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California Energy Commission

DRAFT CONSULTANT REPORT

Sea Space Analysis for Wave and Tidal Energy

Prepared for: California Energy Commission
Prepared by: Aspen Environmental Group, Integral Consulting Inc.,
H.T. Harvey & Associates

March 2025| CEC-700-2025-004-D

California Energy Commission

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ABSTRACT

Senate Bill 605 (SB 605, Padilla, Chapter 405, Statutes of 2023) directs the California Energy Commission to evaluate the feasibility, costs, and benefits of using wave energy and tidal energy as forms of clean, renewable energy for California. This work is to be done in coordination and consultation with the California Coastal Commission, the Department of Fish and Wildlife, the Ocean Protection Council, and the State Lands Commission. Additional outreach on this work includes other state and local agencies, California Native American tribes, the offshore wave energy and tidal energy industry, the commercial and recreational fishing communities, nongovernmental organizations, and other stakeholders.

The evaluation of feasibility, costs, and benefits were discussed in a report published in November 2024 and summarized in the draft *2024 Integrated Energy Policy Report Update (IEPR Update)*, published in December 2024. This second draft report analyzes suitable sea space for deploying wave and tidal energy projects in state and federal waters. In identifying suitable sea space, this report considers existing data and information of wave and tidal energy resource potential and commercial viability of current technologies, the protection of cultural and biological resources, monitoring and adaptive management techniques, and required transmission facilities and infrastructure.

Keywords: Offshore renewable energy, wave and tidal energy, transmission, cultural and biological resources, renewable energy, Senate Bill 605

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EXECUTIVE SUMMARY

This report complies with the component of Senate Bill (SB) 605 (Padilla, Chapter 405, Statutes of 2023). The law requires the California Energy Commission, in coordination and consultation with the California Coastal Commission, the Department of Fish and Wildlife, the Ocean Protection Council, and the State Lands Commission "to identify suitable sea space for offshore wave energy and tidal energy projects in state and federal waters." As required by SB 605, this report also addresses conflicts and mitigation approaches.

This report is the second of two reports that comply with the SB 605 requirements. The November 2024 SB 605 report, *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits*, details existing wave and tidal generation technologies, feasibility of wave and tidal energy, permitting requirements, economic and workforce development, and monitoring strategies.

Within this second report focused on sea space identification, Chapter 1 describes California's wave and tidal energy resources, illustrated with maps of the state's coast. Wave and tidal energy can be harnessed through different technologies to convert the kinetic energy from water movements into electricity. Wave energy conversion captures energy from ocean waves, while tidal energy conversion captures energy from ocean circulation patterns, cyclical movement due to tides, or the flow of rivers and streams. Chapter 1 outlines the analysis required to define marine energy resources, including defining resource potential while considering power matrices and device specifications, as well as site-specific considerations. A power matrix defines the expected energy output of a specific technology at varying resource levels. Finally, Chapter 1 considers economic viability. These factors were then used to define a set of resource potential maps and a geodatabase for Southern, Central, and Northern California. The highest energy resources available for wave energy converters exist farther offshore, and there are limited data available for nearshore conditions (within 50 meters water depth or less). Tidal energy has fewer opportunities than wave energy in the state because of a small number of suitable tidal inlets and areas of restricted flow, although there are potential high tidal resource areas identified in Central and Northern California.

Chapter 2 describes constraints to commercial viability, including permitting, potential impacts, and proximity to ports and marine industry centers. The chapter summarizes the strengths and weaknesses of the various regions of the state for marine energy and defines commercial-scale and near-term distributed (small-scale) generation. Future commercial-scale opportunities need to consider the alignment of coastal energy demand, given the concentration of California's population in Southern and Central California, with the locations of wave and tidal resources, which are greatest in the north of the state.

However, near-term distributed applications for wave and tidal energy are likely to be focused on monitoring buoys (for example, buoys equipped with sensors to measure temperature or wind speed) and navigational buoys (for example, buoys to mark areas or zones in the waterways), aquaculture (for example, fish, shellfish, seaweed farming), and desalination (i.e. the process of removing salt and other impurities from seawater or brackish water to produce fresh water). These technologies also support the "Powering the Blue Economy" initiative, which seeks to support the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems. Further, Chapter 2 describes examples of previous California marine energy projects. Additional worldwide projects are listed in Appendix B: Case Studies.

Chapter 3 identifies suitable sea space for wave and tidal energy and potential conflicts that exist in areas with generation potential. It addresses environmental resources and protected areas, including marine protected areas; national marine sanctuaries; cultural and historical resources, including Native American cultural sites and viewsheds; as well as shipwrecks and other archaeological sites. Other potentially conflicting ocean uses are also defined, including potential interference with commercial and recreational fishing, beaches and shoreline recreation areas, aquaculture, and ocean infrastructure (for example, cables and pipelines).

Chapter 4 describes required electrical infrastructure for transmitting generation to electricity users. It describes onshore and offshore electrical cables and transmission systems, and cable or interconnection requirements for various types of marine energy. The chapter also describes existing wave and tidal energy projects and the infrastructure used for electrical connection to provide insights into the size and scale of the transmission infrastructure required.

Chapter 5 identifies potential environmental impacts that can be created by wave and tidal energy, including descriptions of collision, entrainment, and entrapment of marine species; effects of underwater noise; presence of electromagnetic fields; entanglement; displacement; reduced water quality; and conflict with existing ocean uses. Protective measures to avoid or minimize potential environmental and ecosystem impacts and use conflicts are presented for each set of impacts.

Chapter 6 describes monitoring and adaptive management strategies that can be applied to marine energy. Monitoring is important for detecting the frequency and magnitude of environmental interactions, such as changes to habitats. Adaptive management enables regulators and developers to address potential environmental effects while balancing the economic viability of wave and tidal energy projects. An example of adaptive management is periodically reviewing the monitoring data and adjusting management actions as needed to minimize environmental impacts and improve project outcomes.

Chapter 7 describes the outreach and engagement efforts that were undertaken by the CEC in implementing SB 605 thus far. Outreach included California Native American tribes, commercial and recreational fisheries, environmental nongovernmental organizations, and wave and tidal energy developers. Outreach efforts are expected to continue throughout SB 605 work.

Three appendices are included in the report. Appendix A presents a glossary of terms. Appendix B lists wave and tidal project examples from around the world. Appendix C presents metadata for the geodatabases, a database for spatial (geographic) data, used in developing maps for the report.

CHAPTER 1:
California's Wave and Tidal Energy Resources

1.1 Introduction and Technology Overview

As described in the November 2024 SB 605 report, *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits*,[1] wave energy converter (WEC) devices may be designed for deployment onshore, nearshore, or offshore:

- **Onshore WECs** are typically fixed structures that are deployed on land or in shallow water. These can be integrated into breakwaters or piers, or built as stand-alone structures. Onshore WEC installations are easy to maintain and require less adaptation for use in marine environments as compared with offshore WECs. However, onshore WECs typically generate less electricity than the offshore counterparts because of the decrease in energy as waves propagate to shore.
- **Nearshore WECs** are deployed within a few hundred meters (m) of shore, in water depths of 10–25 m. They are generally mounted directly to the seafloor; however, some devices have floating, semisubmerged, or submerged components as well.
- **Offshore WECs** are deployed in waters deeper than 25 m. These devices may float at the surface, be near the surface (semisubmerged), or be submerged. As such, they require moorings and anchors to hold them in place. These devices exploit the highest energy in waves, before breaking, and therefore must be designed to withstand large forces. Offshore devices are also more difficult and costly to maintain and require longer electrical cables to shore (if grid-connected).
- **Tidal energy** can be generated in areas where there is a large difference in tidal range (between high and low tide). Electricity generated is transmitted via submerged cables to onshore substations.[2]

This chapter summarizes California's wave and tidal energy resources by region, water depth, and proximity to shore. It focuses on theoretical energy resources, with consideration given to potentially constrained areas identified as:

- Marine disposal sites
- U.S. Bureau of Ocean Energy Management (BOEM) wind lease areas

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[1] Lee, Susan and Vida Strong (Aspen Environmental Group). *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits.* California Energy Commission. Publication Number: CEC-700-2024-005, https://efiling.energy.ca.gov/GetDocument.aspx?tn=260013&DocumentContentId=96224. The November 2024 SB 605 Report was delivered by the consultant to the CEC. The findings in that consultant report were summarized in the *Draft 2024 Integrated Energy Policy Report (IEPR) Update* posted on November 26, 2024 (https://efiling.energy.ca.gov/GetDocument.aspx?tn=260322&DocumentContentId=96547), and supported proposed recommendations anticipated for future adoption by the Commission in the *Final 2024 IEPR Update*.

[2] Pacific Northwest National Laboratory. "Tidal Energy: A Comprehensive Guide to Understanding and Harnessing the Power of the Ocean." Accessed February 14, 2025. https://www.pnnl.gov/explainer-articles/tidal-energy.

- Oil and gas planning and lease areas
- Submarine cables and pipelines
- Munitions areas
- U.S. Department of Defense military defense areas
- Danger zones[3]
- Marine protected areas

Some of these potential constraints will be evaluated in more detail in Chapter 3, along with a discussion of marine protected areas and other such classified areas. In that evaluation, some areas will be categorized as "no-go" areas, distinct from what is discussed in this chapter. This chapter aims to highlight the overlap of energy resources and all manner of potential sea-space conflicts, including those that may not be a steadfast barrier to development.

The availability of wave and tidal energy is unevenly distributed along the coastline. Wave energy is highest in the north, and tidal energy is available only where there are physical conditions that result in more rapid tidal flows, typically near major estuaries and bays. Wave and tidal energy statistics are reported in this chapter for three regions:

- Southern California (from the Mexico border north to Point Conception in southwestern Santa Barbara County)
- Central California (from Point Conception north to Bodega Bay in Sonoma County)
- Northern California (from Bodega Bay north to the Oregon border)

The boundaries of these regions were chosen based on common delineations for the regions of California (see Figure 1). These regions also reflect differences in the distribution of wave energy and human population, with the lowest available wave energy and the highest human population in Southern California, whereas Northern California has the highest resource availability and the lowest population. Central California is at the center of the spectrum for both measures. Further, Point Conception serves as a critical juncture where the California Current meets the Southern California Countercurrent, creating a dynamic convergence of two large marine ecosystems.

About 220 terawatt-hours per year (TWhr/yr) is within 10 nautical miles (nm) of the California shoreline.[4] In comparison, the tidal energy resource potential for California has been estimated at 1.8 TWhr/yr. These are the theoretical maximum amounts of energy available, based on the wave or tidal climate. These estimates do not consider technical limitations (how much of that energy can be extracted using existing technologies), which in 2019 was estimated to reduce

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[3] These data represent the location of Danger Zones and Restricted Areas within coastal and marine waters, as outlined by the Code of Federal Regulations (CFR) and the Raster Navigational Charts (RNC). The CFR defines a Danger Zone as, "A defined water area (or areas) used for target practice, bombing, rocket firing or other especially hazardous operations, normally for the armed forces." The CFR defines a Restricted Area as, "A defined water area for the purpose of prohibiting or limiting public access to the area."

[4] Kilcher, L., M. Fogarty, and M. Lawson. 2021. *Marine Energy in the United States: An Overview of Opportunities*. NREL/TP-5700-78773. National Renewable Energy Laboratory, Golden, CO.

the technical resource potential to 91 TWh/yr. Given energy consumption rates from 2019, this amount was estimated to provide enough power for 8.5 million homes.

Tidal energy was estimated to provide sufficient energy for an additional 84,[5] The estimates also do not consider practical limitations, such as overlap with other incompatible marine uses or environmental constraints. These considerations place important limits on potential marine energy production, discussed further in Chapters 1–3 of this report. For energetic, practical and economic reasons, deployment of wave energy converters (WEC) off the California coast are likely to focus on areas closest to shore, particularly those within state waters (typically within three nautical miles of the shoreline). Deployment of WECs in the nearshore region would reduce the cost and complexity of mooring the devices, the length of necessary transmission lines, and monitoring and maintenance costs. Based on existing WEC technologies, most have been designed for deployment in water depths of 100 meters (m) or less. Wave energy testing locations (for example, PacWave and the U.S. Navy Wave Energy Test Site in Hawaii) are also located in water depths of 80 m or less. For this chapter, analysis was focused on areas with a water depth of 200 m or less. This focus allows an assessment of potential technological innovations that may increase the viable depth of deployment of WECs and tidal energy converters (TECs). There is the potential for WECs and TECs to operate without mooring to the seafloor, so they can be deployed at any depth or could be integrated with existing and future oil, gas, or offshore wind platforms in deeper waters.

Chapter 1 is organized as follows:

- Section 1.2: Potential Marine Energy Applications
- Section 1.3: Tidal Energy Resource Potential
- Section 1.4: Wave Energy Resource Potential

1.2 Potential Marine Energy Applications

Marine energy technologies use different methods to harness power based on the available energy and intended uses. When selecting appropriate sites power projects, tidal and ocean current velocities are important to consider for TECs, whereas wave height, wave period, and wave direction are important considerations for WECs.

The Water Power Technologies Office (WPTO) funding opportunity "Oceans of Opportunity: U.S. Wave Energy Open Water Testing" describes the potential application of marine energy in three topic areas (Table 1):

- Topic Area 1: Distributed applications which include Powering the Blue Economy projects (such as supporting aquaculture or powering autonomous vessels)
- Topic Area 2: Community applications
- Topic Area 3: Utility applications (devices that support coastal communities and connect to the energy grid).

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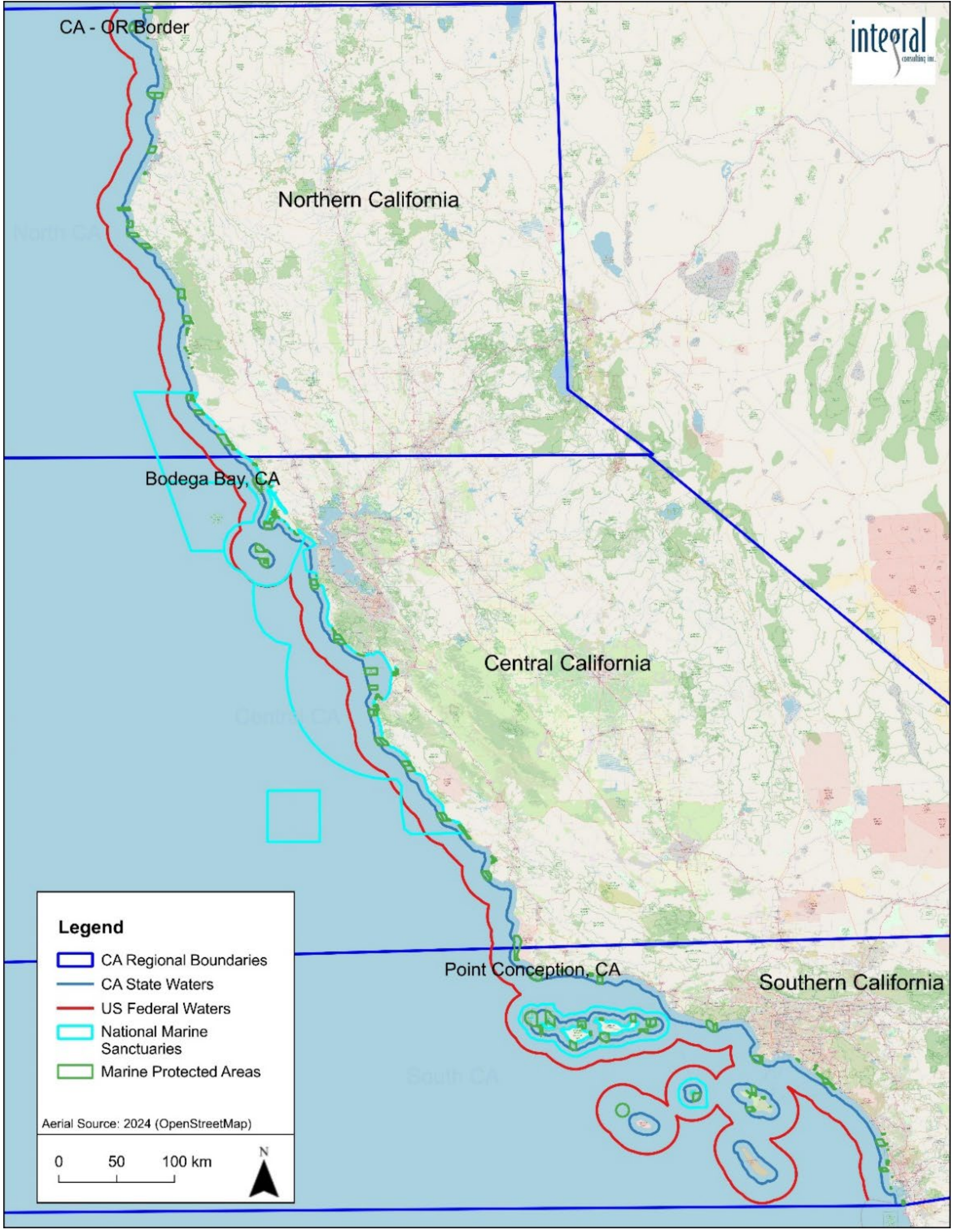
[5] Ibid.

Table 1: DOE Funding Opportunity Announcement Oceans of Opportunity Topic Area (Adapted From Original Table)

Characteristics	Distributed (Topic Area 1)	Community (Topic Area 2)	Utility (Topic Area 3)
Electrical Interconnection	Not grid connected	Prefer non-grid-connected	Connected to electrical grid or major industrial process
Shore Connection	When commercially deployed, would not be reconnected to shore (but may be connected to shore during testing)	Associated with a small coastal community or facility user (usually connected to shore)	Nearshore or offshore
Typical Deployment Area	Associated with a Blue Economy end use at sea (offshore)	Deployed in a nearshore environment (generally defined as state waters according to the Submerged Lands Act and generally 1 to 100 meter depth range)	Nearshore or offshore
Power Output	Average power output likely milliwatts to 50 Kilowatts (kW)	Range of 1–100 kW average power output	Average power output (rated 500 kW or more aggregate, not necessarily per device)

Source: Integral Consulting Inc. analysis

Figure 1: California Regional Marine Energy Resource Assessment Zones



Source: Integral Consulting Inc. analysis

1.2.1 Estimating Marine Energy Resources

There are four key steps in identifying optimal locations for marine energy deployments:

1) Identify available energy resource potential.
2) Align resource characteristics with the operating parameters of individual devices.
3) Consider additional site features that may enhance or hinder potential deployment and operation.
4) Assess costs.

These steps are defined below.

Step 1: Identify Resource Potential

The first step of estimating marine energy resources involves oceanographic studies to measure wave conditions, tidal ranges, and ocean currents. Wave conditions in the Pacific Ocean vary with global weather patterns throughout a range of timescales and directions. Another consideration is the variation in wave conditions generated by geographic features such as islands and other coastal features, which affect the amount and predictability of wave energy available in nearshore areas. Developers typically rely on a combination of historical data and advanced modeling techniques to create a resource profile at a particular site of interest. For this report, resource availability was estimated from publicly available estimates published in the National Renewable Energy Laboratory's (NREL) *Marine Energy Atlas.*[6]

According to the *Marine Energy Atlas*, there are three levels of energy resources assessments:

- **Theoretical resource potential:** the annual average amount of physical energy that is hypothetically available
- **Technical resource potential:** the portion of a theoretical resource that can be captured using a specific technology (see Step 2)
- **Practical resource potential:** the portion of the technical resource that is available when other constraints are considered (for example, economic, environmental, and regulatory considerations).

This report is agnostic to device and location; therefore, it does not measure technical resource potential. Instead, this report summarizes the theoretical resource potential and examines opportunities and constraints for harvesting marine energy in California by exploring ocean use constraints within a spatial framework. Given that this report does not include device-specific technoeconomic estimates, it provides a limited analysis of practical resource potential in the form of a high-level overview of areas along the Californian coast that may be more promising or have more constraints for deployment of WECs or TECs.

Step 2: Power Matrices and Device Specifications

With a clear understanding of the theoretical resource potential, developers can compare site conditions with the performance parameters of a device. This comparison represents the definition of technical resource potential. A power matrix defines the expected energy output of a specific technology at varying resource levels. For example, a TEC output will vary based on water velocity, while the efficiency of a WEC will fluctuate with wave height and period. By mapping the resource data against the power matrix of a device, developers can forecast potential energy generation. This analysis not only helps in estimating energy yield, but also in identifying the optimal design and configuration of devices for the specific environment. Figure 2 shows an example of a hypothetical mechanical power matrix sourced from the U.S.

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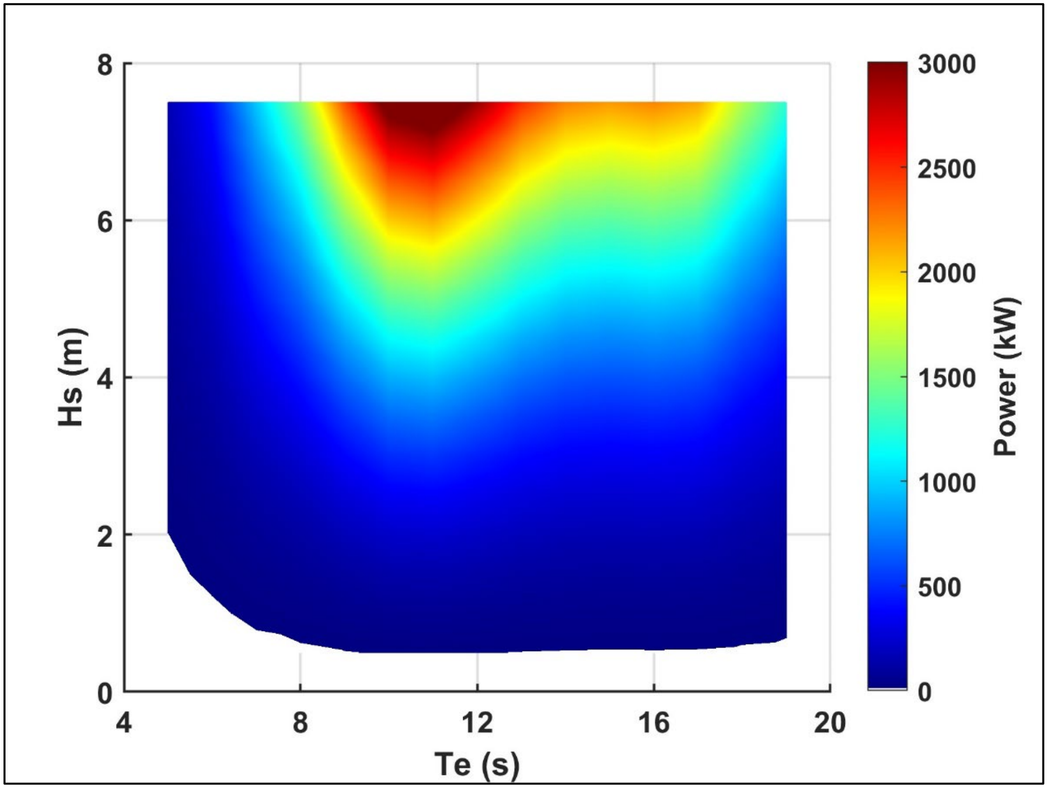
[6] https://maps.nrel.gov/marine-energy-atlas

Department of Energy (DOE)-sponsored Reference Model Project, which developed open-source reference models for marine hydrokinetic energy production estimates.[7]

Figure 2: Mechanical Power Matrix Illustrating Device Power Output in kW for a Range of Significant Wave Heights (Hs) and Wave Energy Periods (Te) for a Reference Model Wave Energy Converter



Power matrices for individual devices are not readily available. Also, this report does not attempt to examine the extent to which wave or tidal energy resource availability is aligned with the necessary conditions for any one type of device.

Source: Neary et al. 2014 (see footnote #7)

Step 3: Site-Specific Considerations

Once resource potential is established, site-specific considerations come into play for selecting the best sites for deploying WECs and TECs. This step involves assessing environmental impacts, regulatory frameworks, and socioeconomic factors. The local ecosystem, including marine habitats and species, plays a crucial role in determining where and how devices can be deployed. Developers should engage with parties concerned — including local communities, Native American tribes, environmental groups, and government agencies — to understand potential concerns and ensure regulatory compliance.

Chapter 3 of this report describes environmental constraints to developing wave and tidal energy. For example, of the roughly 1.4 million hectares (ha) of marine area within California's

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[7] Neary, V., M. Previsic, R. Jepsen, M. Lawson, Y. Yu, A. Copping, A. Fontaine, K. Hallett, and D. Murray. 2014. *Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies.* SAND2014-9040. Sandia National Laboratories, Albuquerque, NM, https://www.osti.gov/servlets/purl/1143279.

state coastal waters, approximately 221 kilohectares (kha), or 16.2 percent, are within marine protected areas (MPAs).[8] A hectare represents an area of 10,000 square meters or about 2.471 acres. Furthermore, 566 kha (40.6 percent) fall within national marine sanctuaries (NMS). There is considerable overlap between MPAs and NMS (about 118 kha), meaning that the total marine area in either an MPA or NMS totals 648 kha (48.1 percent).[9] These figures relate only to state coastal waters (within 3 nm of the shoreline), except between Santa Cruz and Monterey, where state waters extend up to 12 nm offshore to include the entirety of Monterey Bay. They do not include protected areas within San Francisco Bay, which largely cover areas of mudflats, marshes or wetlands and do not overlap with potential wave or tidal energy resources. Chapter 3 of this report provides further information on the environmental information considered in this analysis.

