related moored structures Debris can attach to moorings and be a hazard to wildlife	Less expensive than vessels at sea for similar time periods, though they need deployment, maintenance, and retrieval using vessels Can be deployed long-term (years) Cause less sound and emissions than most mobile platforms Cause very minimal adverse effects to seafloor and wildlife and can be retrieved after use

Fixed Platforms	***Examples***	***Limitations***	***Opportunities***
Other infrastructure	Aquaculture infrastructure Academic and government research platforms	Requires collaboration with other industrial and research projects Addition of sensors may require changes to design and engineering Warranties can be voided on equipment if external sensors are added to industrial infrastructure Insurance can be affected by addition of external sensors to industrial infrastructure Field-of-view can be limited on the infrastructure depending on sensor location Could compromise the ability of the infrastructure to function as intended Potential cybersecurity issues for data Potential inaccessibility of sensors on some industrial platforms - human health and safety risks Need improvements in integration of sensors during design and engineering of infrastructure Need improved autonomy, redundancy, and remote operations of sensors Platforms may be far from wind infrastructure	Collaborative opportunity with other industries and organizations Potential for expanded range and duration of data collection and development of calibration, validation, and control datasets May be a useful alternative when it is infeasible or impracticable to collect data from offshore wind infrastructure itself

Appendix K. Sensor/data categories tables

Table K1. *Data categories and relevant sensors/data collectors for Habitats, Ecosystems, and Oceanography*

Data Categories	**Presence/ distribution/ use pattern/ seasonality**	**Abundance and population dynamics**	**Demography and life history/ life stages**	**Behavior and behavioral response (short- and long-term)**	**Oceanographic**	**Productivity/ upwelling**	**Physiological health and growth**	**Biodiversity/ biomass/ species richness**	**Habitat composition/ recovery**	**Water quality**	**Sediment composition, movement, and toxicity**	**Trophic relationships**	**Injury/ Mortality**
Related Habitats and Ecosystems and Oceanography Impact Topics	Impacts from infrastructure during construction phase	Impacts from infrastructure during construction phase		Impacts from infrastructure during construction phase	Impacts from infrastructure during construction phase	Biological oceanographic impacts	Biological oceanographic impacts		Impacts from infrastructure during construction phase		Impacts from infrastructure during construction phase		
	Impacts from infrastructure during operations	Impacts from infrastructure during operations		Impacts from infrastructure during operations	Impacts from infrastructure during operations	Physical oceanographic impacts			Impacts from infrastructure during operations		Impacts from infrastructure during operations		
	Impacts from port improvements	Biological oceanographic impacts		Impacts from port improvements	Impacts from port improvements				Impacts from port improvements		Impacts from port improvements		
	Biological oceanographic impacts				Biological oceanographic impacts								
					Physical oceanographic impacts								
Relevant Sensors / Data Collectors													
Passive acoustic monitors	yes	yes	yes	yes				yes					
Active acoustic monitors	yes	yes	yes	yes					yes				yes
Tags	yes	yes	yes	yes			yes	yes				yes	
Environmental sample collectors	yes	yes	yes	yes	yes	yes		yes	yes	yes	yes		

Data Categories	Presence/ distribution/ use pattern/ seasonality	Abundance and population dynamics	Demography and life history/ life stages	Behavior and behavioral response (short- and long-term)	Oceanographic	Productivity/ upwelling	Physiological health and growth	Biodiversity/ biomass/ species richness	Habitat composition/ recovery	Water quality	Sediment composition, movement, and toxicity	Trophic relationships	Injury/ Mortality
Vibration sensors													yes
Light/heat sensors				yes	yes								
Radar	yes	yes	yes	yes				yes					yes
Metocean condition sensors	yes	yes	yes		yes	yes				yes			
Nets, traps, and other items for organism collection	yes	yes	yes				yes	yes				yes	
Imaging systems	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes
Biological/ physiological samplers/ monitors	yes	yes	yes				yes					yes	

Table K2. *Data categories and relevant sensors/data collectors for Marine Mammals and Sea Turtles*