Step 4: Economic Viability and Technological Adaptation

The final step in identifying appropriate locations for marine energy deployments involves assessing the economic viability of the project. This assessment includes calculating the levelized cost of energy[10] and evaluating factors such as capital investment, operational costs, and the expected lifespan of the technology. Developers may need to adapt their technology based on site-specific factors — harsher weather conditions, access requirements, and environmental monitoring — to ensure reliability and efficiency. This report does not quantify financial performance metrics for individual devices; instead, it examines commercial viability considerations at the industry scale in Chapter 2.

1.2.2 Limitations and Caveats – Need for Detailed Site-Specific Data

Translation of resource estimates from offshore wave buoys or large-scale numerical model grid cells to the nearshore requires an application of models with sufficiently fine spatial resolution. While the hindcast models used for these analyses use high-resolution model grids that extend to the coastline, they do not account for localized coastline morphology, coastal structures, and bathymetry that significantly impact nearshore wave dynamics. As a result, potential regions of higher, localized wave energy may not be captured and would require a site-specific resource assessment to determine the available marine energy resource in the areas closest to the shoreline, and in depths of 50m or less, where WECs are more likely to be deployed.[11] This data gap is particularly important for devices integrated with coastal structures since there is limited information on energy resource availability for these device types, and even more limited publicly available information about the interaction of incoming swell energy with those structures.

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[8] State MPAs include state marine reserves, state marine recreational management areas, state marine conservation areas, no-take state marine conservation areas, state marine parks, and marine life refuges.

[9] California Natural Resources Agency. 2024. "Conserved Areas Explorer." Accessed October 10, 2024. California Natural Resources Agency, Sacramento, California, https://experience.arcgis.com/experience/83b5c08cae8b47d3b7c623f2de1f0dcc/page/Marine-Detailed/.

[10] The average cost per kilowatt-hour (kWh) of electricity produced by a system over the lifetime, calculated by dividing the total cost for building and operating the system by the total electrical load served.

[11] Yang, Z., G. Garcia Medina, W. Wu, and T. Wang. 2020. "Characteristics and Variability of the Nearshore Wave Resource on the U.S. West Coast." *Energy.* 203:117818, https://www.sciencedirect.com/science/article/pii/S0360544220309257?via%3Dihub.

Wave energy at the installation location must be estimated through additional wave modeling to establish compatibility with individual WEC power matrices. By completing this detailed modeling and matching WEC devices to local energy demand, it may be possible to identify additional viable locations or opportunities for deployment, such as the pilot project by Eco Wave Power at the AltaSea campus at the Port of Los Angeles.[12]

1.2.3 The Map and Geodatabase

The geodatabase created to assess the available tidal and wave energy resources along the California coastline consists of 47 mapping layers (38 base layers and 9 synthesized layers). Each base layer visually addresses questions regarding competing use, regulatory boundaries, colocation of resources, and potential energy production, along with production asset (wave or tidal energy converter) placement.

Areas where development could be limited were merged to create a complete synthesized layer representing potentially constrained areas for each of the geographic regions to aid in the spatial analysis of viable marine energy areas. Each synthesized constraint layer consists of offshore disposal sites, BOEM wind lease areas, oil and gas planning and lease areas, submarine cables, submarine pipelines, munitions areas, defense areas, danger zones, and MPAs, but does not include NMS, which is further discussed in Chapter 3.[13]

The mean, standard deviation, minimum, and maximum energy density were determined for each tidal and wave power layer and are discussed in the following two sections. The project team then added bathymetry data to these layers to derive availability of each power category based on water depth. Distance-to-shore statistics were calculated for different ranges of wave energy (low, medium, and so forth) to provide additional information about the spatial distribution of the areas of highest energy, as distance to shore is a key driver of economic and logistical factors for marine energy deployments. Distance to shore is not an informative metric for tidal power, as the tidal energy is typically created by features of the shoreline such as embayments and narrow straits, so this measure is not reported for. Instead, the project team selected and analyzed individually promising areas of relatively higher tidal power density.

Appendix A provides a tabular outline of the base and synthesized layers and includes additional metadata for each base layer.

1.3 Tidal Energy Resource Potential

The NREL estimated that tidal energy along the entire U.S. West Coast could produce up to 4.1 TWh/yr with California resources exceeding 1.8 TWh/yr.[14] The estimates are based on the proportion of energy available in wave motion and tidal currents that can be captured using existing TEC technologies. Typical current speeds of 0.5 to 3 m/s are generally targeted for

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[12] https://www.ecowavepower.com/eco-wave-power-receives-final-permit-from-u-s-army-corps-of-engineers-for-first-onshore-wave-energy-project-at-port-of-los-angeles/

[13] Initial indications from regulatory agencies is that deployment of WECs or TECs in MPAs or NMSs would be unlikely to be permittable, but that there may be potential for cable routes to pass through NMS boundaries.

[14] Kilcher, L., M. Fogarty, and M. Lawson. 2021. *Marine Energy in the United States: An Overview of Opportunities*.

consideration of tidal energy conversion.[15] Given this range of current velocities needed for tidal energy conversion, analyses by NREL indicate the entrance to the San Francisco Bay is likely the only site that has true resource potential for commercial tidal energy deployments, representing 89 percent of the tidal energy resource for California. Potential distributed energy applications may also exist for tidal energy generation at Humboldt Bay, lower Eel River, and Tomales Bay.[16]

To evaluate the tidal energy resource potential offshore of California, the annual depth-averaged tidal power density was downloaded from the NREL's Marine Energy Atlas.[17] These data were then separated into the three analysis regions (Southern California, Central California, and Northern California) and then analyzed using an array of statistics, including calculating the mean, maximum, and minimum tidal power density. The project team also analyzed the depth and distance to shore of each grid cell. Finally, the team categorized the tidal power density grid cells into five power categories representing increasing ranges of available tidal power:

- Low tidal power density: <200 W/m^2
- Medium-low: ≥200 to <400 W/m^2
- Medium: ≥400 to <600 W/m^2
- Medium-high: ≥600 to <800 W/m^2
- High tidal power density: ≥800 W/m^2

The project team selected the power categories using equal interval spacing over the range of tidal power density values. These power categories, or bins, allowed for additional classification of the available tidal energy resources within each of the geographic regions, which is summarized in the sections below.

1.3.1 Southern California Tidal Energy Resource Potential

The Southern California region extends from the Mexico border to Point Conception and is the most densely populated. The absence of large tidal inlets or geographically restricted flows means that this region has limited to no available tidal energy resources. (Tidal power density is low throughout the region, as shown in Figure 3**.**) Moreover, the presence of MPAs and military installations around the Channel Islands further complicates the deployment of marine energy infrastructure in the few areas that have some potential tidal energy availability.

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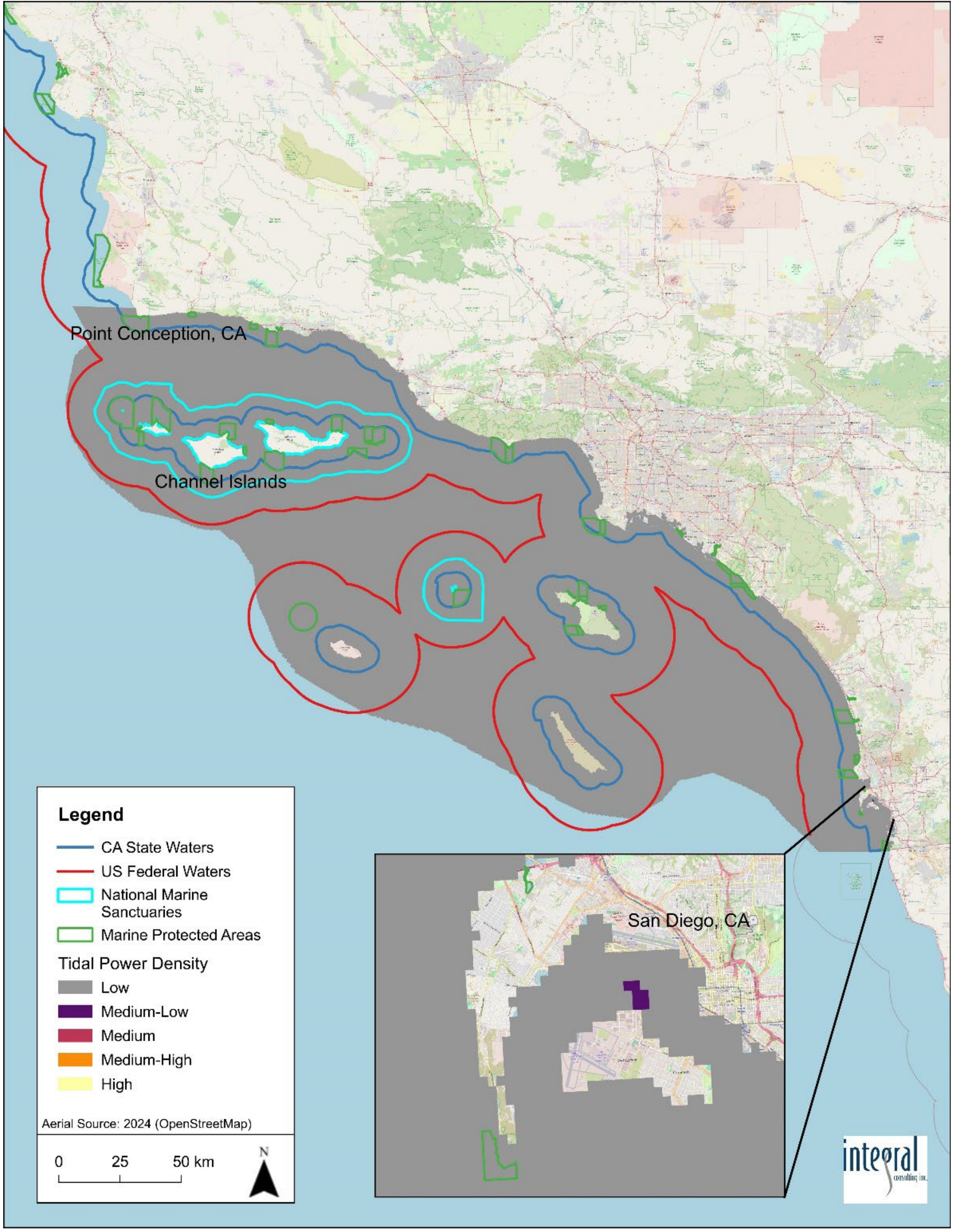
[15] Ibid.

[16] Ibid.

[17] Haas, K. A., H. M. Fritz, S. P. French, B. T. Smith, and V. Neary. June 29, 2011. *Assessment of Energy Production Potential From Tidal Streams in the United States*. Georgia Tech Research Corporation, Atlanta, Georgia, https://www.osti.gov/servlets/purl/1219367/.

Figure 3: Annual-Averaged Tidal Power Density: Southern California Coastline



Source: Integral Consulting Inc. analysis

As shown in Figure 3, Southern California has mostly low tidal power density with one small region within San Diego Bay that has medium-low tidal power density. There are no regions of medium or higher tidal energy in Southern California. The average tidal power density for the low bin is 5 W/m^2 and 306 W/m^2 for the medium-low bin.

The bathymetric data within each of the regions were analyzed to highlight any patterns in water depth where areas of potential tidal energy exist. (Mean sea level of 0 m was assumed to calculate depth.) Table 2 summarizes water depth statistics and the percentage of the tidal energy resource areas in Southern California within potentially constrained zones and the total marine area that falls within each tidal power bin. These potentially constrained areas are mainly composed of oil and gas planning areas, active oil and gas leases, and areas of oil and gas resource potential. Other potentially constrained areas, which comprise a much smaller proportion of the total potential conflict area, include munitions and explosives of concern, ocean disposal sites, and MPAs.

Table 2: Tidal Power Density Bins and Overlap With Potentially Constrained Areas: Southern California

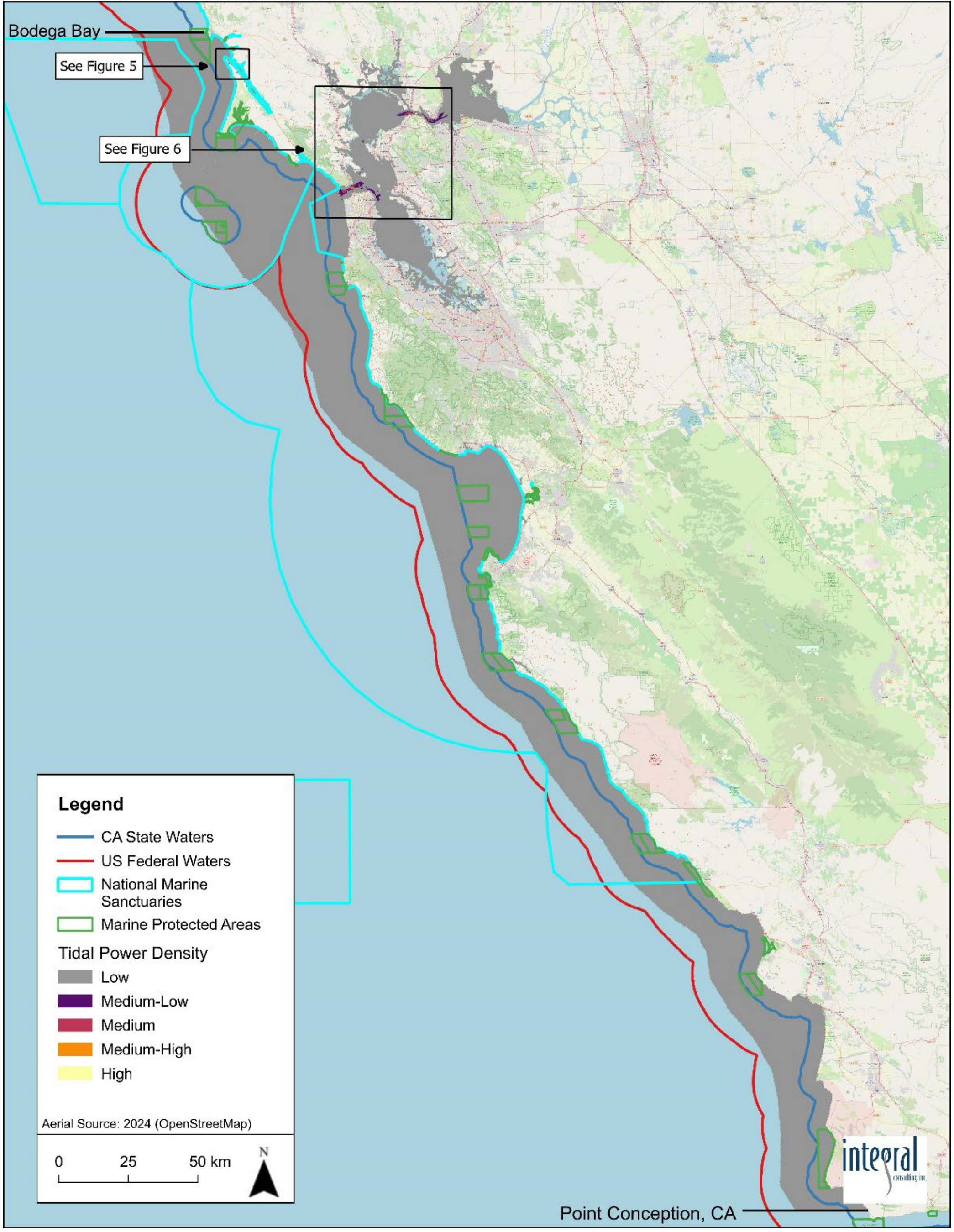
Tidal Power Bin	Mean (Range) Depth (m)	Percentage of Area Overlapping With Potentially Constrained Zones	Tidal Power Area in Unconstrained Zones (ha)
Low	647 (10 – 1916)	92.6	258,428
Medium-Low	15 (16 – 16)	14.7	46
Medium	n/a	n/a	n/a
Medium-High	n/a	n/a	n/a
High	n/a	n/a	n/a

Source: Integral Consulting Inc. analysis

1.3.2 Central California Tidal Energy Resource Potential

The Central California region extends from Point Conception to Bodega Bay, north of San Francisco Bay. San Francisco Bay has the largest area of medium-high and high tidal energy resource along the California coastline (Figure 4). Accelerated water movement through the bay entrance and estuarine channels offers the highest potential for harnessing tidal power. However, this potential is tempered by the presence of busy shipping lanes and commercial vessel anchorages that cover much of these waters, posing significant challenges for marine energy deployments. Outside the San Francisco estuary, the overall tidal power density is comparatively low.

Figure 4: Annual-Averaged Tidal Power Density: Central California Coastline



Source: Integral Consulting Inc. analysis

Most of the higher tidal power resource zones occur in shallower water near or within tidal inlets, which aligns with the zones within San Francisco Bay. Table 3 shows water depth statistics and the percentage of the tidal energy resource areas in Central California within potentially constrained zones and the total marine area that falls within each tidal power bin.

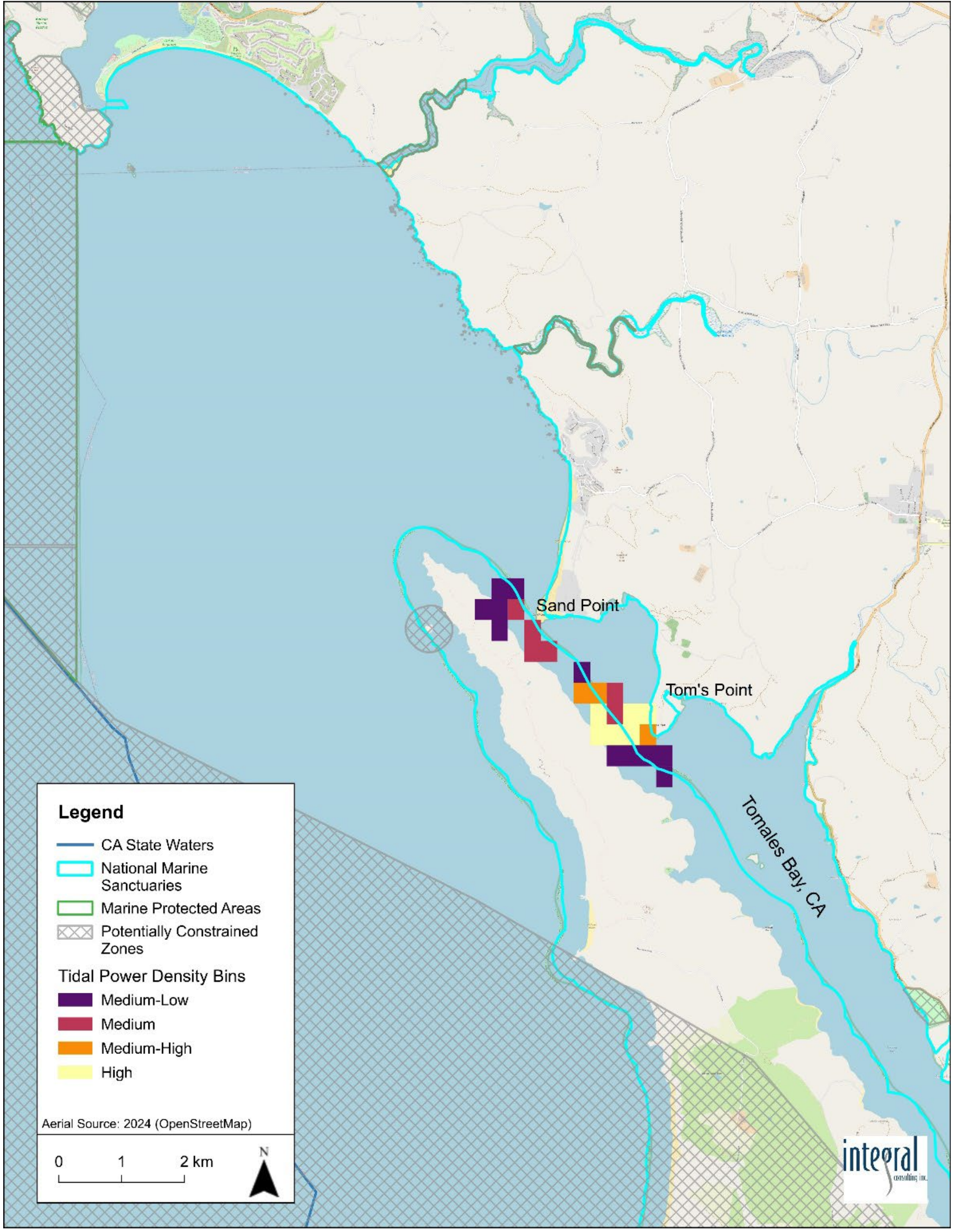
Table 3: Tidal Power Density Bins and Overlap With Potentially Constrained Areas: Central California

Tidal Power Bin	Mean (Range) Depth (m)	Percentage of Area Overlapping With Potentially Constrained Zones	Tidal Power Area in Unconstrained Zones (ha)
Low	150 (0 2,000)	71	399,824
Medium-Low	22 (7 - 103)	51	1,442
Medium	37 (4 – 88)	59	274
Medium-High	47 (25 – 88)	58	48
High	1 (0 - 7)	7	80

Source: Integral Consulting Inc. analysis

The project team considered three areas in the broader San Franscisco region for additional spatial analysis because of the associated higher energy potential. The first is a 134-ha area at the mouth of Tomales Bay, which is north of San Franciso Bay and south of Bodega Bay, with an average tidal power density of 566 W/m^2 (Figure 5). The lowest tidal power density bin was excluded from Figure 5 to highlight the areas with greater potential energy. Two land protrusions amplify tidal currents in this area: Sand Point and Tom's Point. The widths at these pinch points are about 400 and 770 m, respectively. This area lies entirely within the Greater Farallones NMS (not shown below), which means that resource utilization is likely not possible. Constraints due to protected areas and NMS are discussed further in Chapter 3.

Figure 5: Tomales Point Area of Potential Tidal Energy Resource



Source: Integral Consulting Inc. analysis

The main areas of the highest tidal energy resource potential within the region are within San Francisco Bay, within the strait under the Golden Gate Bridge, as well as north San Francisco Bay and San Pablo Bay (Figure 6).[18]

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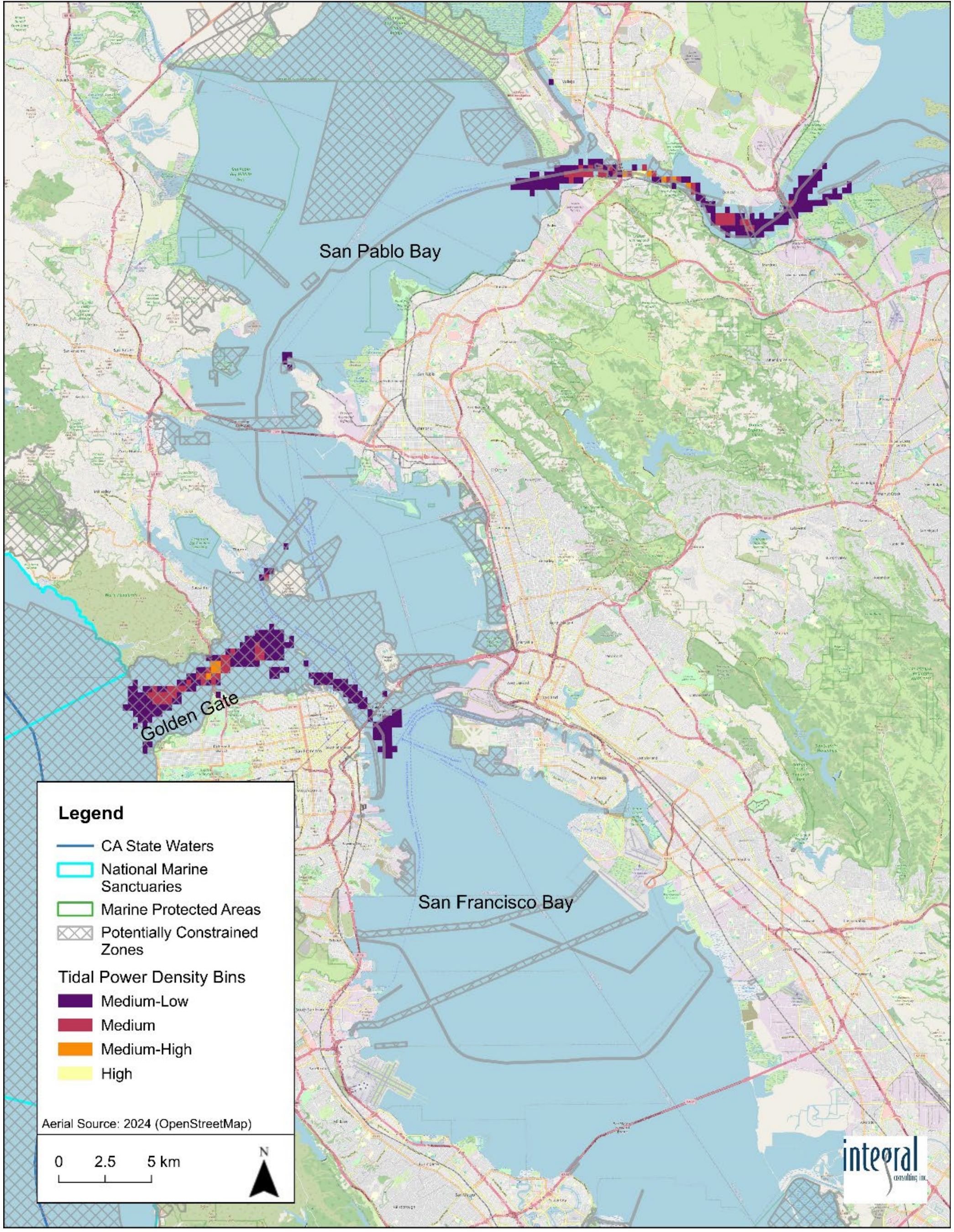
[18] The lowest tidal power density bin was excluded from the map to highlight the areas with greater potential energy.

Figure 6: San Francisco Bay Area of Potential Tidal Energy Resource



Source: Integral Consulting Inc. analysis

These areas exchange a large volume of water during the flood and ebb tidal cycles, providing regions of higher tidal power density. This region of California has a greater potential for tidal energy compared to the Southern California region; however, as discussed below, these higher-energy regions coincide with exclusionary areas.

The main tidal channels within San Francisco Bay have the highest tidal power densities; however, they are almost entirely covered by potentially constrained areas, including former defense sites, major shipping channels, and several submarine cable crossings. Passenger ferry routes and the BART tunnel between Oakland and San Francisco, though not included in

Figure 6, are also potentially constraining factors. These transportation routes overlap almost completely with at least one other potentially constraining factor, and thus the presence of these routes does not impose significant additional limitations.

The Carquinez Strait, at the eastern portion of San Pablo Bay, is a potential deployment area with high tidal power; however it overlaps with navigational use and underwater pipes or cables or both. The strait is relatively uniform in width (about 2,300 m wide), and the higher power density spans almost the entire width of the strait. The area of interest is about 19 kilometers (km) in length, and the estimated average power density of the usable area is about 356 W/m^2 over roughly 898 ha, excluding the areas within potentially constrained areas.

1.3.3 Northern California Tidal Energy Resource Potential

The Northern California region extends from Bodega Bay to the Oregon border and has the lowest population of the three regions. The overall tidal power density for Northern California is relatively low. The water depth for the tidal power bins for Northern California show that most of the higher-resource zones occur in shallower water in river areas and in areas not subject to the same types of overlay constraints described in this study (Table 4). The depth statistics presented in this table are based on average water depths within gridded areas and relatively coarse bathymetric data. More detailed site-specific data collection would be necessary to determine the true physical parameters within an area of interest for project development.

Table 4: Tidal Power Density Bins and Overlap With Potentially Constrained Areas: Northern California

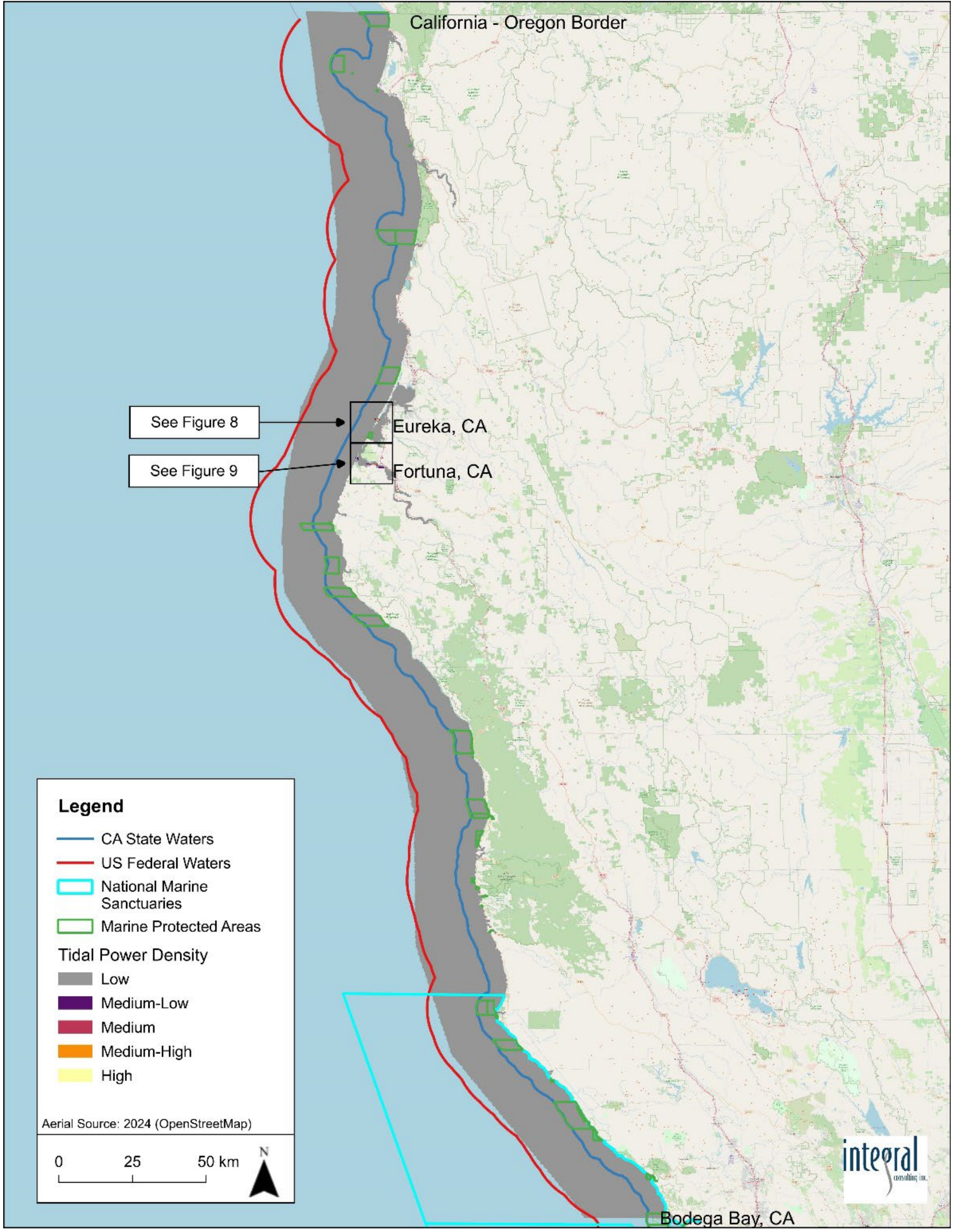
Tidal Power Bin	Mean (Range) Depth (m)	Percentage of Area Overlapping With Potentially Constrained Zones	Tidal Power Area in Unconstrained Zones (ha)
Low	159 (10 – 1570)	78	236,702
Medium-Low	0 (0 – 21)	0	304
Medium	2 (2 – 2)	0	93
Medium-High	15 (0 – 24)	0	59
High	9 (0 – 19)	0	17

Source: Integral Consulting Inc. analysis

In this region, the vast majority of potentially constrained areas are comprised of offshore oil and gas resources and oil and gas planning areas. Both areas are located farther offshore, about 0.8 to 3.5 nautical miles on average from the shoreline. The third most common potentially constrained area type is protected areas such as state-designated Marine Conservation Areas, which intersect with a large percentage of the potential WEC potential installation areas.

Two areas in this region, one at the mouth of Humbolt Bay in Eureka and one at the mouth of the Eel River near Fernbridge (Figure 7), have large tidal prisms that flow through constricted tidal channels, creating a large tidal energy potential. These areas do not overlap with the constraint data layers used in the analysis in this report; however, there are practical constraints that limit potential for resource utilization, either because of physical parameters (water depth) or operational requirements (navigational dredging).

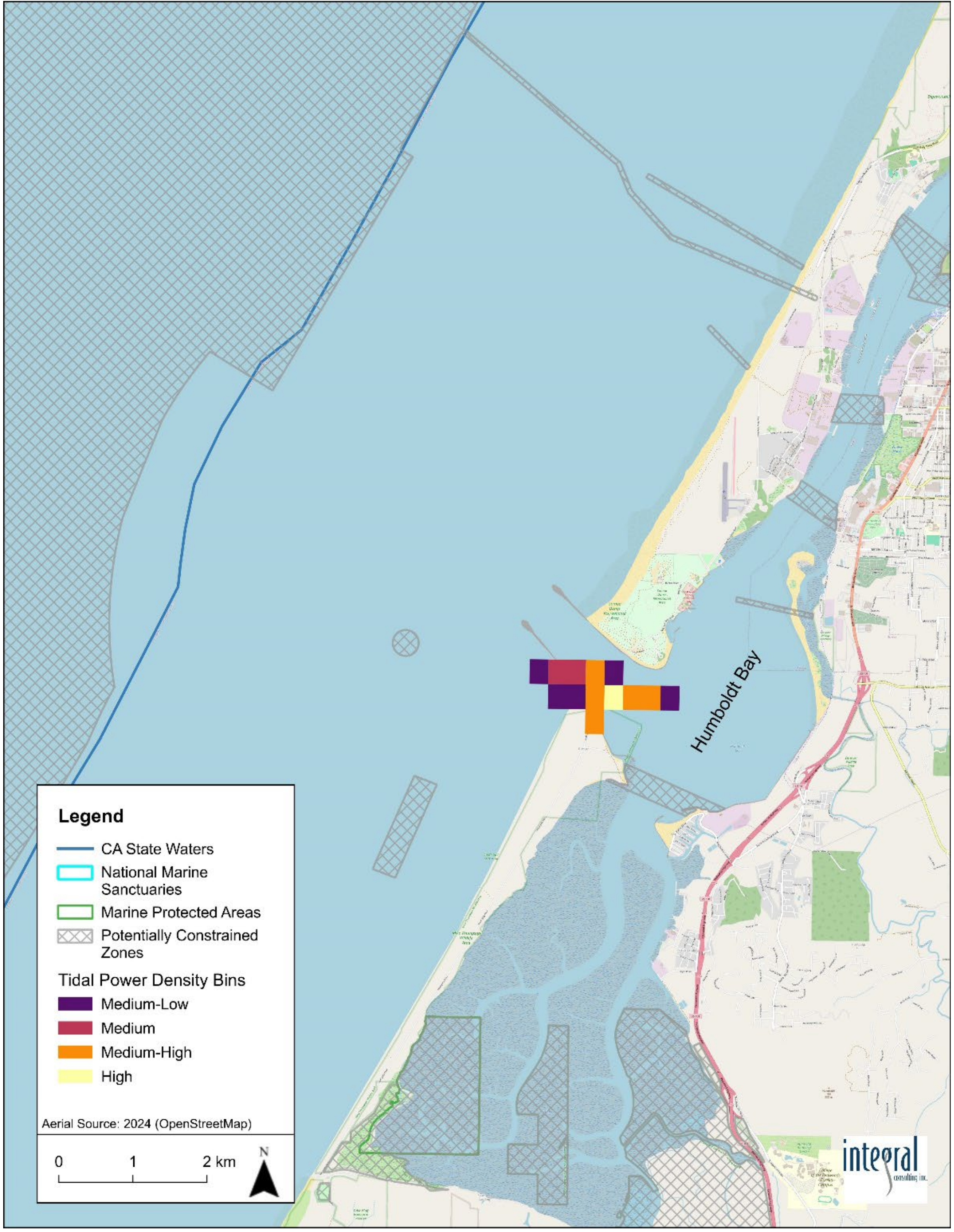
Figure 7: Annual-Averaged Tidal Power Density: Northern California Coastline



Source: Integral Consulting Inc. analysis

The area in the mouth of Humboldt Bay has an estimated average power density of about 486 W/m2 over roughly 75.6 ha (Figure 8). The area sits between two manmade jetties at a width and length of 630 m and 1850 m, respectively. The energetic regions in Humboldt Bay, however, are within an important navigational corridor dredged annually by the U.S. Army Corps of Engineers, making it likely infeasible for TEC deployment under current conditions.

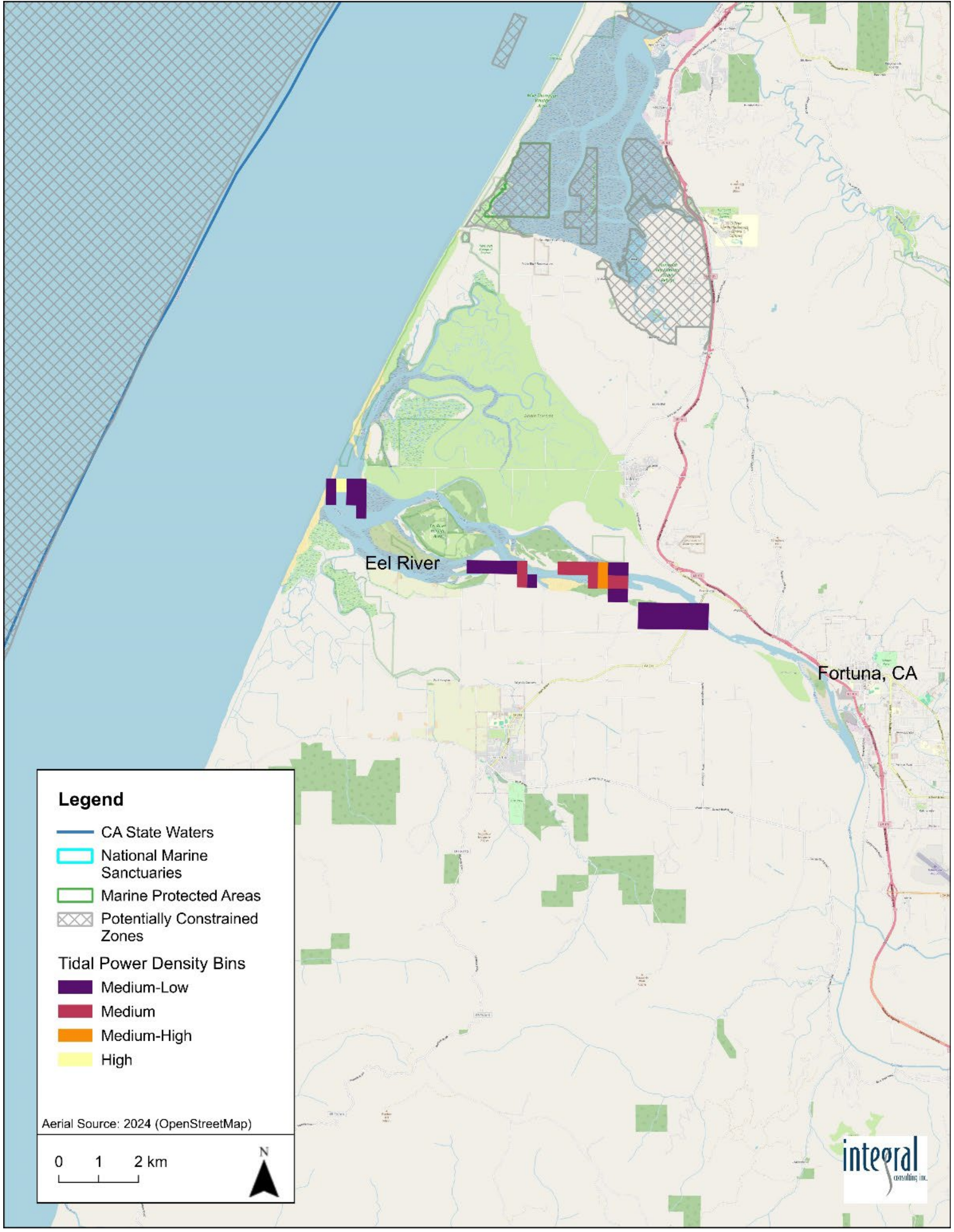
Figure 8: Humboldt Bay Area of Potential Tidal Energy Resource



Source: Integral Consulting Inc. analysis

The second site with high tidal energy in Northern California is an area east of the mouth of the Eel River, near Fernbridge (Humboldt County) (Figure 9). The river separates into multiple branched channels about 140 m wide as it gets closer to the outlet, limiting the available space for marine energy infrastructure. Upriver, toward Fernbridge, the river is about 150 m wide. The river mouth has the highest power density because of the small opening to the ocean (about 110 m wide). The average power density of the entire area is about 400 W/m^2 over roughly 176 ha. None of these areas of interest intersect with potential sea-space constraints; however, environmental constraints as described in Chapter 3 could pose challenges.

Figure 9: Eel River Area of Potential Tidal Energy Resource



Source: Integral Consulting Inc. analysis

1.4 Wave Energy Resource Potential

The estimated power available from waves along California's coastline has been reported at more than 37 gigawatts (GW).[19] Using the assumption that existing WEC technologies could extract around 20 percent of this available power, the *California Ocean Wave Energy Assessment*[20] determined in 2007 that waves could provide 23 percent of the state's energy needs. This estimate represents the maximum theoretical resource potential based on energy analyses and does not consider practical constraints or socioeconomic considerations (the practical resource potential), nor does the estimate take into account projected technological innovations for WECs (the possibility of changes in the technical resource potential).

To evaluate the wave energy resource potential for offshore California, the omnidirectional wave power[21] estimates for 2010 were downloaded from the NREL's Marine Energy Atlas[22] and averaged over the entire year. The annual-averaged wave energy data were divided into the three geographic regions, constrained to and limited to include only areas where water depths were less than or equal to 200 m. Distance to shore and water depth were calculated for the remaining wave power estimate points. Finally, the data were separated into five bins, representing increasing ranges of available energy:

- Low omnidirectional wave power: < 10 kW/m
- Medium-low: ≥ 10 to < 20 kW/m
- Medium: ≥ 20 to < 40 kW/m
- Medium-high: ≥ 40 to < 50 kW/m
- High omnidirectional wave power: ≥ 50 kW/m

These bins allowed for additional classification of the available resources within each of the geographic regions, which is summarized below. The bin boundaries were selected to represent a roughly equal set of intervals that covered the range of annual average wave power between the Californian coast and the 200-m water depth contour. Due to the scale of grid cells used for wave power estimates, potential regions of higher, localized wave energy may not be captured. These potential regions would require a site-specific resource assessment to determine the available marine energy resource in the areas closest to the shoreline within 50 m of the California coast.

The available wave data are point-based rather than area-based. Although it is possible using GIS techniques to convert these point estimates to buffered polygons or a raster grid, these methods introduce potential errors that do not reflect underlying geographical variability. This

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[19] Beyene, A., and J. H. Wilson. 2007. "Digital Mapping of California Wave Energy Resource." *International Journal of Energy Research*. 31:1156–1168, https://cdip.ucsd.edu/themes/media/docs/publications_references/journal_articles/Digital_Mapping_of_California_Wave_Energy_Resource.pdf.

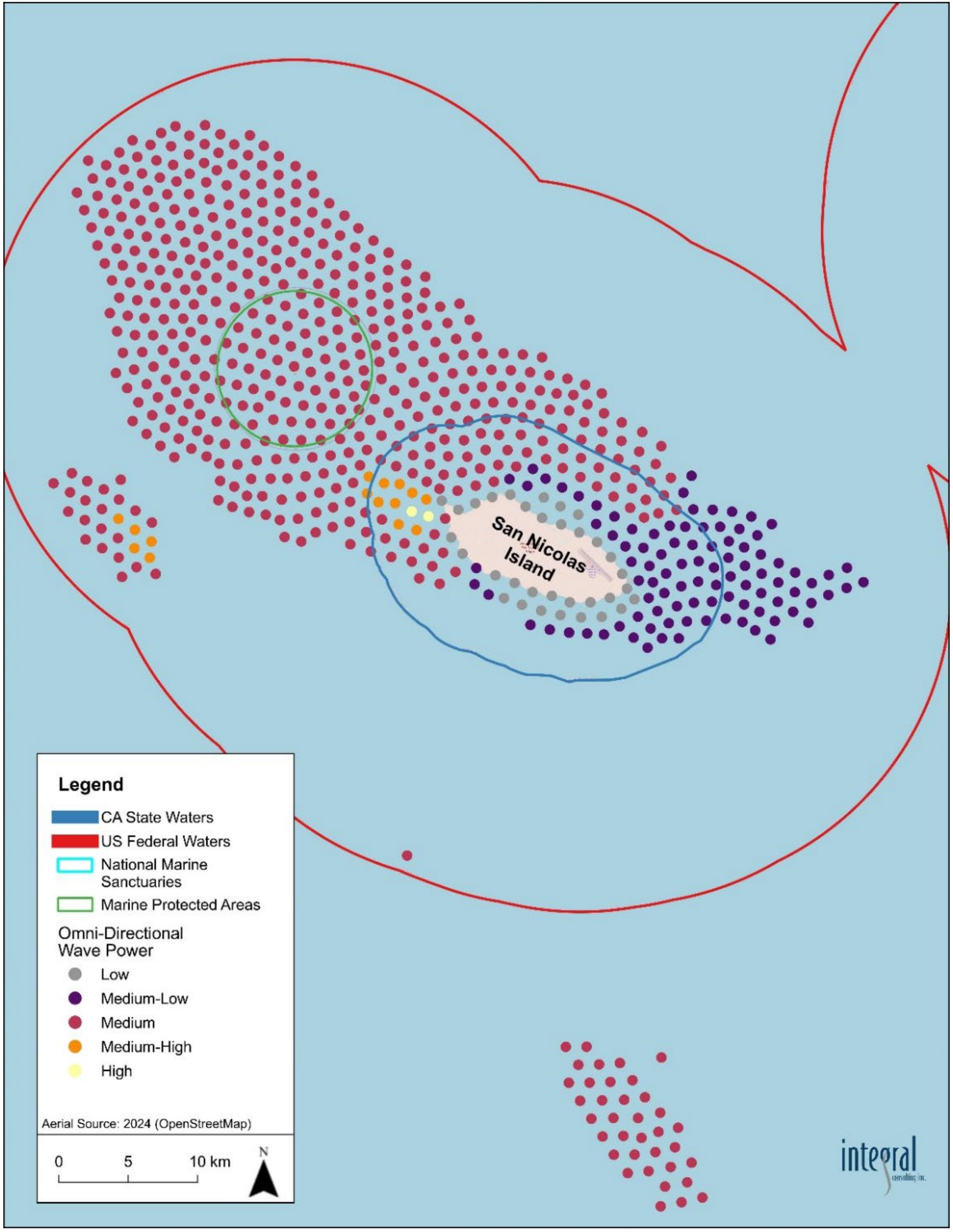
[20] Electric Power Research Institute. 2007. *California Ocean Wave Energy Assessment*. Final Project Draft. CEC-500-206-119-D. Electric Power Research Institute, Palo Alto, CA. 85 pp., https://www.re-vision.net/documents/California%20Ocean%20Wave%20Energy%20Assessment.pdf.

[21] The capture of wave energy from all directions.

[22] NREL. "Marine Energy Atlas," https://maps.nrel.gov/marine-energy-atlas.

distinction is particularly important when translating wave energy data toward the shoreline or around islands, where it is not possible to simply interpolate between two points for which wave energy estimates are available, or assume that wave energy decays in a linear fashion toward the shore. For an example, see Figure 10, which shows high energy on the northwest side of San Nicolas Island and low energy on the sheltered eastern side. Interpolation between these points across San Nicolas Island (Ventura County), or toward the shoreline, would erroneously suggest a lower wave energy availability because of averaging over this area.

Figure 10: Wave Energy Point Estimates in the Vicinity of San Nicolas Island, Southern California



Source: Integral Consulting Inc. analysis

As a result, summary statistics for wave energy in this report use point counts rather than spatial estimates, which provide a more realistic representation of the underlying wave energy data. Detailed, site-specific modeling would be necessary before WEC deployment, particularly for nearshore applications.

The wave energy resource is highest in the Northern California region, and in areas farther away from shore, as wave energy is dissipated as waves break in shallower water. In Southern California, wave energy is blocked by Point Conception and the Channel Islands, leading to a relatively modest wave climate. The wave climate of the Central Coast is moderate in the south and increases toward the north of the region. Bathymetric features such as underwater canyons can result in higher energy wave resources closer to shore.

1.4.1 Southern California Wave Energy Resource Potential

While several areas within the Southern California region (Point Conception to the Mexico border) show potential for high wave energy, wave energy diminishes between Los Angeles to San Diego (Figure 11). Here the coastline shifts eastward, and Point Conception and the Channel Islands block larger swells from the northwest, creating a shadowing effect and significantly reducing available wave power. WECs have been tested off the coast of San Diego, and a structure-integrated WEC[23] is approved for the Port of Los Angeles,[24] so the relatively low wave energy potential does not preclude nearshore deployment in this region.