Data Categories	**Presence/ distribution/ use pattern/ seasonality**	**Abundance and population dynamics**	**Demography and life history/ life stages**	**Behavior and behavioral response (short- and long-term)**	**Oceanographic**	**Productivity/ upwelling**	**Physiological health and growth**	**Biodiversity/ biomass/ species richness**	**Habitat composition/ recovery**	**Water quality**	**Sediment composition, movement, and toxicity**	**Trophic relationships**	**Injury/ Mortality**
Related Marine Mammal & Sea Turtle Impact Topics	Acoustic Impacts and Behavioral modifications	Acoustic Impacts and Behavioral modifications		Acoustic Impacts and Behavioral modifications	Spatial Distribution and Connectivity Impacts	Spatial Distribution and Connectivity Impacts	Acoustic Impacts and Behavioral modifications				Spatial Distribution and Connectivity Impacts	Acoustic Impacts and Behavioral modifications	Acoustic Impacts and Behavioral modifications
	Vessel Traffic and Strike Risk	Vessel Traffic and Strike Risk		Vessel Traffic and Strike Risk	Non-acoustic environmental impacts		Spatial Distribution and Connectivity Impacts				Non-acoustic environmental impacts	Spatial Distribution and Connectivity Impacts	Vessel Traffic and Strike Risk
	Spatial Distribution and Connectivity Impacts	Spatial Distribution and Connectivity Impacts		Spatial Distribution and Connectivity Impacts			Entanglement risk					Non-acoustic environmental impacts	Spatial Distribution and Connectivity Impacts
	Entanglement risk	Entanglement risk		Entanglement risk			Non-acoustic environmental impacts						Entanglement risk
	Non-acoustic environmental impacts	Non-acoustic environmental impacts		Non-acoustic environmental impacts									Non-acoustic environmental impacts
Relevant Sensors / Data Collectors													
Passive acoustic monitors	yes	yes	yes	yes				yes					
Active acoustic monitors	yes	yes	yes	yes					yes				yes
Tags	yes	yes	yes	yes			yes	yes				yes	
Environmental sample collectors	yes	yes	yes	yes	yes	yes		yes	yes	yes	yes		
Vibration sensors													yes

Data Categories	Presence/ distribution/ use pattern/ seasonality	Abundance and population dynamics	Demography and life history/ life stages	Behavior and behavioral response (short- and long-term)	Oceanographic	Productivity/ upwelling	Physiological health and growth	Biodiversity/ biomass/ species richness	Habitat composition/ recovery	Water quality	Sediment composition, movement, and toxicity	Trophic relationships	Injury/ Mortality
Light/heat sensors				yes	yes								
Radar	yes	yes	yes	yes				yes					yes
Metocean condition sensors	yes	yes	yes		yes	yes				yes			
Nets, traps, and other items for organism collection	yes	yes	yes				yes	yes				yes	
Imaging systems	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes
Biological/ physiological samplers/ monitors	yes	yes	yes				yes					yes	

Table K3. *Data categories and relevant sensors/data collectors for Marine Birds and Bats*

Data Categories	**Presence/ distribution/ use pattern/ seasonality**	**Abundance and population dynamics**	**Demography and life history/life stages**	**Behavior and behavioral response (short- and long-term)**	**Oceanographic**	**Productivity/ upwelling**	**Physiological health and growth**	**Biodiversity/ biomass/ species richness**	**Habitat composition/recovery**	**Water quality**	**Sediment composition, movement, and toxicity**	**Trophic relationships**	**Injury/ Mortality**
Related Bird & Bat Impact Topics	Spatial distribution and responses to infrastructure	Resource Changes	Spatial distribution and responses to infrastructure	Spatial distribution and responses to infrastructure			Resource Changes	Resource Changes				Resource Changes	Collision Risk
		Spatial distribution and responses to infrastructure										Spatial distribution and responses to infrastructure	
Relevant Sensors/ Data Collectors													
Passive acoustic monitors	yes	yes	yes	yes				yes					
Active acoustic monitors	yes	yes	yes	yes					yes				yes
Tags	yes	yes	yes	yes			yes	yes				yes	
Environmental sample collectors	yes	yes	yes	yes	yes	yes		yes	yes	yes	yes		
Vibration sensors													yes
Light/heat sensors				yes	yes								
Radar	yes	yes	yes	yes				yes					yes
Metocean condition sensors	yes	yes	yes		yes	yes				yes			
Nets, traps, and other items for organism collection	yes	yes	yes				yes	yes				yes	