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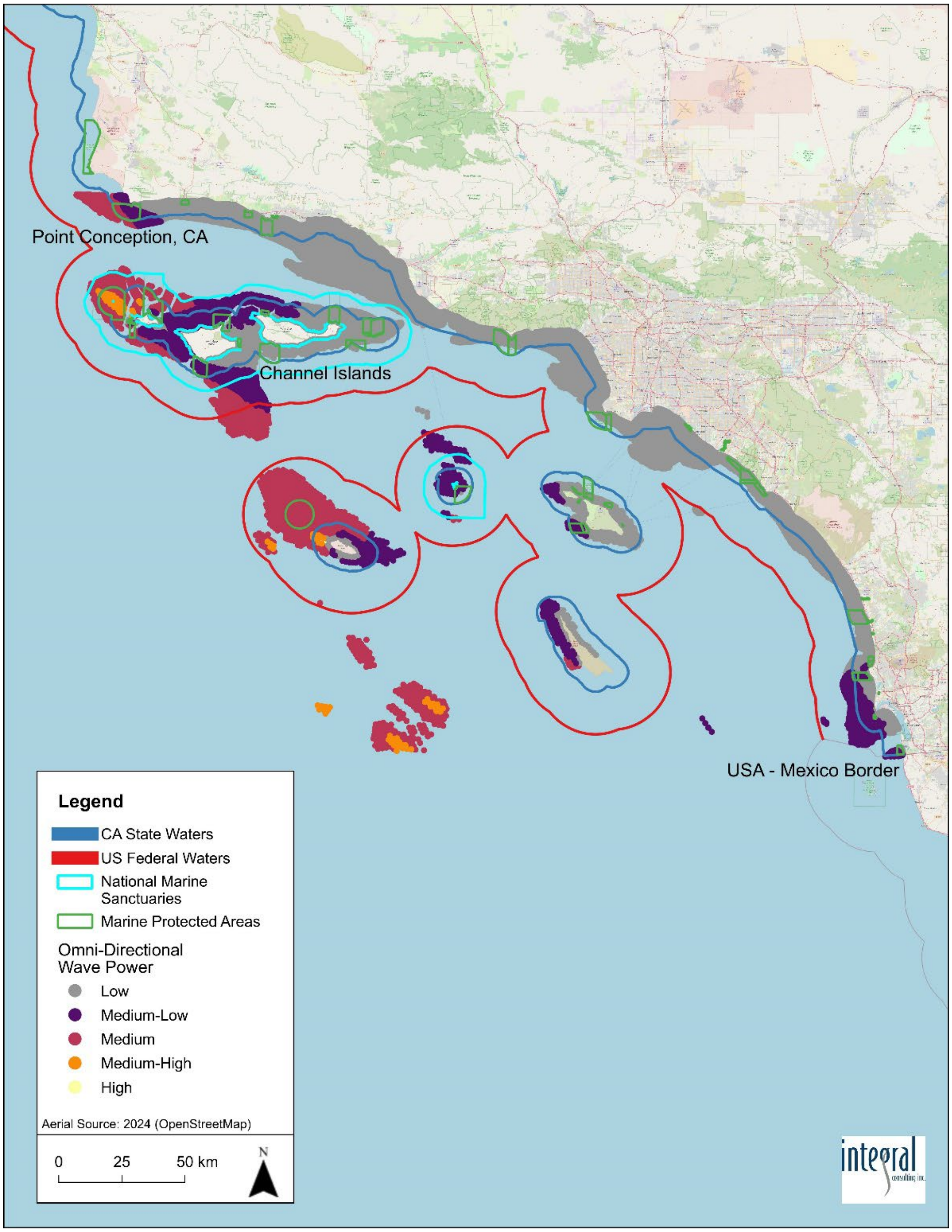
[23] A structure-integrated WEC is designed to be incorporated directly into an existing coastal structure, like a pier, wharf, or breakwater, effectively using the structure itself to capture wave energy and convert it into electricity, rather than deploying a separate, standalone WEC device in the ocean.

[24] Eco Wave Power. November 18, 2024. News release. "Eco Wave Power Receives Final Permit From U.S. Army Corps of Engineers for First Onshore Wave Energy Project at Port of Los Angeles," https://www.ecowavepower.com/eco-wave-power-receives-final-permit-from-u-s-army-corps-of-engineers-for-first-onshore-wave-energy-project-at-port-of-los-angeles/.

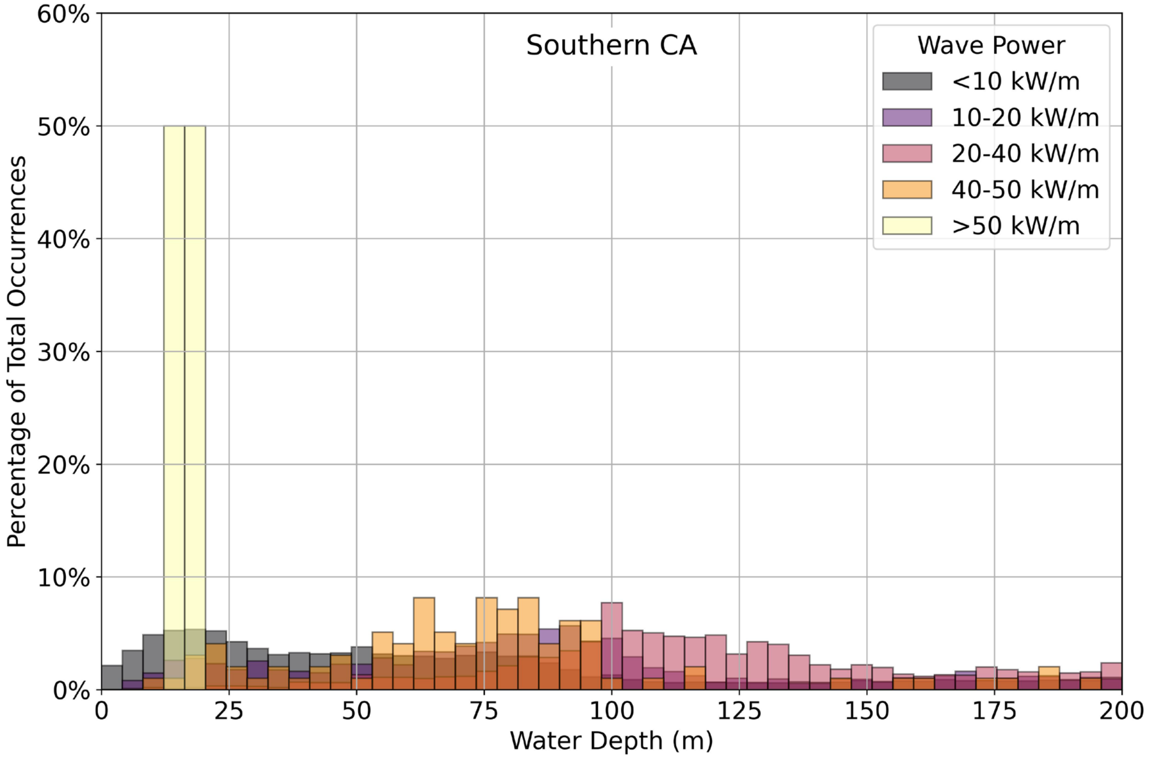
Figure 11: Annual-Averaged, Omnidirectional Wave Power: Southern California Coastline



Source: Integral Consulting Inc. analysis

The bathymetric data within the region were then used to highlight any relationship between water depth and potential wave power (Figure 12). A water level of 0 m mean sea level (MSL) was assumed to convert the bathymetric data to water depth. The first four wave power bins have locations within the full range of depths, from 0 to 200 m; however, the highest wave power occurs only in shallower water depths (that is, < 25 m).

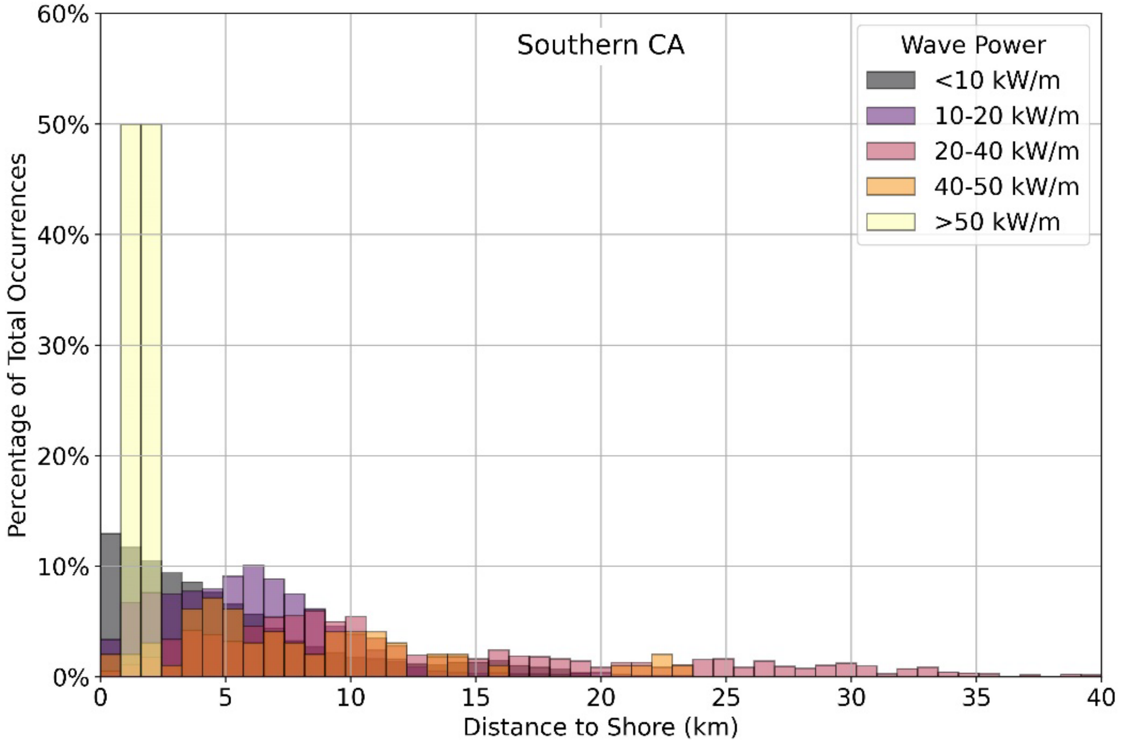
Figure 12: Percentage of Total Occurrences of Wave Power Categories by Water Depth for Southern California



Source: Integral Consulting Inc. analysis

As an additional analysis, the wave power data for Southern California were binned based on distance to the mainland shore (0–5, 5–10, 10–25, 25–50, and > 50 km) to further examine spatial patterns (Figure 13). The majority of the wave energy within 5 km of the shoreline for Southern California ranges from 0 to 10 kW/m, while the majority of offshore wave energy potential is in the range of 20–40 kW/m. The majority of the shallow locations with high wave power (> 50kw/m) occur within a small area around the Channel Islands.

Figure 13: Percentage of Total Occurrences of Wave Power Categories by Distance to Shore for Southern California



Source: Integral Consulting Inc. analysis

In addition to relatively low wave energy close to major population centers such as Los Angeles and San Diego, Southern California also has substantial limitations on available deployment sites because of military, environmental, and navigational constraints (Table 5). These potentially constrained areas include potential oil and gas resources, oil and gas planning areas, MPAs, military danger zones and restricted areas, and areas containing munitions and explosives of concern. Please see Chapter 3 for more detail on marine protected areas and sanctuaries.

Table 5: Potentially Constrained Area Overlap With Wave Bins: Southern California

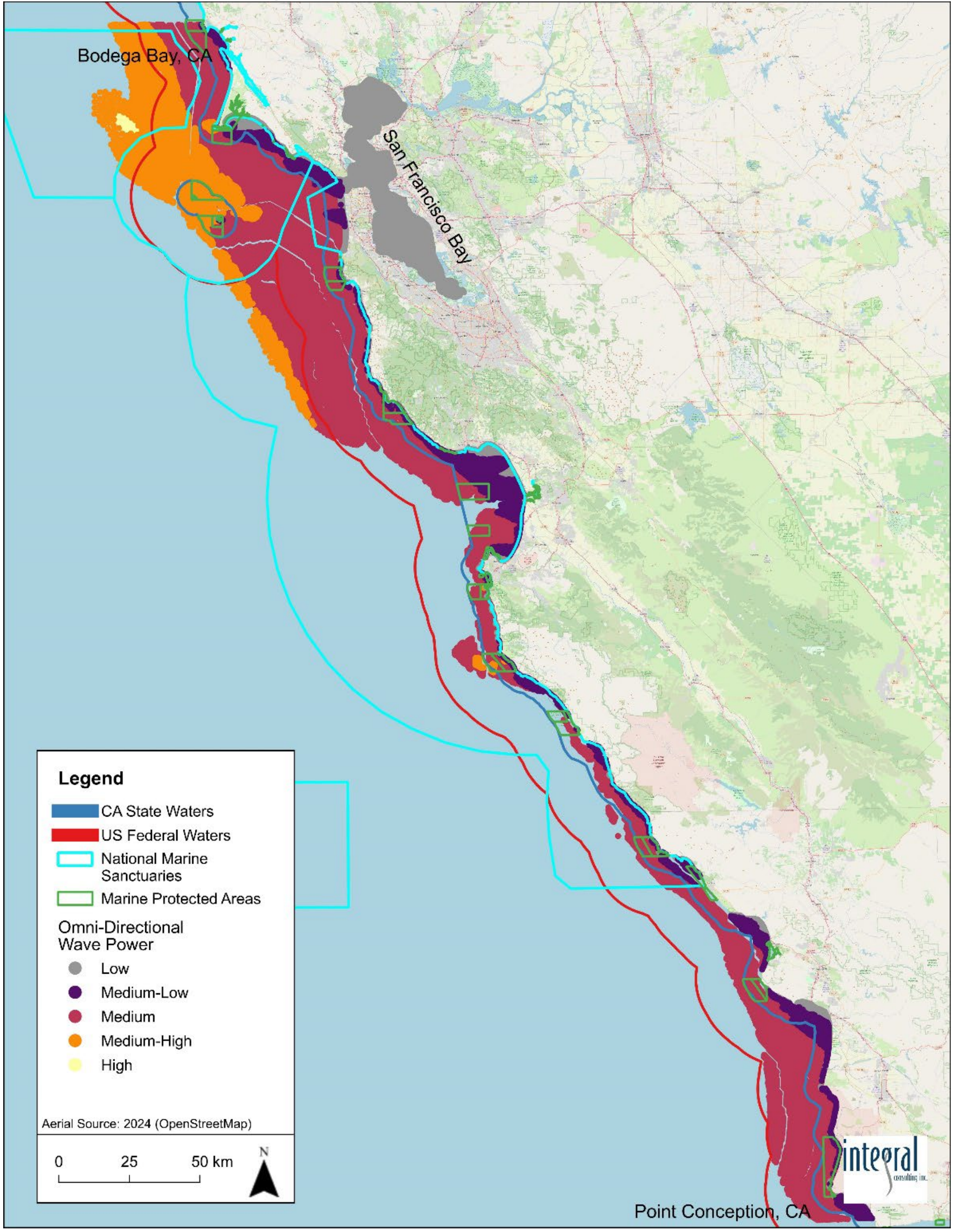
Power Bin	Point Count Total	Percent of Point Count in Unconstrained Zone
Low	31,884	22
Medium-Low	3,258	20
Medium	2,088	6
Medium-High	98	19
High	2	0

Source: Integral Consulting Inc. analysis

1.4.2 Central California Wave Energy Resource Potential

The Central California region's highest potential energy lies to the northwest, where it transitions into the larger wave climate of Northern California (Figure 14). Closer to the shore, wave resource potential diminishes, highlighting the influence of coastal geography on wave energy distribution. Closer analysis reveals that there are some regions where wave focusing, a phenomenon where wave energy becomes concentrated due to geomorphology, could occur, potentially leading to localized zones of greater wave heights and enhancing the available energy.

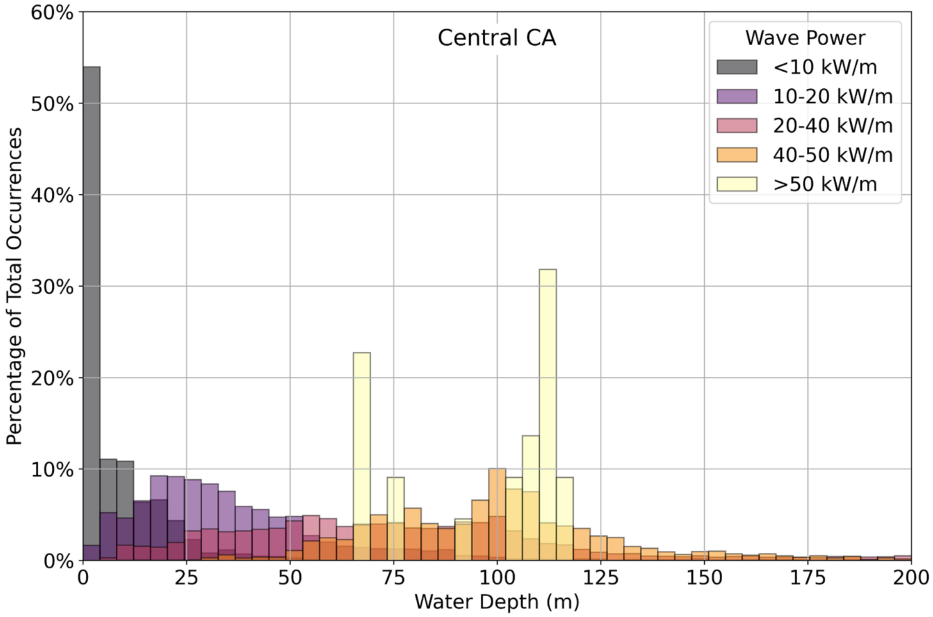
Figure 14: Annual-Averaged, Omnidirectional Wave Power: Central California



Source: Integral Consulting Inc. analysis

The lowest wave power bins occurs in water depths less than 50 m, while the middle power bins occur in the full range of water depths, from 0 to 200 m, and are more prevalent in water depths in excess of 50 m (Figure 15). The highest wave power bins occur in multiple depth ranges, with the highest concentration between 100 m to 125 m, shown in Figure 14 as the area offshore and to the northwest of San Francisco Bay.

Figure 15: Percentage of Total Occurrences of Wave Power Categories by Water Depth for Central California (The Percentage of Total Occurrences Is Symbolized by Wave Power)



Source: Integral Consulting Inc. analysis

The majority (> 50 percent) of the wave energy close to shore is within the low energy bin, less than 10 kW/m (Figure 16).[25]

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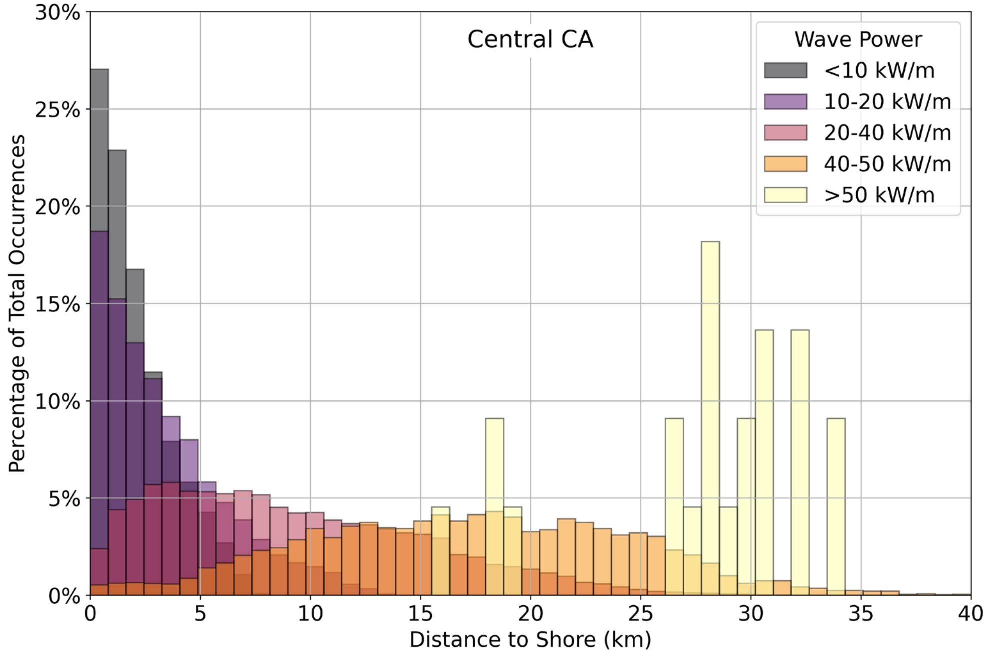
[25] More detailed nearshore modeling may change this estimate.

Figure 16: Percentage of Total Occurrences of Wave Power Categories by Distance to Shore for Central California (The Percentage of Total Occurrences Is Symbolized by Wave Power)



Source: Integral Consulting Inc. analysis

Moving offshore (> 10 km from shore), the potential wave energy increases, as expected with the transmission of wave energy from Northern California. However, this increase provides logistical and economic challenges for deployment and operation of WEC devices. The region between 5 and 10 km from shore appears to hold development potential, with moderate-high wave energy potential. The highest energy resources (> 50 kW/m) are more than 15 km from shore.

The majority of the high-quality wave energy resources within Central California are within potentially constrained areas (Table 6). Nearshore and within San Francisco Bay, the factors most likely to constrain WEC application are (in order of highest prevalence by area) protected areas, formerly used defense sites, military danger zones and restricted areas, pipelines, and submarine cables. Farther out from shore, oil and gas resource and planning areas are the main contributors to the delineation of the potentially constrained area.

Table 6: Potentially Constrained Area Overlap With Wave Bins: Central California

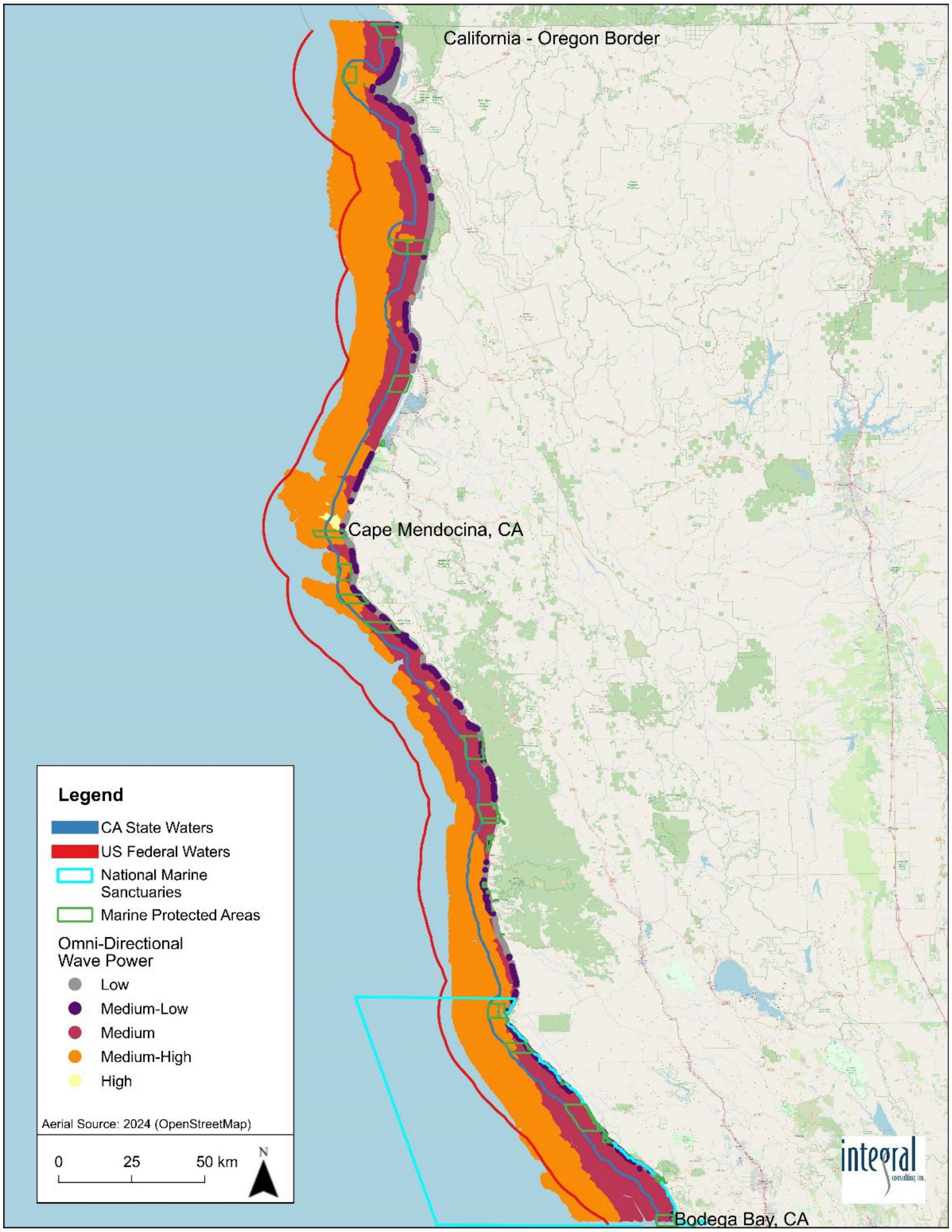
Power Bin	Point Count Total	Percentage of Point Count in Unconstrained Zone
Low	20,002	68
Medium-Low	6,956	46
Medium	39,901	17
Medium-High	6,406	6
High	22	5

Source: Integral Consulting Inc. analysis

1.4.3 Northern California Wave Energy Resource Potential

The Northern California region benefits from the larger wave climate of the Pacific Northwest, which provides significant energy potential, especially in offshore areas (Figure 17). However, near the shoreline, the wave energy diminishes because of local geographical factors. Further analysis suggests the possibility of wave focusing on certain regions, particularly around canyon heads, which could enhance energy generation in areas closer to shore.

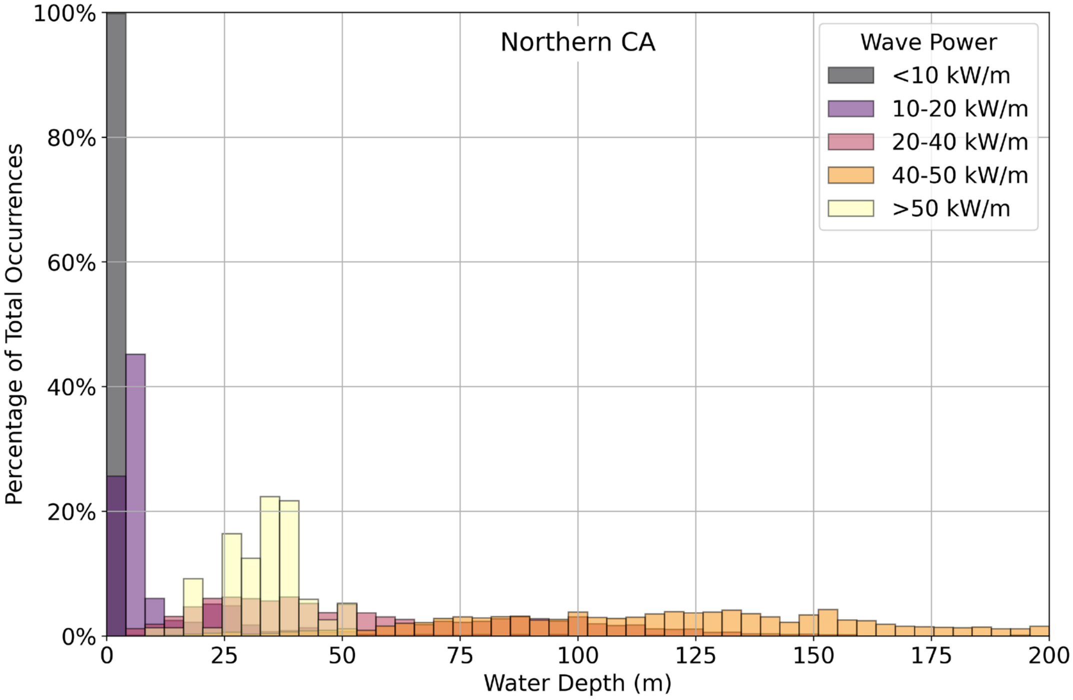
Figure 17: Annual-Averaged, Omnidirectional Wave Power: Northern California Coastline



Source: Integral Consulting Inc. analysis

Figure 18 shows that, as with Central California, the lowest wave power estimates are in shallower water (for example, < 50 m). The midrange wave energy resources in Northern California occur in the full range of water depths, and there are high-energy resources in relatively shallower depths (compared to the Central California region), shown in Figure 17 as the high wave power area along the coastline at Cape Mendocino.

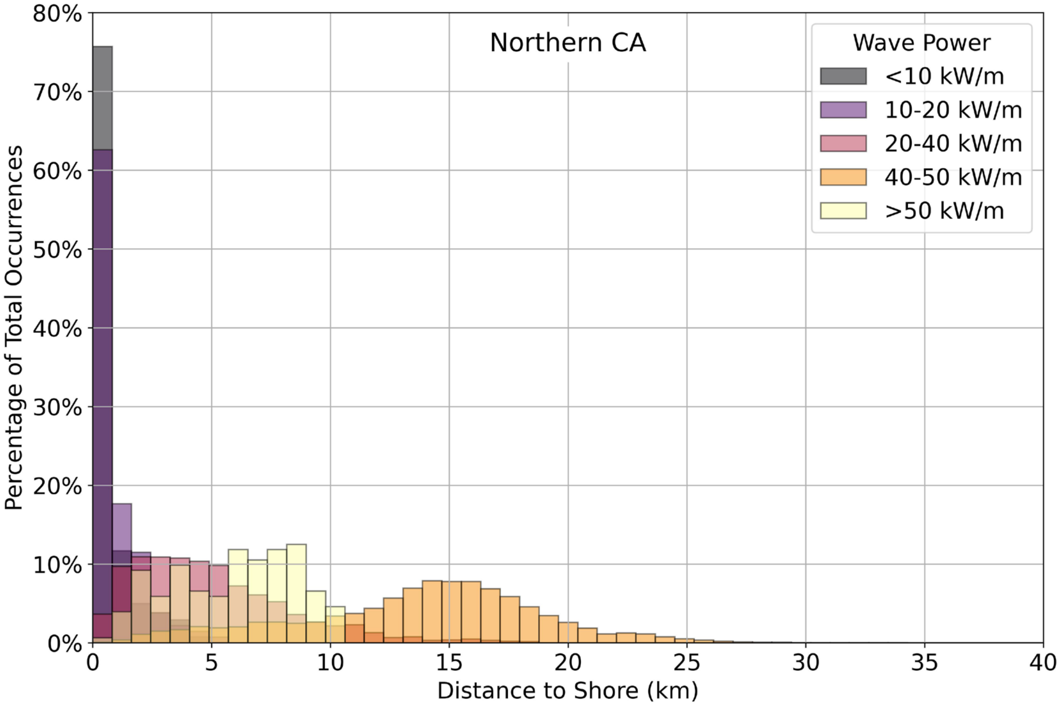
Figure 18: Percentage of Total Occurrences of Wave Power Categories by Water Depth for Northern California (The Percentage of Total Occurrences Is Symbolized by Wave Power)



Source: Integral Consulting Inc. analysis

For Northern California, the wave power data reveal that there are substantial areas of moderate to high wave energy within 10 km of shore (Figure 19), which aligns with the understanding of offshore wave energy in this region. These trends provide valuable insights into the wave power potential along the Northern California coastline, identifying key areas of interest for future wave energy projects. This comparison enhances an understanding of regional differences in wave energy availability, which is crucial for strategic planning and resource optimization.

Figure 19: Percentage of Total Occurrences of Wave Power Categories by Distance to Shore for Northern California (The Percentage of Total Occurrences Is Symbolized by Wave Power)



Source: Integral Consulting Inc. analysis

Table 7 shows considerable constraints for development of wave energy in the Northern California region, with most of the high-quality resources within potentially constrained areas. Farther from shore (about 0.8 to 3.5 nautical miles), the area is designated as mostly oil and gas planning and resource areas. Within 0.8 nautical miles of shore, the most prevalent potential conflict areas are protected zones such as MPAs. Chapter 3 discusses this specific constraint. Secondary, nearshore, potential conflict areas include the two former bombing targets Big Lagoon and Gualala because of the potential for unexploded ordnance. These two areas comprise a small percentage of the overall available water space for WEC installment.

Table 7: Potentially Constrained Area Overlap With Wave Bins: Northern California

Power Bin	Point Count Total	Percentage of Point Count in Unconstrained Zone
Low	1,638	83
Medium-Low	679	72
Medium	19,478	46
Medium-High	22,641	7
High	152	84

Source: Integral Consulting Inc. analysis

1.5 Conclusions

The resource assessment has highlighted that while there are abundant wave energy resources off the coast of California, the greatest resources are in the northwest of the state, far from major population centers. The highest energy locations for WECs, particularly at the grid scale, are also located some distance offshore. It should be stressed that the availability of nearshore wave climate information that incorporates the presence of existing coastal structures is limited, which provides challenges for a statewide assessment of relative resource availability by water depth and distance to shore. Tidal energy opportunities in the state are limited due to a small number of suitable geographical features. Several potential locations were identified for further consideration, primarily in Central California, although most are subject to some form of potential constraint.

Chapter 2 provides further details of near-term distributed energy opportunities for marine energy and longer-term potential for grid-scale production and integration. Chapter 3 provides additional information about environmental and regulatory constraints, and Chapter 4 discusses the location of transmission infrastructure necessary to convey electricity from the zones of production to where it is needed most.

CHAPTER 2:
Marine Energy Project Considerations

The potential benefits of wave and tidal energy were described in the November 2024 SB 605 report, *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits*.[26] The November 2024 report identified that marine energy is one component of a robust energy portfolio. The following is a discussion of factors that influence the selection of locations, technologies and applications to optimize the potential use of the wave and tidal energy resources outlined in Chapter 1. Chapter 2 is organized as follows:

- Section 2.1 discusses site selection from the perspective of developers of marine energy technologies, focused on elements that influence the cost and capacity of energy production.
- Section 2.2 presents the demand-side factors, including the distribution of energy demand with respect to population centers and marine and coastal industries, and types of deployment opportunities.
- Section 2.3 concludes with an examination of previous marine energy projects in California, including lessons learned from some earlier projects.

2.1 Technologies and Site Selection

2.1.1 Device Suitability

Device design will dictate which locations will work best for the deployment and operations of WECs and TECs. For example, bottom-mounted WECs such as oscillating wave surge devices may work more efficiently in relatively shallow areas where the influence of surface waves extends well into the water column. Mooring design for floating systems will depend on the size of the device, and associated location and costs will grow as deployment depth increases. While there is no maximum viable depth for deployment, current technologies and wave energy testing locations have focused mostly on depths of under 100 m.

This report uses a depth of 200 m to allow for technological advances that would enable deployment in greater depths. Ultimately, deployment locations and identification of optimal deployment depths will require balancing mooring requirements with deployment methods, operational considerations, and capital expenditures. The variation in device sizes, power capture methods, and use cases restricts the ability for this report to evaluate the full range of permutations.

2.1.2 Site Selection

Developers must consider a range of environmental and economic factors when selecting a site for development. Costs for transmission cables and grid integration components will vary depending on distance, requirements for cable burial, proximity to other economic zones, sea

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[26] Lee, Susan and Vida Strong. (Aspen Environmental Group). 2024. *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits. SB 605 Report.*

space constraints or protected areas, and electrical grid capacity. Remote areas may require the development of battery storage or upgrades to local infrastructure to support new power sources, which could be incorporated into existing programs and plans to improve these networks. Proximity to ports and staging areas will affect servicing and deployment options. Vessels capable of servicing the devices and the skilled workforce required for offshore operations may need to be sourced from elsewhere while local capacity is developed.

Lastly, changes to viewsheds should be considered as they are a large factor in permit approval, particularly in important cultural areas. Developers will need to consult with California's Native American tribes that may have cultural resources within a desired development area. Communications with tribes and nearby communities should occur early and often to ensure concerns are known. In addition to economic viability, there are ecological considerations to site selection, which are discussed in Chapter 3.

2.1.3 Summary of Strengths and Weaknesses of Regions for Marine Energy

California as a whole presents abundant opportunities for marine energy deployment; however, some regions are more suited to particular applications than others. Both near-term distributed opportunities (small-scale) and commercial-scale opportunities are considered below.

Table 8: Relative Strengths and Weaknesses for Marine Energy Development

Region	Strengths	Weaknesses
Northern California	• High wave energy potential, some high energy locations for tidal energy • More isolated communities that require independent/resilient energy infrastructure • Smaller energy infrastructure – better for smaller projects • Wind energy lease area – potential colocation opportunity • Humboldt Bay port • Numerous smaller fishing ports	• Smaller population – lower overall energy demand • No principal ports[27]
Central California	• Medium levels of potential wave energy • Moderately high population – high energy demand • Substantial energy infrastructure – many opportunities for integration • Several principal ports – high marine energy needs	• Strong tidal resource, but heavily impacted by potential constraints • Principal ports are inside San Francisco Bay, potentially adding more sea space conflicts, and wave energy is limited
Southern California	• High population – high overall energy demand • Substantial energy infrastructure – many opportunities for integration • Several principal ports – high marine energy needs	• Relatively low energy potential for both wave and tidal energy

Source: Integral Consulting Inc. analysis

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[27] Principal Ports defined as major ports of California as opposed to small-medium sized ports.

2.2 Potential Opportunities and Applications

2.2.1 Commercial-Scale Opportunities

Alignment of Energy Demand and Wave Resource

Most of the California population is within coastal counties (defined in this report as those that intersect with the Coastal Zone Management Boundary defined in the Coastal Zone Management Act). Thus, much of the electricity demand is located near the coast.[28] In 2020, 54 percent of California's population lived in Coastal Zone counties.[29]

Most of the coastal population lives in the Central and Southern California regions. The Northern California region contains 26 percent of the number of coastal counties but only about 3.5 percent of the coastal population.[30]

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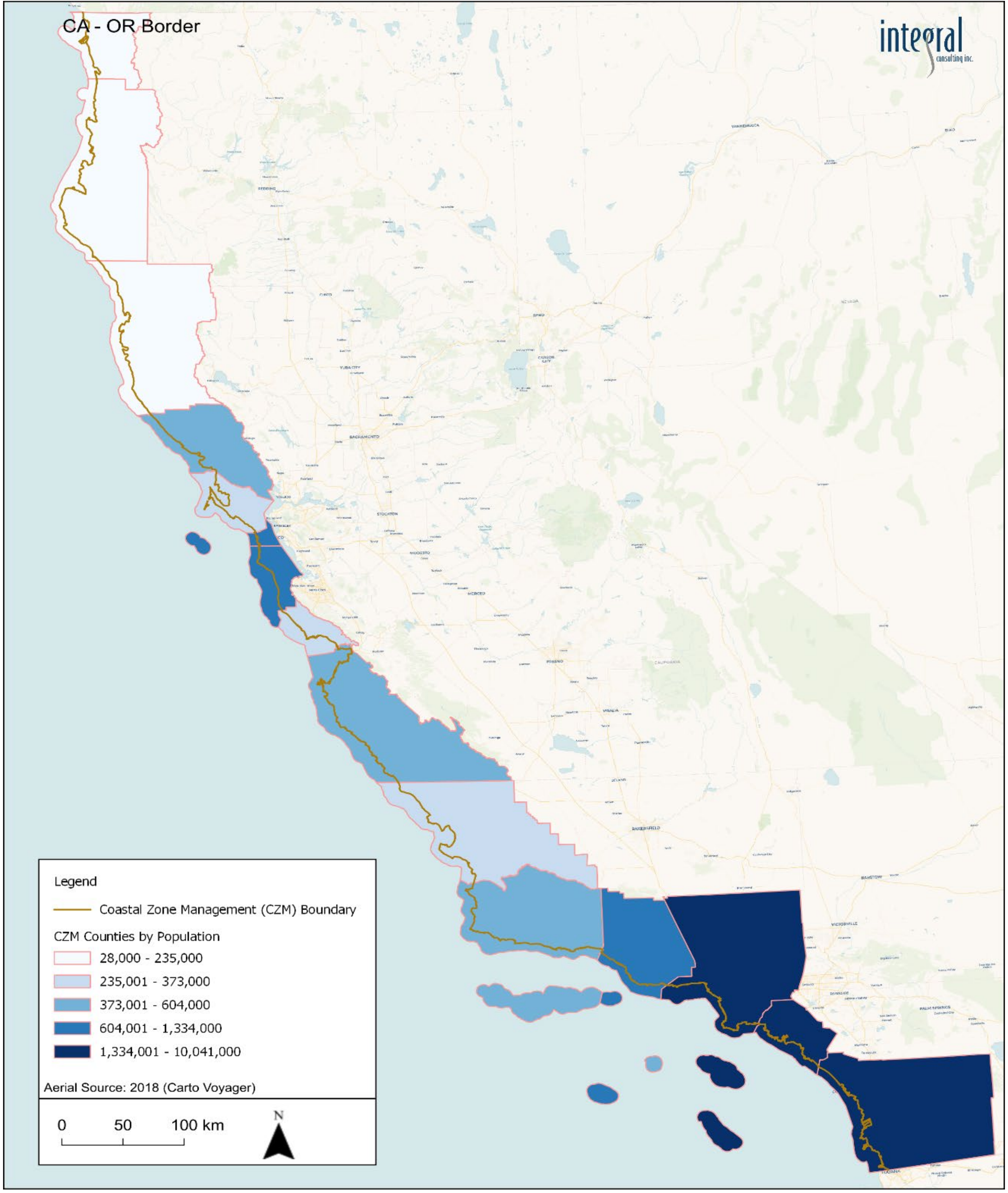
[28] Regions defined as follows: Northern California (Sonoma County and above), Southern California (Santa Barbara County and below), Central California is the remaining coastal counties (Marin to San Luis Obispo).

[29] U.S. Census Bureau, "Race," Decennial Census 2020 Subject Tables, Table P1, 2020, https://data.census.gov/table?t=Population%20Total&g=040XX00US06$0500000&y=2020, accessed on January 15, 2025.

Although the COVID-19 pandemic did have an impact on population and energy use distributions in California, data limitations from the CEC energy database and the Census population estimates required that 2020 be used as the most recent, complete-pair year.

[30] U.S. Census Bureau, "Race," Decennial Census 2020 Subject Tables, Table P1, 2020.

Figure 20: California Coastal Counties by Population



Source: U.S. Census Bureau[31]

The energy consumption in each region follows the population pattern along the coast, as shown in Table 9.

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[31] U.S. Census Bureau, "Race," Decennial Census 2020 Subject Tables, Table P1, 2020.

Table 9: Residential Electrical Energy Consumption in Coastal California, by Region, 2020

Region	Population in Coastal Zone Counties, 2020	Total Residential Electricity Use 2020 (GWh/year)	Annual Residential Electricity Use per Capita, 2020 (kWh/person/year)
Northern	744,670	2,137	2,870
Central	2,893,048	5,888	2,035
Southern	17,791,704	40,942	2,301

Source: California Energy Commission[32]

Energy Infrastructure Replacement

As of 2024, there are 500 power plants (of varying sizes and fuels) and 791 substations in the coastal zone that supply energy to coastal population centers in California.[33] These power plants and substations are distributed more densely in Central and Southern California to match their relatively higher demand. Substations are potential locations for the future integration of new energy resources, including commercial-scale marine energy facilities into the grid as existing generation capacity is retired or replaced.

Of the existing 500 power plants in coastal counties, 168 are fueled by oil or natural gas.[34] Oil and natural gas power plants are of particular interest because they have existing infrastructure and electrical grid connections and will likely be phased out as California continues to pursue its goal of economywide emissions being 85 percent below 1990 emissions levels and carbon neutrality by 2045.[35] The retirement of oil and natural gas power plants could present opportunities for the integration of new power sources into their former transmission systems.

Table 10: Number and Percentage of Oil or Gas Power-Sourced Plants in Coastal Zone Counties by Northern, Central, and Southern Regions

Region	Number and Percentage (%) of Total Substations (*n* = 791) in Coastal Zone Counties	Number and Percentage (%) of Total Oil or Gas Power Plants (*n* = 168) in Coastal Zone Counties
Northern	57 (7.2%)	2 (1.2%)
Central	172 (21.7%)	34 (20.2%)
Southern	561 (70.9%)	132 (78.6%)

Source: Office for Coastal Management[36]

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[32] California Energy Commission. 2025. "Electricity Consumption by County, Total, 2020," http://www.ecdms.energy.ca.gov/elecbycounty.aspx.

[33] Office for Coastal Management. 2025. "Power Plants," https://www.fisheries.noaa.gov/inport/item/66174.; Office for Coastal Management. 2025. "Electric Power Substations," Accessed December 2024. https://www.fisheries.noaa.gov/inport/item/66139.

[34] Ibid.

[35] California Air Resources Board. 2022. *Final 2022 Scoping Plan,* https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents.

[36] Ibid.

2.2.2 Near-Term Distributed Opportunities

In addition to diversifying grid power sources, wave and tidal energy may also be well-suited for non-grid-connected applications focused on providing power to a specific end user. While some endeavors may aim to connect large arrays of devices into the power grid, deployment in ports and harbors and colocation with marine aquaculture and scientific research equipment may be alternative applications when paired with battery storage or directly connected to a sensor network for powering research equipment.

Wave energy has been proposed as a mechanism to support the development of aquaculture where coastal sites may have limited access to power. The power required for filtering, feeding, navigational equipment, and internal monitoring packages may be supplied or supplemented by the environment within which the aquacultural farm is deployed (Chapter 3).

Areas where potential energy sources are not high enough to support a grid-connected array may still provide enough energy to power scientific research equipment such as monitoring buoys, sensor arrays, or underwater charging stations for autonomous vehicles. The benefit of this approach is that sensor deployment life cycles may be extended by increasing the time between servicing, which usually requires costly vessel support.[37] The economic and societal barriers to entry are much lower in these application areas than on commercial-scale sites where developments must reach a certain size to compete economically with alternative power generation methods. The advantages of small-scale deployments may also be realized when working through the state and federal permitting processes. Devices without a need for shore connection may also see reduced resistance to deployment in coastal communities where land use is at a premium and cable landing sites would displace other uses.

Monitoring and Navigational Buoys

Environmental monitoring buoys are distributed throughout California's coastal waters, with a slightly higher prevalence in the San Francisco and San Diego areas. These buoys are mostly in lower-energy areas, in part because they collect data on water quality and are therefore located near large bays with urban inflows and reduced circulation. This lower-energy environment may not be well-suited to WECs/TECs, depending on their energy needs, resulting in fewer colocation opportunities.

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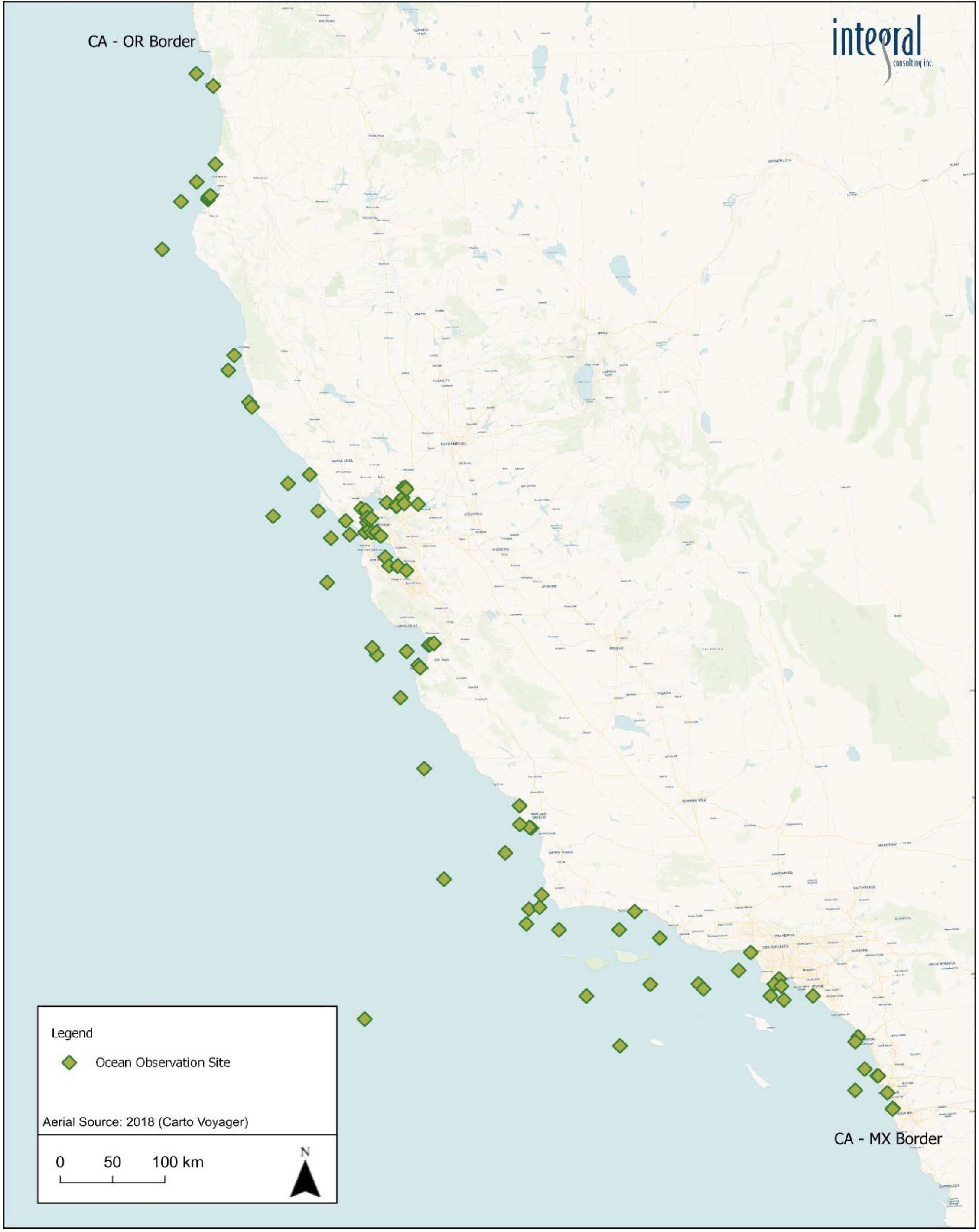
[37] Chen, Ming, Rakesh Vivekanandan, Curtis J. Rusch, David Okushemiya, Dana Manalang, Bryson Robertson, Geoffrey A. Hollinger. "A Unified Simulation Framework for Wave Energy Powered Underwater Vehicle Docking and Charging." *Applied Energy,* Volume 361,2024, 122877, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2024.122877. (https://www.sciencedirect.com/science/article/pii/S0306261924002605).