Data Categories	Presence/ distribution/ use pattern/ seasonality	Abundance and population dynamics	Demography and life history/life stages	Behavior and behavioral response (short- and long-term)	Oceanographic	Productivity/ upwelling	Physiological health and growth	Biodiversity/ biomass/ species richness	Habitat composition/recovery	Water quality	Sediment composition, movement, and toxicity	Trophic relationships	Injury/ Mortality
Imaging systems	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes
Biological/ physiological samplers/ monitors	yes	yes	yes				yes					yes	

Table K4. *Data categories and relevant sensors/data collectors for Fish and Invertebrates*

Data Categories	**Presence/ distribution/ use pattern/ seasonality**	**Abundance and population dynamics**	**Demography and life history/life stages**	**Behavior and behavioral response (short- and long-term)**	**Oceanographic**	**Productivity/ upwelling**	**Physiological health and growth**	**Biodiversity/ biomass/ species richness**	**Habitat composition/recovery**	**Water quality**	**Sediment composition, movement, and toxicity**	**Trophic relationships**	**Injury/Mortality**
Related Fish & Invertebrates Impact Topics	Physical habitat alteration and benthic ecology impacts	Physical habitat alteration and benthic ecology impacts		Physical habitat alteration and benthic ecology impacts	Physical habitat alteration and benthic ecology impacts	Indirect ecosystem alteration	Physical habitat alteration and benthic ecology impacts		Physical habitat alteration and benthic ecology impacts		Physical habitat alteration and benthic ecology impacts	Physical habitat alteration and benthic ecology impacts	Physical habitat alteration and benthic ecology impacts
	Indirect ecosystem alteration	Indirect ecosystem alteration		Indirect ecosystem alteration	Indirect ecosystem alteration	Planktonic community dynamics	Indirect ecosystem alteration		Indirect ecosystem alteration		Indirect ecosystem alteration	Indirect ecosystem alteration	Indirect ecosystem alteration
	Behavioral ecology and spatial connectivity changes	Behavioral ecology and spatial connectivity changes		Behavioral ecology and spatial connectivity changes	Behavioral ecology and spatial connectivity changes		Behavioral ecology and spatial connectivity changes		Behavioral ecology and spatial connectivity changes			Behavioral ecology and spatial connectivity changes	
	Impacts to population dynamics	Impacts to population dynamics		Impacts to population dynamics	Impacts to population dynamics		Impacts to population dynamics		Planktonic community dynamics				Impacts to population dynamics
	Planktonic community dynamics				Planktonic community dynamics								
Relevant Sensors / Data Collectors													
Passive acoustic monitors	yes	yes	yes	yes				yes					
Active acoustic monitors	yes	yes	yes	yes					yes				yes
Tags	yes	yes	yes	yes			yes	yes				yes	
Environmental sample collectors	yes	yes	yes	yes	yes	yes		yes	yes	yes	yes		
Vibration sensors													yes

Data Categories	Presence/ distribution/ use pattern/ seasonality	Abundance and population dynamics	Demography and life history/life stages	Behavior and behavioral response (short- and long-term)	Oceanographic	Productivity/ upwelling	Physiological health and growth	Biodiversity/ biomass/ species richness	Habitat composition/recovery	Water quality	Sediment composition, movement, and toxicity	Trophic relationships	Injury/Mortality
Light/heat sensors				yes	yes								
Radar	yes	yes	yes	yes				yes					yes
Metocean condition sensors	yes	yes	yes		yes	yes				yes			
Nets, traps, and other items for organism collection	yes	yes	yes				yes	yes				yes	
Imaging systems	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes
Biological/ physiological samplers/ monitors	yes	yes	yes				yes					yes	