Figure 21: Ocean Observation Sites Along the Coast of California



Source: Office for Coastal Management[38]

Other types of buoys — such as navigational, wave, or meteorological buoys — can be in more energetic locations. WECs integrated in navigational buoys are rare. As of 2019, the Coast Guard manages 1,103 federal fixed and floating navigational aids in District 11 (California, Nevada, Utah, Arizona). The Coast Guard was cited in a Government Office of Efficiency report

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[38] Office for Coastal Management. 2025. "Ocean Observing Sites," https://www.fisheries.noaa.gov/inport/item/67000.

stating that, "as of 2018, nearly a quarter (24 percent) of all floating ATON [Aids to Navigation] and over half (59 percent) of all fixed ATON are operating past their designed service lives."[39] The need to upgrade or replace these floating ATONs relatively soon presents the opportunity to integrate WECs and TECs into the new designs.

Powering the Blue Economy

Marine-dependent infrastructure such as harbors, ports, and marinas require a steady stream of energy to operate. Energy needs within these marine precincts include shipbuilding, maintenance, and repairs; refrigeration, storage, and retail for commercial fisheries; and electrical requirements for ongoing moorage, including providing energy to those ships awaiting docking to avoid the use of bunker fuel.

In October 2024, the federal government awarded seven California ports more than $1 billion for zero-emission infrastructure investments. Of the seven ports awarded funds, none are in Northern California, four are in Central California, and three are in Southern California.[40] Funded ports under this initiative are the Port of San Francisco, Port of Stockton, Port of Oakland, Port of Redwood City, Port of Hueneme, Port of Los Angeles, and the Port of San Diego.

Significant progress has been made in providing solar to some of these facilities.[41] However, solar energy has substantial space requirements that may quickly exhaust available rooftop space, forcing ports to use ground area, which is expensive in a highly productive and busy area. WECs may be a potential resource that can be paired with other zero-emission technologies, such as solar, to provide alternatives in space constrained infrastructure.

Point absorber WECs and other bottom-moored WEC designs are less optimal for powering busy ports and harbors since they can block shipping lanes and other navigational channels. In these cases, and others where moored WECs are not an option, WECs that can be integrated into coastal structures (CSI-WECs) may be of interest. CSI-WECs are physically integrated into a stationary structure like a pier, jetty, or breakwater and may have the additional benefit of attenuating wave forces on these structures. The positioning and scale of CSI-WECs depend on electrical infrastructure and resilience goals and require detailed, site-specific modeling and engineering to estimate the available resource and ensure that the installation will not affect the protective function of the structure.

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[39] Government Accountability Office, Coast Guard. February 5, 2020. *Initiatives to Address Aids to Navigation Challenges Could be Enhanced to Better Ensure Effective Implementation*, https://www.gao.gov/products/gao-20-107.

[40] Environmental Protection Agency. October 24, 2024. News release. "Biden-Harris Administration Announces Over $1 Billion of Clean Ports Investments in California as Part of Investing in America Agenda," https://www.epa.gov/newsreleases/biden-harris-administration-announces-over-1-billion-clean-ports-investments.

[41] Port of Los Angeles. (n.d.). "Solar Power." Solar Power | Sustainability | Port of Los Angeles. https://www.portoflosangeles.org/environment/sustainability/solar-power; Port of San Diego. (n.d.). "Energy Efficiency and Renewable Energy Will Continue to Be Key Initiatives in Reducing Electricity Use and Greenhouse Gas Emissions." Energy, https://www.portofsandiego.org/environment/energy-sustainability/energy; Port of Oakland. (n.d.). Zero emissions future seaport. "Oakland Seaport," https://www.oaklandseaport.com/projects/zero-emission-future-seaport/; Port of San Francisco. (n.d.). "Sustainability." Sustainability | SF Port. https://www.sfport.com/projects-programs/sustainability#tab-12825-pane-3.

Aquaculture

Like environmental monitoring buoys, aquaculture activity is generally located in low-energy areas. This is in part because pens can be broken in more energetic locations. According to the NOAA Office of Coastal Management, there are 40 aquaculture operations across all of California, varying in distance from shore as well as the overall size of the operation.[42] One operational area may be composed of several pens.

The relatively low wave or tidal power in areas traditionally used by aquaculture does not entirely preclude the use of marine energy because energy demands of their operations are relatively small. The energy needs of aquaculture vary by type of operation. Shellfish, for example, have low energy needs since little maintenance is required once the spat or juvenile shellfish are placed on the grow-out racks. Of the listed aquacultural sites, 47.5 percent are classified for shellfish.[43]

Available information about the type of aquaculture is limited, with a large percentage classified as "unknown" in the most recent NOAA data.[44] One potential colocation opportunity is to use a WEC array to reduce the incident energy of waves and thereby protect aquaculture cages in moderate energy environments.

Desalination

WECs are well-suited to the task of desalination, an energy-intensive process of separating dissolved solids (salt) from saline or brackish water. The California Department of Water Resources (DWR) reports that "in 2020, over 100,000 acre-feet of brackish water was desalinated for drinking water."[45] Although California's current water management strategy emphasizes desalinating brackish groundwater as opposed to seawater, this strategy reflects current technological constraints. These constraints include the relatively lower-energy requirements of removing salt from brackish versus saline water and the geographic demand for terrestrial brackish desalination coupled with a reluctance to process seawater.[46]

Coastal cities are key candidate areas for desalination since inland groundwater is frequently a finite resource because recharge is so slow. Areas of brackish groundwater or intruded seawater are commonly found along the coast, and several California desalination operations are coastal, meaning the processing infrastructure could be near a potential WEC installation.

The DWR Water Desalination Grant program could support WEC/TEC deployments for desalination, in partnership with eligible and user entities such as public agencies, nonprofit organizations, California Native American tribes, and water utilities. The City of Fort Bragg was recently a recipient of almost $1.5 million of such funds in 2023 for a pilot deployment of an

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[42] Office for Coastal Management. August 15, 2025. "Aquaculture," https://www.fisheries.noaa.gov/inport/item/53129.

[43] Ibid.

[44] Ibid.

[45] State of California. February 21, 2024. Blog. "State Report Identifies Future Desalination Plants to Meet Statewide Water Reliability Goals." Department of Water Resources, https://water.ca.gov/News/Blog/2024/Feb-24/State-Report-Identifies-Future-Desalination-Plants-to-Meet-Statewide-Water-Reliability-Goals.

[46] Ibid.

Oneka brand desalination buoy, and other pilot-scale offshore desalination buoy systems are under review.[47]

The National Alliance for Water Innovation could also further research and promote use of the technology. In addition to cities and townships that require potable water, agriculture is another potential user of desalinated water, as the availability and reliability of water are limiting factors in some coastal agricultural regions. This situation has a range of causes, including overuse, limited storage capacity, and saltwater intrusion. These agricultural regions could benefit from a reliable, nearby source of fresh water generated from desalination plants powered by WECs. Cost considerations may mean that this desalinated water is not feasible for irrigation but may be used for injection into coastal aquifers, either for storage or increasing hydrostatic pressure and creating a barrier to prevent intrusion of saline water into coastal aquifers.

Marine energy converters, particularly WECs, are relatively robust to natural disasters; they increase energy production in inclement weather.[48] This increased production is a benefit that neither solar nor wind (to a certain extent) can replicate. Desalination in California may become increasingly necessary as water sources become less reliable, climate change worsens, and groundwater levels fall.

Colocation With Offshore Wind Infrastructure

There are five BOEM offshore wind (OSW) leases in federal waters off California, two in Northern California off the coast of Eureka and three in South-Central California off the coast of Morro Bay (Figure 22). While this sea space analysis is constrained to a water depth of 200 m or less, colocation with OSW in deeper waters (up to 1,300 m water depth) may present opportunities for reducing electrical infrastructure needs for both technologies. An OSW project requires underwater cables and connections to the onshore electrical grid. The land-based and nearshore components of marine energy and wind energy operations could be colocated, potentially reducing the overall spatial and visual impact of that supporting infrastructure.

All wind energy lease areas are in medium-high wave energy areas, meaning there is resource potential for colocation of electrical cable connections or integration of WECs either into the turbine platform infrastructure itself or in the area within the turbine arrays. For example, Morro Bay has two substations, while Eureka and the surrounding area have three power plants and several substations. The potential future decommissioning of the Diablo Canyon nuclear facility presents a potential future connection location for marine energy facilities in Central California.

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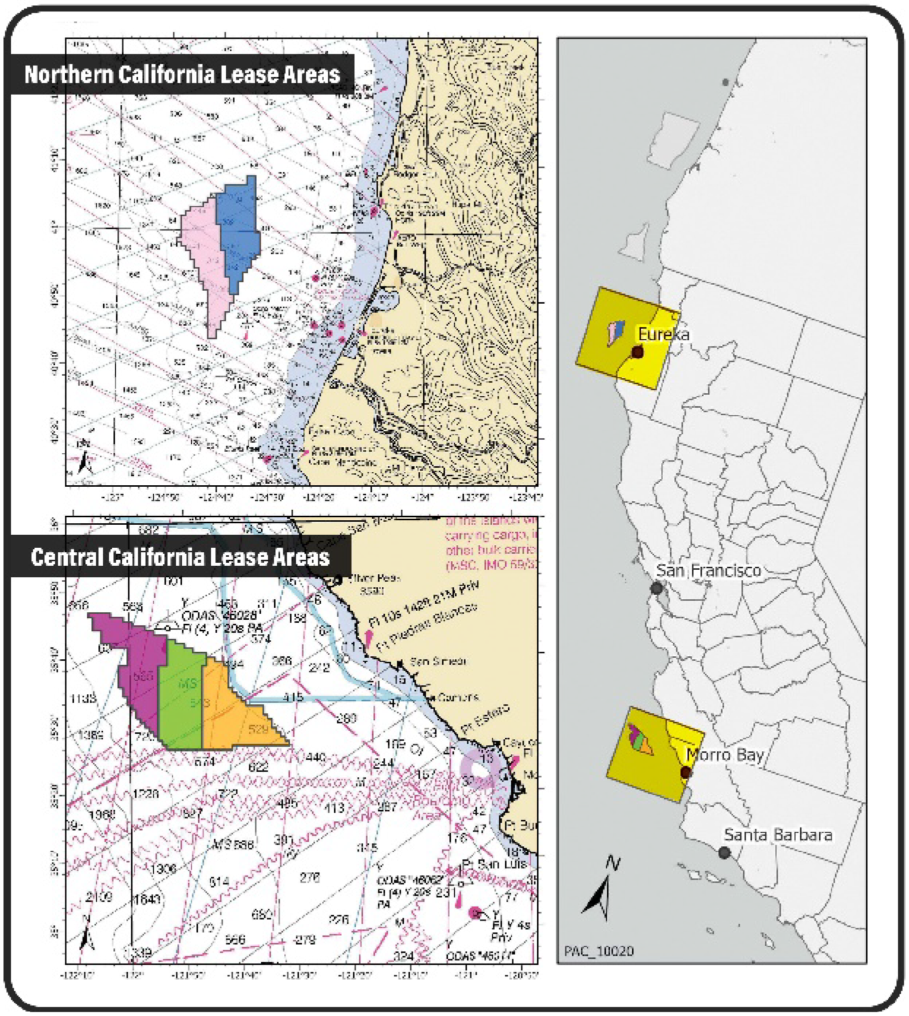
[47] City of Fort Bragg. (n.d.). "Oneka Seawater Desalination Buoy Pilot Study," https://www.city.fortbragg.com/departments/public-works/current-public-works-projects/oneka-seawater-desalination-buoy-pilot-study.

[48] Borthwick, A. G. L. March 2016. "Marine Renewable Energy Seascape." *Engineering*, 2(1), 69-78, https://doi.org/10.1016/J.ENG.2016.01.011.

Figure 22: BOEM Offshore Wind Energy California Lease Areas



Source: Bureau of Ocean Energy Management[49]

2.3 Previous Marine Energy Projects in California

Despite numerous attempts, most previous California marine energy initiatives struggled to progress beyond preliminary stages after encountering significant financial and regulatory challenges. Jason Busch, executive director of Pacific Ocean Energy Trust, noted that early marine energy companies "committed the mortal sin of overpromising and under-delivering to shareholders," leading to numerous bankruptcies.[50]

The Green Wave Mendocino project is an example. Initially granted a preliminary permit by the Federal Energy Regulatory Commission (FERC) in 2008, the project had the preliminary permit revoked in 2010 because of noncompliance with essential federal documentation and progress reporting requirements. Green Wave, a company based in Southern California, failed

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[49] Bureau of Ocean Energy Management. (n.d.). "Winners of the California Lease Areas, $757,100,000 in High Bids." Map. Retrieved January 15, 2025, from https://www.boem.gov/sites/default/files/images/CA_Wind_Auction_Winners.jpg.

[50] Cart, Julie. December 4, 2023. "Blue Power: Can California Harness Clean Energy From Ocean Waves?" KQED-FM, https://www.kqed.org/news/11968802/californias-blue-power-drive-wave-tidal-energy-renewable-grid.

to demonstrate sufficient good faith and due diligence during the permit term. This failure led to the denial of its 2011 bid to regain the preliminary permit in 2012.[51]

The Pacific Gas and Electric Company (PG&E) WaveConnect Program, targeting locations in Humboldt County and near Vandenberg Space Force Base in Santa Barbara County, also faced significant setbacks. The Humboldt WaveConnect project received a preliminary permit from FERC in 2008, while its Central Coast WaveConnect project received a preliminary permit in 2010. PG&E significantly underestimated its project costs, including complex permitting issues, many due to the lack of adequate baseline data about the site and the proposed WECs to be used, as well as unexpectedly high project costs.[52] Community opposition due to environmental and local stakeholder concerns also played a role in PG&E withdrawing its Humboldt WaveConnect draft pilot license application in 2010 and surrendering its Central Coast WaveConnect FERC preliminary permit in 2011.[53]

California Wave Energy Partners, a subsidiary of Ocean Power Technologies, also encountered challenges despite having been issued a three-year preliminary permit by FERC to study wave energy north of Cape Mendocino. In 2009, the organization withdrew from California to concentrate on its Coos Bay and Reedsport projects in Oregon, thus abandoning its FERC preliminary permit.[54]

The San Onofre Electricity Farm Project, led by JD Productions, was a wave energy initiative based in Southern California that also faced significant financial and regulatory challenges. Initially, FERC granted the project a permit to study wave energy generation off San Onofre State Beach, which granted JD Productions priority rights over the project area, including parts of San Onofre State Park. This permit allowed for a three-year feasibility study to install ocean wave electricity generators roughly one mile offshore but did not authorize construction. Soon after the permit was granted, FERC determined that JD Productions lacked the necessary financial resources to proceed with the permitting process. As a result, FERC terminated its Integrated Licensing Process. JD Productions then applied for a successive preliminary permit but was met with opposition from local stakeholders, including the Surfrider Foundation and the National Marine Fisheries Service (NMFS). Furthermore, JD Productions failed to conduct proper due diligence, leading to the denial of its request by FERC in 2014.[55]

In more recent years, there have been some more successful marine energy projects in California, led by CalWave and Eco Wave Power. The CalWave project, launched in 2022,

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[51] Hartzell, Frank. August 23, 2018. "FERC Rejects Mendocino Wave Energy Project." *The Mendocino Beacon,* https://www.mendocinobeacon.com/2012/08/23/ferc-rejects-mendocino-wave-energy-project/.

[52] Dooher et. al. December 1, 2011. *PG&E WaveConnect Program Final Report*. Tethys, https://tethys.pnnl.gov/publications/pge-waveconnect-program-final-report.

[53] Hartzell, Frank. August 23, 2018. "PG&E Abandons Last Study Site." *Fort Bragg Advocate-News,* https://www.advocate-news.com/2011/05/05/pge-abandons-last-study-site/.

[54] Hartzell, Frank. August 23, 2018. "Firm Granted Exclusive Wave Energy Rights." *The Mendocino Beacon,* https://www.mendocinobeacon.com/2008/07/10/firm-granted-exclusive-wave-energy-rights/.

[55] Federal Energy Regulatory Commission. "Docket Sheet for Application for Hydrokinetic Wave Energy Preliminary Permit." *FERC eLibrary*. Retrieved from https://elibrary.ferc.gov/eLibrary/docketsheet?docket_number=p-13679&sub_docket=all&dt_from=1960-01-01&dt_to=2025-01-13&chklegadata=false&pagenm=dsearch&date_range=custom&search_type=docket&date_type=filed_date&sub_docket_q=allsub.

emerged after an extensive 11-year permitting process.[56] The project benefits from the support of the U.S. Department of Energy's Water Power Technologies Office; the University of California, San Diego, Scripps Institution of Oceanography; the National Renewable Energy Laboratory; Sandia National Laboratories; Det Norske Veritas (DNV); and the University of California, Berkeley. Its xWave prototype was launched off the UC San Diego's Scripps Institution of Oceanography research pier in La Jolla (San Diego County).[57]

Similarly, Eco Wave Power has made notable progress, securing a Nationwide Permit from the U.S. Army Corps of Engineers in 2024.[58] Eco Wave Power is a tenant at AltaSea, a public-private research center that operates out of a 35-acre campus located at the Port of Los Angeles.

California's marine energy landscape reveals a pattern of ambitious initiatives confronting substantial economic and regulatory challenges. Recent projects from organizations like CalWave and EcoWave Power suggest future progress can be achieved through collaborative institutional support. Additional factors that contribute to project success include a competitive cost of energy, secure investment opportunity, reliability for grid operations, pathway to permitting, project safety, ability to provide community benefits, and community support.[59] Chapter 3 provides additional details on environmental and regulatory constraints that must be considered for future developments.

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[56] KQED; "CalWave xWave Demonstration," https://tethys.pnnl.gov/project-sites/calwave-xwave-demonstration.

[57] Water Power Technologies Office. March 28, 2022. "CalWave Launches California's First Long-Term Wave Energy Project." U.S. Department of Energy, https://www.energy.gov/eere/water/articles/calwave-launches-californias-first-long-term-wave-energy-project.

[58] Wolfe, Sean. November 18, 2024. "Eco Wave Power Secures Final USACE Permit for Its First U.S. Wave Energy Project," https://www.hydroreview.com/hydro-power/tidal-wave-energy/eco-wave-power-secures-final-usace-permit-for-its-first-u-s-wave-energy-project/.

[59] Lee, Susan and Vida Strong. (Aspen Environmental Group). 2024. *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits. SB 605 Report.*.

CHAPTER 3:
Potential Sea Space Conflicts

Following the framework in SB 605, the selection of sites for wave and tidal energy projects should identify areas with high energy resources (Chapter 1) while prioritizing areas with the lowest risk of harm to environmental, cultural, and historical resources. Additionally, site selection should identify areas with the lowest potential for conflict with ocean infrastructure and other ocean users. Environmental resources include sensitive habitats, migratory routes, and other resources used by marine organisms such as marine mammals, fish, seabirds, and sea turtles.

Cultural resources include areas that are used by or are important to Native American groups, while historical resources include archaeological artifacts such as shipwrecks. Ocean infrastructure includes subsea cables and pipelines, oil platforms, navigational, oceanographic and meteorological ("metocean") buoys, navigational buoys, and planned infrastructure associated with OSW energy lease areas. Other ocean uses include dredging and disposal sites, commercial and recreational fishing areas, recreational and tourism areas, commercial shipping lanes, aquaculture sites, and military operations.

The initial step in identifying potential sea space conflicts is to identify specific marine resources, infrastructure, and ocean uses for the California coast and determine how restrictive these resources and activities are to the development of wave and tidal energy projects. How restrictive an area or resource is to development depends on several factors, including legal protections, permitting complexities, and how controversial the development would be to stakeholders and tribes.

Protected areas and other regions where commercial development is not permitted are considered "no go" constrained areas (in other words, areas to be avoided). Some areas may allow development but would present significant challenges for permitting. Developing in other areas may put energy projects in direct conflict with other sea space uses and resources and, thus, will require collaboration with multiple groups and agencies on specific minimization and management measures. In some instances, whether the resource, structure, or ocean use would allow for development depends on the type of energy device.

Each potential sea space conflict and its permitting challenges are discussed in more detail below, as follows:

- 3.1 Marine Biological Resources
- 3.2 Tribal, Cultural, and Historical Resources
- 3.3 Commercial and Recreational Fisheries
- 3.4 Ocean Uses
- 3.5 Ocean Infrastructure
- 3.6 Sea Space Conflict Analysis
- 3.7 Conclusion

3.1 Marine Biological Resources

The California coast is home to myriad marine species that rely on specific areas and habitats for their life functions. Discrete geographic marine and estuarine areas have been designated to protect or conserve marine life and habitat or both, including state-managed marine protected areas (MPAs) and national marine sanctuaries (NMS). These areas receive special protection through limiting or prohibiting extractive activities.

Moreover, some areas include biologically important areas (for cetaceans),[60] designated critical habitat for species listed or proposed for listing under the federal Endangered Species Act (ESA), and areas defined under the Magnuson-Stevens Fishery Conservation and Management Act. Areas defined under the Magnuson-Stevens Fishery Conservation and Management Act include essential fish habitat (EFH), EFH habitat areas of particular concern (HAPCs), and EFH conservation areas. Some marine species are also listed under the California Endangered Species Act (CESA); however, the act does not designate critical habitat areas.

3.1.1 National Marine Sanctuaries and California Marine Protected Areas

The National Marine Sanctuaries Act (NMSA) of 1972 established the National Marine Sanctuaries Program, which allows the designation of marine sanctuaries. The following five marine sanctuaries have been established in California: the Greater Farallones NMS (formerly Gulf of the Farallones), Cordell Bank NMS, Monterey Bay NMS, Chumash Heritage NMS, and Channel Islands NMS. Marine sanctuaries have prohibitions regarding the take (harm, harassment, killing of) of all marine organisms as well as restrictions on the construction or placement of any structures on the seabed, including anchors.[61] Furthermore, a resolution from the Advisory Councils of both the Greater Farallones NMS and the Monterey Bay NMS dated from 2009 states:

> "Constructing wave energy devices, platforms, seabed anchoring systems, and burying and laying transmission cables along the seafloor of the Gulf of the Farallones National Marine Sanctuary and Monterey Bay National Marine Sanctuary, would directly conflict with sanctuary regulations, and such activities would not likely qualify for a sanctuary permit since such permits are limited to a narrow range of purposes including research, education, salvage and recovery or to assist in managing the sanctuary."[62]

Though the resolution was written for two of the five marine sanctuaries in California, it is assumed that the other sanctuaries have a similar stance on energy development within their

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[60] Calambokidis, J., G. H. Steiger, C. Curtice, J. Harrison, M. C. Ferguson, E. Becker, M. DeAngelis, et al. 2015. "Biologically Important Areas for Selected Cetaceans Within U.S. Waters – West Coast Region." *Aquatic Mammals* 41(1):39–53, https://cascadiaresearch.org/publications/biologically-important-areas-selected-cetaceans-within-us-waters-west-coast-region/.

[61] 15 CFR 922, https://www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-B/part-922.

[62] Gulf of the Farallones National Marine Sanctuary. 2009. "Joint Resolution of the Gulf of the Farallones and Monterey Bay National Marine Sanctuary Advisory Councils Regarding Proposed Wave Energy Projects Within National Marine Sanctuaries. Memorandum." February 18. National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, https://nmsmontereybay.blob.core.windows.net/montereybay-prod/media/sac/2009/021209/021209wave_energy.pdf.

borders. Therefore, each of the marine sanctuaries in California are considered as "no go" zones for wave and tidal energy development.

The Marine Life Protection Act of 1999 mandated California to design and manage an improved network of marine protected areas (MPAs) in state waters (0-3 nautical miles from shore). The three main types of MPAs include state marine reserves, state marine parks, and state marine conservation areas. Each type of MPA has different regulations about what may or may not be undertaken within the MPA. MPAs are a subset of state marine managed areas (MMAs), which are broader groups of discrete geographic areas along the coast that protect, conserve, or otherwise manage a variety of resources and uses. These resources and uses include living marine resources, cultural and historical resources, and recreational opportunities. MMA classifications include state water quality protection area, state marine cultural preservation area, and state marine recreational management area.

Cable emplacement and the construction of infrastructure to support marine energy related activities are not allowable activities within California's MMAs, including MPAs. In certain areas, maintenance of existing infrastructure is allowed; however, installation of new infrastructure is not allowed.

Lastly, California has certain special closure areas where boating access is restricted (for example, seasonal closures of areas around seabird rookeries or sea lion haul-out sites during the breeding season). Given these restrictions, all state MMAs, including MPAs, and special closure zones are considered "no go" zones for marine renewable energy development.

3.1.2 California Coastal National Monument

Another protected area to note is the California Coastal National Monument. Created by a presidential proclamation in 2000, the monument encompasses all islands, rocks, exposed reefs, and pinnacles within 12 nautical miles (22 km) of the shore along the entire California coastline.[63] The islands, rocks, and pinnacles above mean high tide provide important nesting habitat for seabirds, as well as resting and feeding habitat for seals, sea lions, and sea otters. The coastline features of the national monuments are protected from development and, thus, should be viewed as "no go" zones for marine renewable energy projects.

3.1.3 Protected Species and Critical Habitat

California is home to several at-risk species that are either a fully protected species under California law, listed as threatened or endangered under the CESA, or listed under the federal ESA, or a combination thereof. When considering a project in an area where a protected species could occur, developers must ensure that project activities would not result in the take of protected species. "Take" under the ESA means any action that harms, harasses, or kills a listed species, whereas the CESA defines "take" as to hunt, pursue, catch, capture, or kill a listed species or attempt to hunt, pursue, catch, capture, or kill.

If the activities of a project are expected to result in the take of a listed species, then a take authorization and associated mitigation (if appropriate) would be required from the responsible agency, which could delay permitting and increase project costs. Agencies responsible for

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[63] Bureau of Land Management. 'California Coastal National Monument.' BLM, https://www.blm.gov/programs/national-conservation-lands/california/california-coastal. Accessed February 2025.

managing listed species include the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS), and California's Department of Fish and Wildlife (CDFW).

In addition, when a species is listed under the federal ESA, agencies are required to designate critical habitat for the species. The CESA does not designate critical habitat. Critical habitat areas contain oceanic or geographical features or both that are critical for conserving the species. Any commercial activities within these areas must avoid destroying or adversely modifying the essential physical and biological features of designated critical habitat. Not all federally listed species that occur within California have designated critical habitat. For example, neither blue whales (*Balaenoptera musculus*) nor fin whales (*B. physalus*) have designated critical habitats; however, both species have designated biologically important areas (see next section).

Federally listed species with critical habitats in California waters where wave or tidal energy projects could occur include:

- Black abalone (*Haliotis cracherodii*)
- Western distinct population segment (DPS) of Steller sea lions (*Eumetopias jubatus*)
- Sacramento River winter-run Evolutionary Significant Unit (ESU) of Chinook salmon (*Oncorhynchus tshawytscha*)
- Southern DPS of green sturgeon (*Acipenser medirostris*)
- Southern Resident Killer Whale (SRKW) DPS (*Orcinus ater*)
- Leatherback sea turtles (*Dermochelys coriacea*)
- Central America DPS of humpback whales and the Mexico DPS of humpback whales (*Megaptera novaeangliae*).

Specific features within designated critical habitats may be difficult to protect or to mitigate for damage from device installations. For example, the critical habitat for endangered black abalone includes rocky intertidal habitat that cannot be easily repaired or replaced if lost or damaged. Moreover, designated critical habitat for black abalone includes intertidal and subtidal areas out to a depth of 6 meters relative to mean lower water level,[64] which is likely too shallow for most wave energy converters (WECs). While siting devices in black abalone habitat is not advised, it may be possible to route transmission cables under these areas using directional drilling or by routing in sand channels between hard substrates used by black abalone. Further analysis will be needed during the project-level environmental review process to determine if routing transmission lines through critical habitat areas is the least impactful option.

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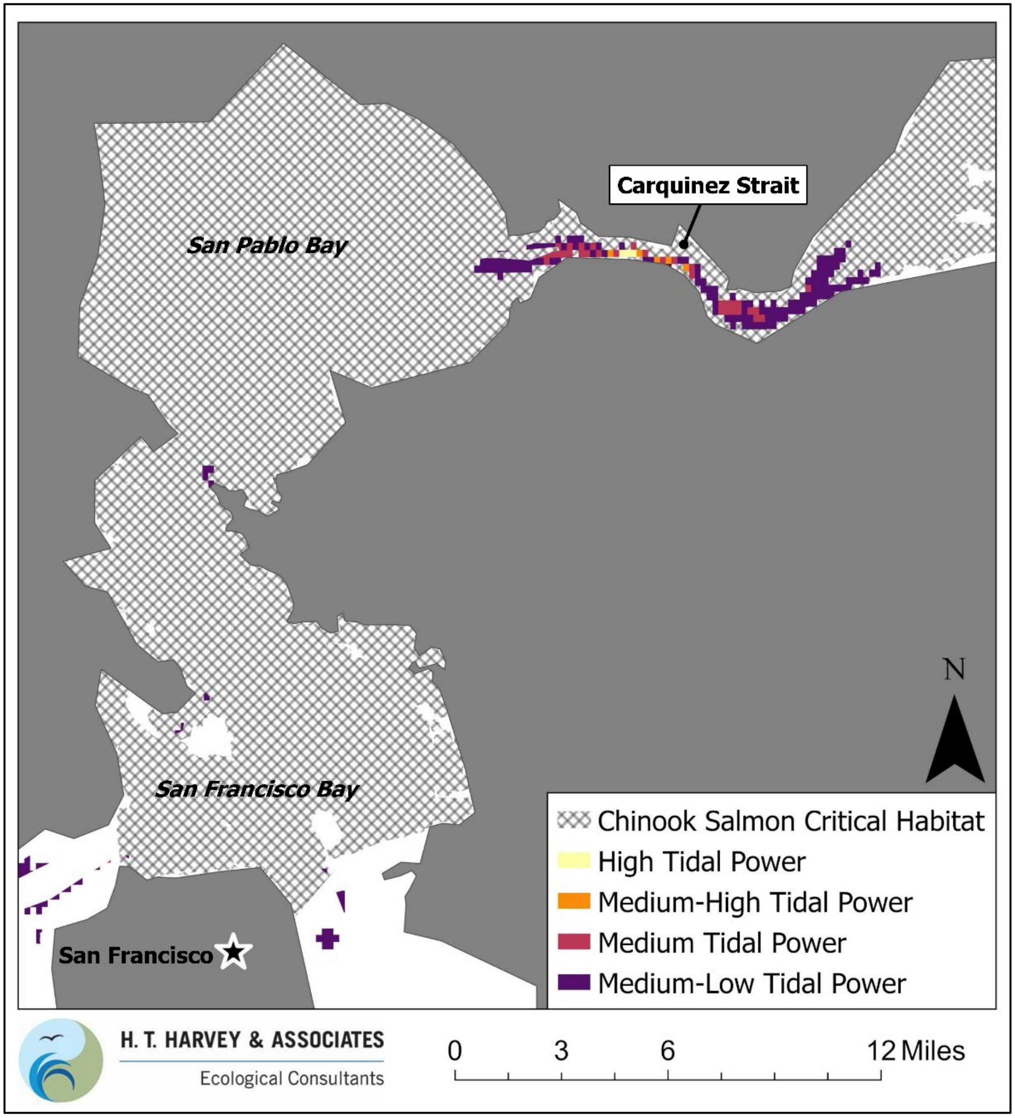
64 Federal Register. "Endangered and Threatened Wildlife and Plants; Final Rulemaking to Designate Critical Habitat for Endangered Species." Accessed February 14, 2025. https://www.federalregister.gov/documents/2011/10/27/2011-27376/endangered-and-threatened-wildlife-and-plants-final-rulemaking-to-designate-critical-habitat-for.

Some critical habitat areas are already protected from development since they overlap with marine reserves or with other constrained areas for marine energy development or both. The critical habitat areas for Steller sea lions are completely within an NMS or an MPA and, therefore, are protected from development. Critical habitat for the winter-run Chinook salmon ESU is within San Francisco Bay near Carquinez Strait (Figure 23), which has multiple ship traffic lanes in addition to a ferry route. Though the area has the highest potential tidal energy resource for Central California, development in this area will be difficult since the Carquinez Strait is an important migration corridor for listed Chinook salmon and other listed species. Other designated critical habitats in California cover large swaths of marine areas (that is, the critical habitats for green sturgeon, leatherback turtles, SRKW, and humpback whales; Figure 24) and will likely require more site-specific analysis and mitigation.

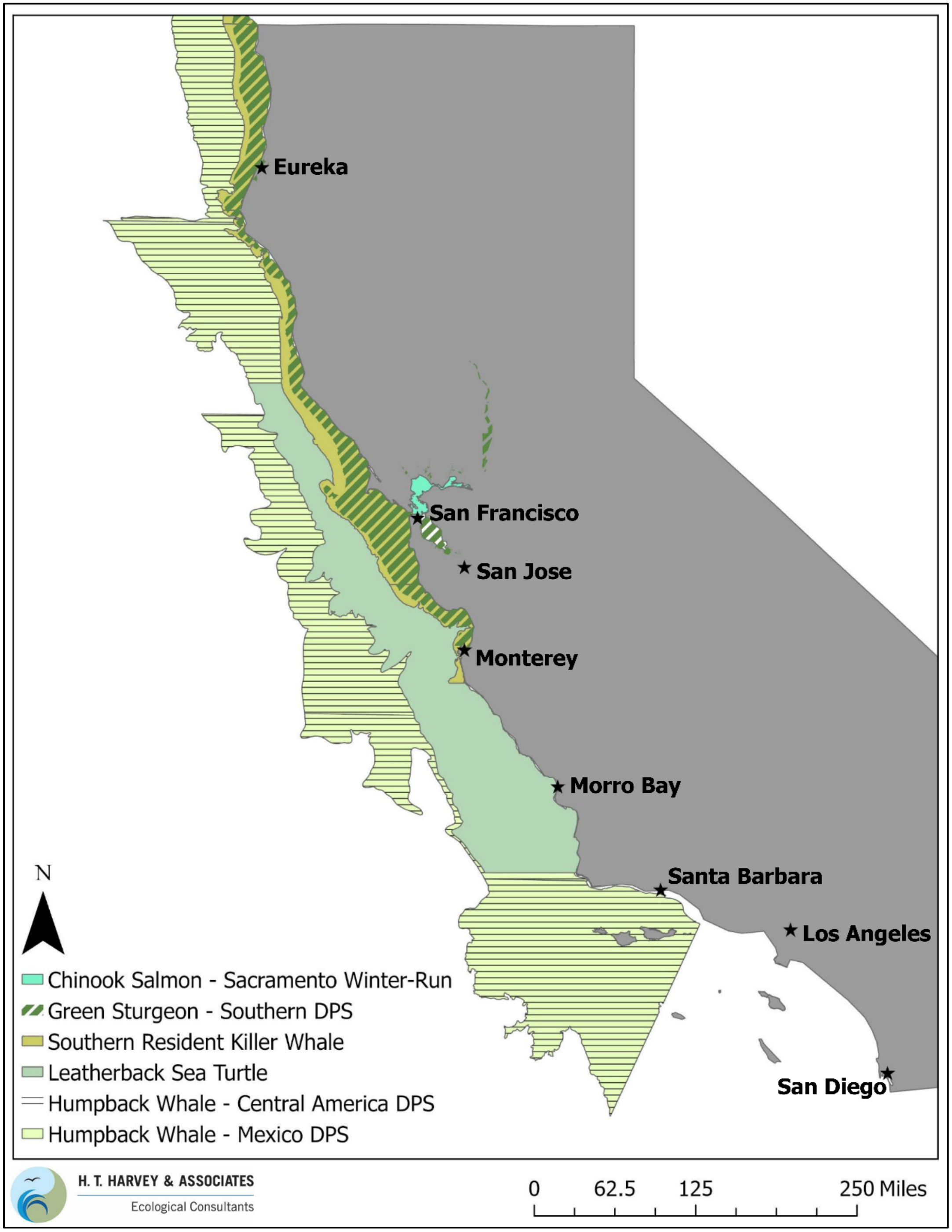
Figure 23: Critical Habitat for the Sacramento River Winter-Run Chinook Salmon ESU and Potential Tidal Energy



Note that the low tidal energy power polygons were removed from the map to highlight the other power categories.

Source: H. T. Harvey & Associates

Figure 24: Select Critical Habitats for ESA-Listed Species



Note that the critical habitats for the Central America and Mexico DPS of humpback whales overlap with the critical habitat for leatherback sea turtles

Data Source: NMFS ESA critical habitat spatial database

Development within any designated critical habitat areas will require ESA Section 7 consultation with NMFS or USFWS or both to ensure that project activities, such as installation and operation, do not negatively impact development within designated critical habitats that are outside protected areas. Development could be feasible if developers can ensure that project activities will not interfere with, adversely modify, or destroy the essential physical and biological features of that habitat. Adverse effects to designated critical habitat must be avoided, minimized, or addressed, which could cause permitting delays and increase project costs.

Not all marine mammal species that occur within California waters are listed under the ESA; however, all marine mammals are protected by the Marine Mammal Protection Act (MMPA), which prohibits the take of marine mammals. "Take" under the MMPA is defined as "to harass, hunt, capture, collect, or kill, or attempt to harass, hunt, capture, collect, or kill any marine mammal."[65] The NMFS Office of Protected Resources and USFWS allow for incidental take of marine mammals if the activity would affect only a small number of marine mammals or have a negligible impact on the population(s) or both. Authorization must be acquired for incidental take if project activities (for example, construction) are estimated to produce harmful noise levels. See the following web page for examples of take authorizations related to marine renewable energy projects: https://www.fisheries.noaa.gov/national/marine-mammal-protection/incidental-take-authorizations-other-energy-activities-renewable.

3.1.4 Biologically Important Areas (Cetaceans Only)

Regional experts on cetaceans (baleen whales, toothed whales, dolphins, and porpoises) consulted survey data, habitat density models, and other scientific research studies, Indigenous and local knowledge, and community science to document areas of biological importance to cetaceans within U.S. waters.[66] These biologically important areas (BIAs) do not have any regulations associated with them but rather serve as a summation of the best available science on important feeding areas, migratory routes, and population boundaries for marine spatial planning.

California has several BIAs: a "feeding BIA" for humpback whales, fin whales, and blue whales (Figure 25); "migratory and reproductive BIAs" for gray whales (*Eschrichtius robustus*) (Figure 26); and "small and resident population BIAs" for SRKW and for harbor porpoises (*Phoceona phocoena*) (Figure 27). SRKWs are not considered residential to California. Feeding BIAs represent areas and times within which aggregations of a species preferentially feed, with "core" feeding BIAs indicating areas that are used with higher intensity.[67] These BIAs can either be persistent in space and time or contain features that are ephemeral and less predictable but are located within a larger area.[68]

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[65] Electronic Code of Federal Regulations. "Title 50: Wildlife and Fisheries; Chapter II: National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce; Subchapter C: Marine Mammals; Part 216: Regulations Governing the Taking and Importing of Marine Mammals." Accessed February 14, 2025. https://www.ecfr.gov/current/title-50/chapter-II/subchapter-C/part-216.

[66] Harrison, J., M. C. Ferguson, L. New, J. Cleary, C. Curtice, S. DeLand, E. Fujioka, et al. 2023. "Biologically Important Areas II for Cetaceans Within U.S. and Adjacent Waters — Updates and the Application of a New Scoring System." *Frontiers in Marine Science* 10:1081893.

[67] Frontiers in Marine Science. "Article: Understanding Marine Ecosystems: Current Research and Future Directions." Accessed February 14, 2025. https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1283231/full.

[68] Harrison, J., M. C. Ferguson, L. New, J. Cleary, C. Curtice, S. DeLand, E. Fujioka, et al. 2023. "Biologically Important Areas II for Cetaceans Within U.S. and Adjacent Waters — Updates and the Application of a New Scoring System." https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1283231/full.

Migratory route BIAs represent spatially restricted areas and periods of time within which a substantial portion of a species migrates.[69] There are multiple migratory route BIAs for gray whales since there are two phases of the northbound migration and the whales tend to venture farther from the coast during the southbound migration (November–February).[70] The northbound migration is separated into Phase A (January–May), which is composed mostly of adults and juveniles, and phase B (March–May) which primarily consists of adult females (cows) and their young (calves).[71] The Phase B migration corridor (less than 5 km from the shore) is also treated as a reproductive BIA since it is primarily used by cow/calf pairs and, thus, is an area in which a species is found with newborns or calves.[72]

Reproductive BIAs also consist of areas where a species mates or gives birth. Lastly, small and resident population BIAs are areas and times within which a small and resident population of cetaceans occupies a limited geographic area.[73] The boundaries for the harbor porpoise and SRKW BIAs were based on existing management units (that is, stock boundaries). Monterey Bay and Morro Bay have resident populations of harbor porpoises, and the range of SRKWs extends down to Point Sur (Monterey County). Because of their small population sizes, all three populations could have an outsized reaction to anthropogenic disturbance and habitat loss/degradation. Extra caution must therefore be taken when planning energy projects within the small and resident population BIAs.

Similar to critical habitats for cetacean species, the BIAs in California cover large areas of the coast and, in some cases, are seasonal. Both the migratory BIAs for gray whales and the feeding BIAs for blue, fin, and humpback whales are used only during specific times of the year. The northbound migration of gray whales occurs from January through May while the southbound migration occurs from November to February, leaving the routes mostly unoccupied during the summer. As for blue, fin, and humpback whales, abundance and density of the three species are highest during the summer and fall months when the whales are feeding.[74] Conflicts with these periods and BIAs can be avoided through careful siting and timing of construction, along with other mitigation measures.

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[69] Ibid.

[70] Calambokidis, J., M. A. Kratofil, D. M. Palacios, B. A. Lagerquist, G. S. Schorr, M. B. Hanson, R. W. Baird, et al. 2024. "Biologically Important Areas II for Cetaceans Within U.S. and Adjacent Waters — West Coast Region." *Frontiers in Marine Science* 11:1283231, https://www.frontiersin.org/articles/10.3389/fmars.2024.1283231/pdf.

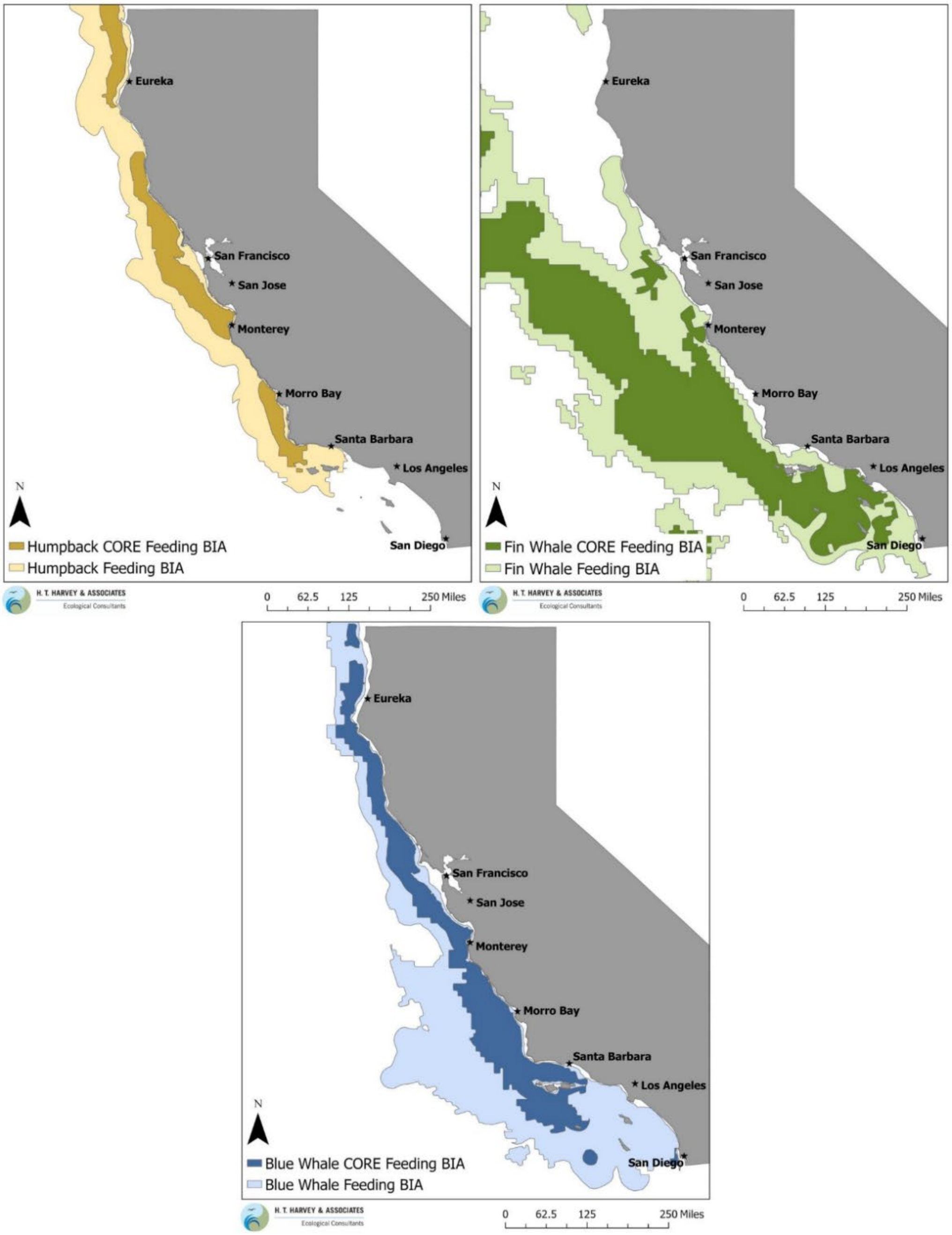
[71] Calambokidis, J., G. H. Steiger, C. Curtice, J. Harrison, M. C. Ferguson, E. Becker, M. DeAngelis, et al. 2015. "Biologically Important Areas for Selected Cetaceans Within U.S. Waters — West Coast Region." *Aquatic Mammals* 41(1):39–53, https://cascadiaresearch.org/publications/biologically-important-areas-selected-cetaceans-within-us-waters-west-coast-region/.

[72] Ibid.

[73] Ibid.

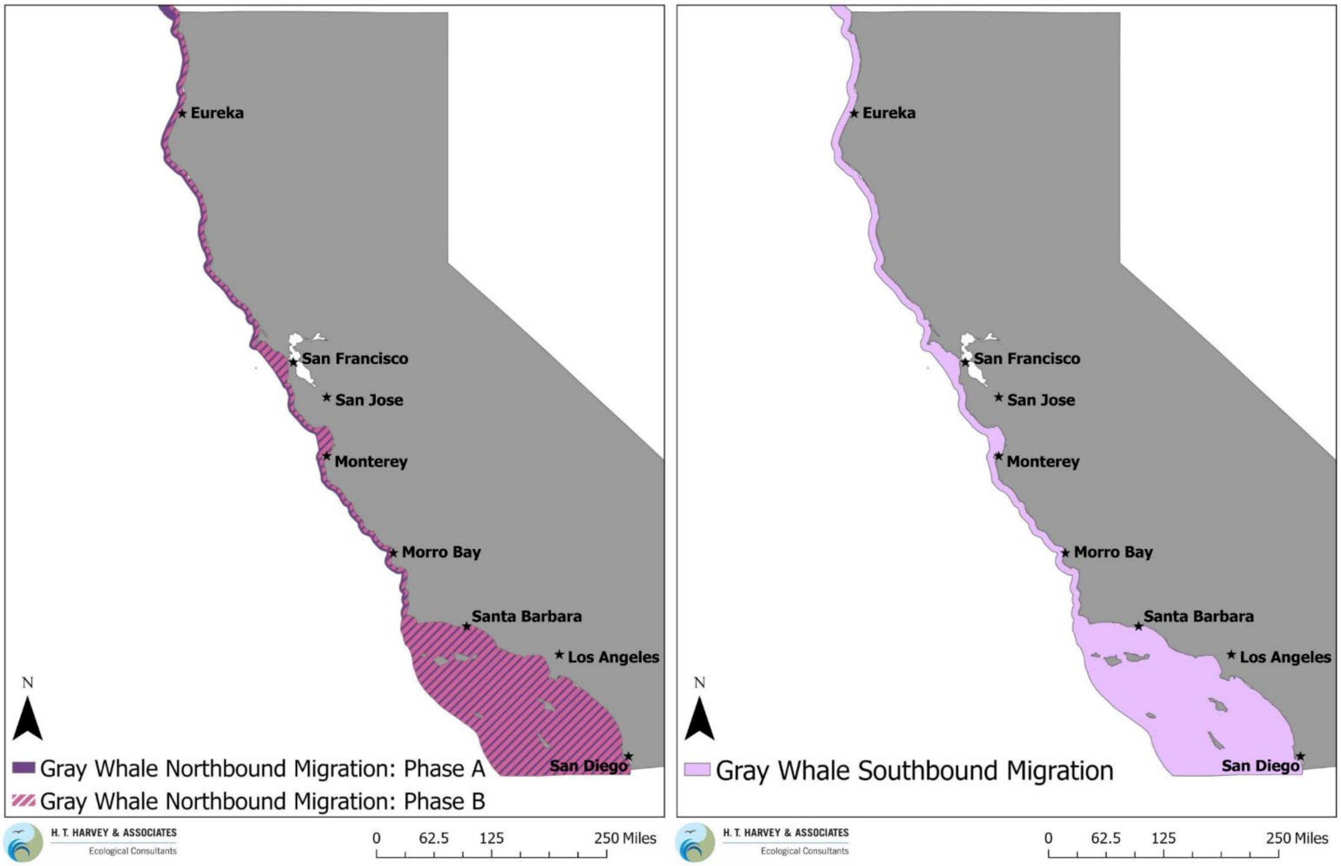
[74] Calambokidis, J., M. A. Kratofil, D. M. Palacios, B. A. Lagerquist, G. S. Schorr, M. B. Hanson, R. W. Baird, et al. 2024. "Biologically Important Areas II for Cetaceans Within U.S. and Adjacent Waters — West Coast Region." https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1283231/full.

Figure 25: Feeding BIAs for Humpback, Fin Whales, and Blue Whales



Data Source: NOAA Ocean Noise Strategy BIA II GIS shapefile

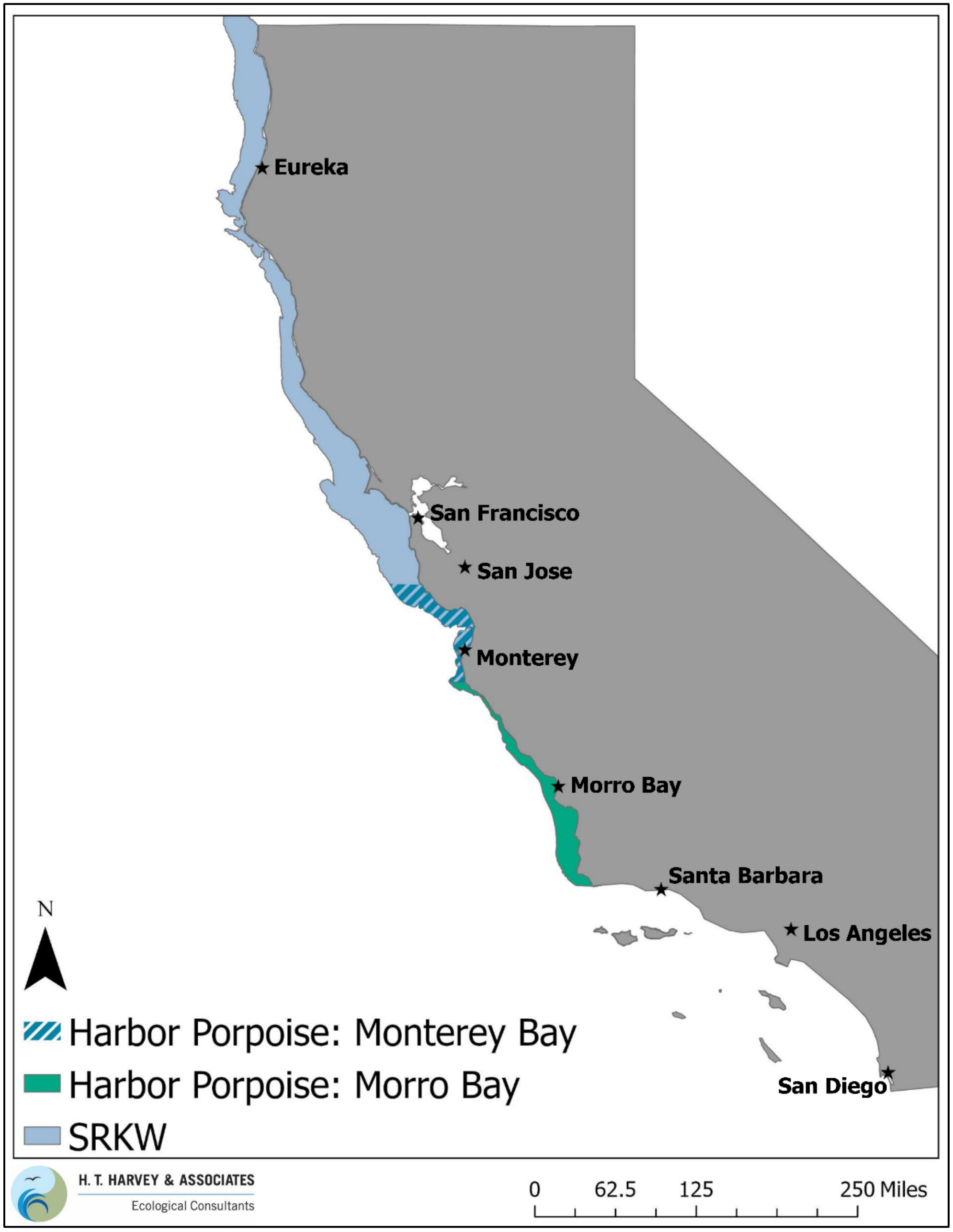
Figure 26: Migratory BIAs for Gray Whales



Data Source: NOAA Ocean Noise Strategy BIA II GIS shapefile

The Phase B Migration Corridor is considered a ”Reproductive BIA” for gray whales since it is primarily used by cows and calves

Figure 27: Small and Resident Population BIAs for Harbor Porpoise and Southern Resident Killer Whales (SRKW)



Data Source: NOAA Ocean Noise Strategy BIA II GIS shapefile

3.1.5 Essential Fish Habitat: Habitat Areas of Particular Concern and Conservation Areas

The 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (that is, the Sustainable Fisheries Act) define EFH as the waters and substrates that are vital for spawning, breeding, feeding, or growing to maturity.[75] The NMFS uses the best available scientific information along with expert input to identify habitat areas and features that are essential for every life stage of federally managed fish species. Areas that are especially

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[75] [16 U.S.C. 1801 et seq.](#)

important or that contain habitat features that are rare, stressed due to development, or especially vulnerable to degradation or a combination thereof are designated as HAPCs. HAPCs are subsets of EFH that are considered high-priority areas for conservation; however, they do not have specific protections or restrictions. Rather, the identification of HAPCs is intended to help focus conservation and research efforts. EFH conservation areas are another subset of EFH, and are closed to specific types of fishing or gear types or both.[76]

EFH, HAPCs, and EFH conservation areas (EFHCAs) have been identified along the U.S. West Coast under the Pacific Coast Groundfish Fishery Management Plan (FMP), the Pacific Coast Salmon FMP, and the FMPs for Highly Migratory Species and Coastal Pelagic Species. The FMPs for Highly Migratory Species and Coastal Pelagic Species specify EFH only. The EFH for Pacific Coast Salmon includes freshwater habitats, as well as estuarine and marine habitats extending from the extreme high tide line in nearshore and tidal submerged environments within state territorial waters out to the exclusive economic zone (EEZ),[77] 200 nautical miles offshore California north of Point Conception.[78]

The EFH for Pacific groundfish species covers the full extent of the West Coast from the high tide line (including estuaries) to 3,500 m depth.[79] The EFH for highly migratory species and coastal pelagic, or open sea, species covers an even larger area, spanning from the shoreline to the edge of the U.S. EEZ. Marine areas identified as HAPCs under both the groundfish and salmon FMPs include estuaries, kelp canopies, seagrass beds, and rocky reefs (groundfish only). The groundfish FMP also identified "areas of interest" because of the unique geological and ecological characteristics, such as all seamounts off the California coast, the Mendocino Ridge, Cordell Bank, Monterey Canyon, and other areas within the Channel Islands NMS and the Cowcod Conservation Area (Figure 28).[80]

Also included in the groundfish FMP are multiple EFHCAs along the coast of California and the EFH Deep-sea Ecosystem Conservation Area (DECA) which was created to protect deep sea habitats such as corals. The DECA includes all federal waters south of the Mendocino Ridge and out to depths >3500 m.[81] Given the large extent of the EFH areas, analysis is focused only on HAPCs since these areas are likely to be more sensitive to disturbance. Furthermore,

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76 50 CFR 660.12

77 An "exclusive economic zone" is an area of coastal water and seabed within a certain distance of a country's coastline, generally 200 nautical miles, to which the country claims exclusive rights for fishing, drilling, and other economic activities.

78 Pacific Fishery Management Council (PFMC). *Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California as Revised Through Amendment 24*. PFMC, Portland, OR. 84 p., https://www.pcouncil.org/documents/2022/12/pacific-coast-salmon-fmp.pdf/

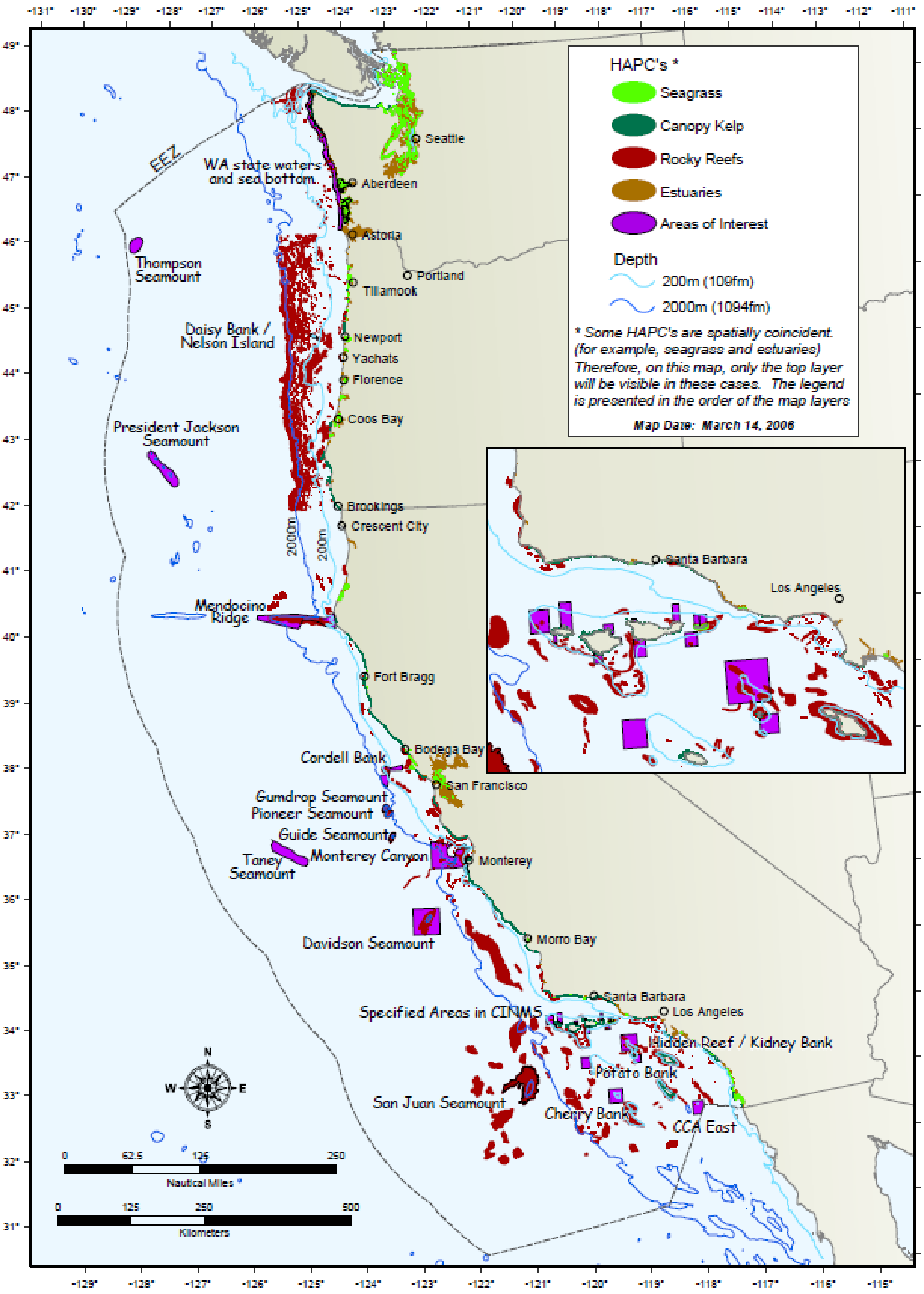
79 50 CFR 660.75

80 NOAA Fisheries. 2021. "Habitat Areas of Particular Concern on the West Coast." Updated December 21, 2021. Accessed December 2024, https://www.fisheries.noaa.gov/west-coast/habitat-conservation/habitat-areas-particular-concern-west-coast.

81 NOAA Fisheries. 2024. Deep-Sea Ecosystem Conservation Area. Updated May 15, 2024. Accessed December 2024. https://www.fisheries.noaa.gov/west-coast/habitat-conservation/habitat-areas-particular-concern-west-coast.

the DECA is likely too deep for most wave and tidal energy installations and was therefore removed from consideration.

Figure 28: EFH Habitat Areas of Particular Concern (HAPC) and Areas of Interest for Groundfish



Source: NMFS West Coast Regional Office[82]

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[82] NOAA Fisheries. 2024. "Essential Fish Habitat – Groundfish and Salmon." Updated January 22, 2024. Accessed December 2024, https://www.fisheries.noaa.gov/resource/map/essential-fish-habitat-groundfish-and-salmon.

Deployment of energy devices near or within an HAPC will require site-specific evaluation depending on the nature of the habitat. For example, one challenge with installing a device within a canopy kelp HAPC is that the stipes of canopy-forming kelp species (for example, *Macrocystis* spp. and *Nereocystis* spp.) could become entangled in the device. Rocky reef habitats are another example of a HAPC that could restrict device installation since the device could displace marine life that rely on the reef, or the anchor(s) of the device could damage sensitive colonizing organisms on the rocky substrate.

There is a precedent for avoiding rocky reef habitats from established wave energy projects, such as PacWave South and Wave Dragon Wales. In its environmental statement, Wave Dragon Wales Ltd stated that it planned to avoid rocky reef and intertidal areas in siting its cable landfall areas for its precommercial wave energy device.[83] Likewise, PacWave South avoided rocky reef areas when routing its transmission cables from the WEC berths to the shore, making the transmission cable route longer than if it had taken a direct route to shore through rocky reef habitat.[84] While EFH can be addressed through permitting and, if necessary, mitigation measures, it is recommended that developers avoid HAPCs when considering where to site wave and tidal energy projects.

3.2 Tribal, Cultural, and Historical Resources

Protecting and minimizing the risk of damage to cultural and historical resources should be a priority when siting wave and tidal energy projects.

3.2.1 Native American Cultural Sites, Resources, and Viewsheds

Before any siting for wave and tidal development, it will be important to identify areas of cultural importance to California Native American tribes. California Native American tribes have stewarded the lands, waters, ocean, and coast since time immemorial. Tribal expertise, traditional ecological knowledge, science, ceremonies, customs, and practices are tied to these places and are critical components of best available environmental management. Many California Native American tribes and people have a significant connection with the Pacific Ocean and the marine habitats and species that rely on a healthy coast and ocean. These connections vary from active stewardship, subsistence, cultural, and commercial relations with the coast and ocean to indirect relations through trade, trails, seasonal ceremonies, and kinship with coastal Native American tribes.[85]

Many tribes have expressed that tribal cultural resources are not limited to archaeological resources, but encompass full landscapes, plant and animal species, water, air, and the

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[83] Project Management Support Services. April 2007. *Wave Dragon Pre-Commercial Wave Energy Device. Environmental Statement Volume 1: Non-Technical Summary*. Prepared for Wave Dragon Wales Ltd., https://tethys.pnnl.gov/sites/default/files/publications/WDNTS.pdf.

[84] Federal Energy Regulatory Commission. April 2020. *Environmental Assessment for Hydropower License: PacWave South Project.* FERC Project No. 14616-001 Oregon. Prepared for the Bureau of Ocean Energy Management and the Department of Energy, https://www.boem.gov/sites/default/files/documents/regions/pacific-ocs-region/environmental-analysis/PacWave%20South%20EA.pdf.

[85] Jones, Melissa, Jim Bartridge, and Lorelei Walker. 2024. *Assembly Bill 525 Offshore Wind Energy Strategic Plan*. California Energy Commission. Publication Number: CEC-700-2023-009-V2-F, https://www.energy.ca.gov/publications/2023/ab-525-offshore-wind-strategic-plan.

interconnection of tribal lifeways with the environment. Western laws and the English language typically cannot capture the full understanding of the importance of tribal cultural resources to Native American tribes.[86] Many cultural resources are not mapped for reasons such as confidentiality, resource constraints, and lack of documentation. Site characterization for placement of a wave or tidal project will require government-to-government consultation with California Native American tribes to ensure that these projects do not have adverse impacts on cultural resources. Developers should work directly with tribes and communities to avoid impacts to cultural resources, and when avoidance is not an option, collaboration is needed to minimize and address impacts to these areas.

Government-to-government consultation and communication by appropriate state agencies and potential developers with tribes will be important to ensure that deployment sites do not overlap with important areas and that project activities do not interfere with tribal uses (including site surveys, installation, operations, and maintenance schedules). There is potential for deployment of marine renewable energy projects within tribal lands with tribal approval, or even the option of tribally owned or co-managed projects. An example of this is the Igiugig Hydrokinetic Project in Igiugig, Alaska. This project harnesses the power of river currents in the Kvichak River to provide clean electricity. The project is a collaboration between the Igiugig Village Council and the Ocean Renewable Power Company (ORPC), with support from the U.S. Department of Energy. This system has significantly reduced the village's reliance on costly diesel fuel.[87]

Figures 28, 29, and 30 display maps of wave energy resource overlayed with NMS and MPAs, as well as tribal cultural regions in California. Similarly, Figures 31 and 32 display tidal resource overlayed with NMS and MPAs with tribal cultural regions in California.

The tribal cultural regions are indicated by two nonconfidential, terrestrial tribal datasets to display general regions. The first dataset is the map of California Native American cultural regions sourced from the Native American Heritage Commission’s (NAHC) Digital Atlas of California Native Americans.[88] The NAHC’s Digital Atlas — and this figure — avoid determining precise boundaries for different California Native American cultural regions. Identifying these cultural regions indicates to readers that California Native American tribes are present in California and are knowledgeable about California’s coastal environments. As such, studies of wave and tidal energy resources must consider input from California Native American tribes.

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[86] Ibid.

[87] U.S. Department of Energy. March 9, 2022. “River currents power remote Alaskan village.” https://www.energy.gov/eere/water/articles/river-currents-power-remote-alaskan-village. Accessed March 2025; Copping, A. E. and Hemery, L. G. 2024. “Progress in Understanding Environmental Effects of Marine Renewable Energy.” In L. Garavelli, A. E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), OES Environmental *2024 State of the Science report: Environmental Effects of Marine Renewable Energy Development Around the World*. Report for Ocean Energy Systems (OES). (pp. 8-25), https://tethys.pnnl.gov/publications/2024-state-science-report-chapter-2-progress-understanding-environmental-effects.

[88] California Native American Heritage Commission. "Digital Atlas of California Native Americans," https://nahc.ca.gov/cp/. Accessed January 2025; The Digital Atlas of California Native Americans is provided solely for educational purposes and may not be used in determining locations of cultures, boundaries or people for recognition, consultation or any other legal or policy purpose. The resources displayed in the Atlas remain the property of their owners as cited.

Here "California Native American tribes" refers to federally and nonfederally recognized Native American tribes within California on the NAHC's list.

The second tribal dataset on these maps is the land areas of federally recognized tribal lands, sourced from the Bureau of Indian Affairs.[89] This dataset is shown to identify federally designated tribal, allotted, and jointly managed tracts and parcels.

Tribes with lands directly along the coast could be interested in marine renewable energy because wave and tidal energy projects could provide reliable and sustainable energy to coastal communities that are otherwise isolated from the grid or experience frequent outages or both. These distributed energy systems can be integrated into microgrids to supplement or replace diesel generators, reducing reliance on fossil fuels and improving energy resilience.[90] The Yurok previously explored wind and hydroelectric energy installations on their lands; however, the selected sites were not considered commercially viable at the time.[91] Any area of interest for technology deployment within Native American lands or near sites of cultural importance will require clear and direct communication. It is recommended that wave and tidal energy developers include early, frequent, and meaningful consultations with California Native American tribes to develop appropriate avoidance, minimization, and mitigation strategies for impacts to tribal cultural resources.

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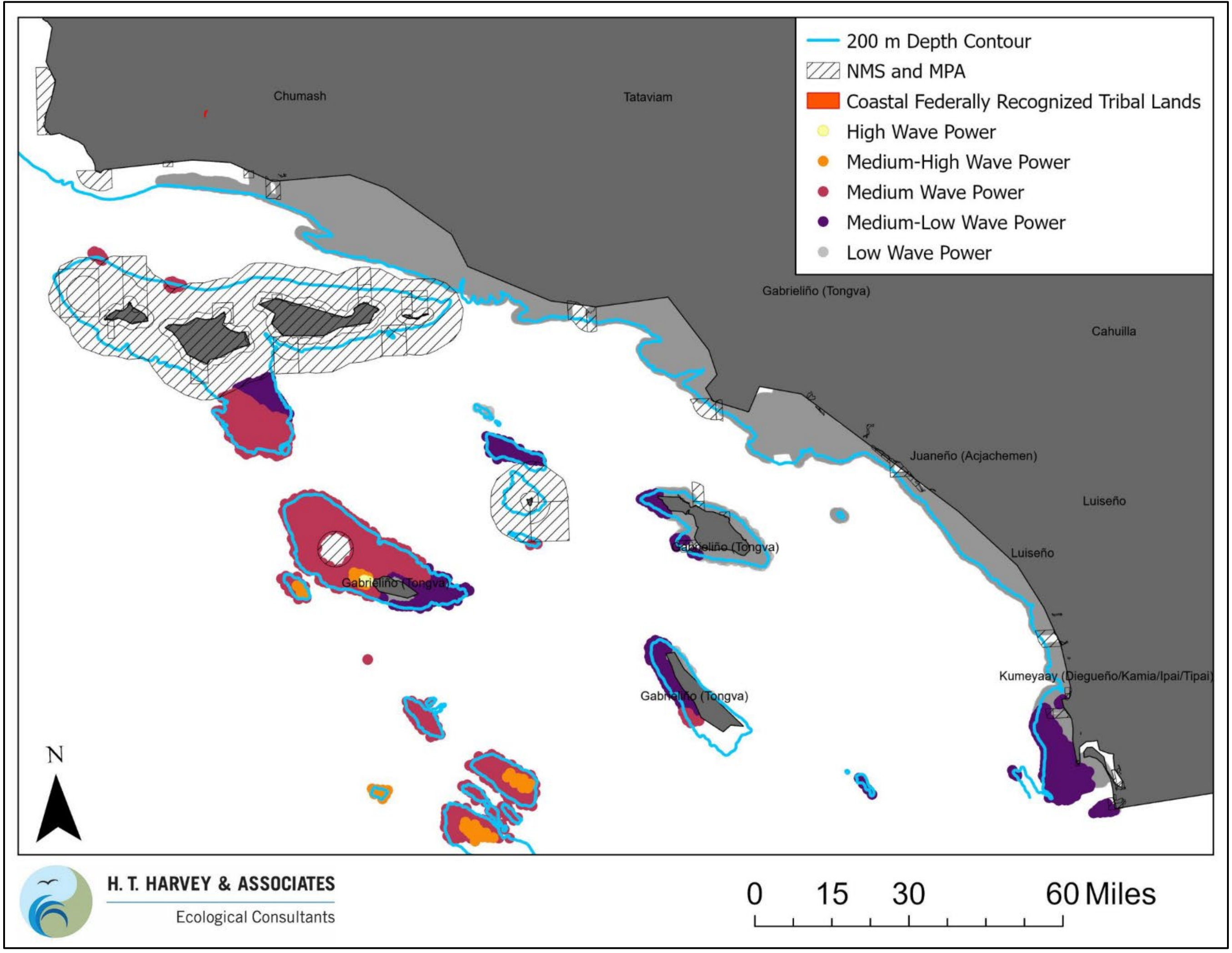
89 BIA Maps: "Bureau of Indian Affairs Open Data Portal." *BIA Maps*, https://biamaps.geoplatform.gov/BIA-Opendata/. Accessed January 2025.

90 Lee, Susan and Vida Strong. (Aspen Environmental Group). 2024. *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits*.

91 Zoellick, J., R. Engel, R. Garcia, and C. Sheppard. June 17, 2011. *Wind and Hydro Energy Feasibility Study.* Final report. Prepared by Schatz Energy Research Center and the Yurok Tribe. Prepared for the U.S. Department of Energy Tribal Energy Program, https://www.energy.gov/sites/default/files/2016/02/f29/yurok_final_report.pdf.

Figure 29: Southern California Potential Wave Energy Sites With Coastal California Native American Groups

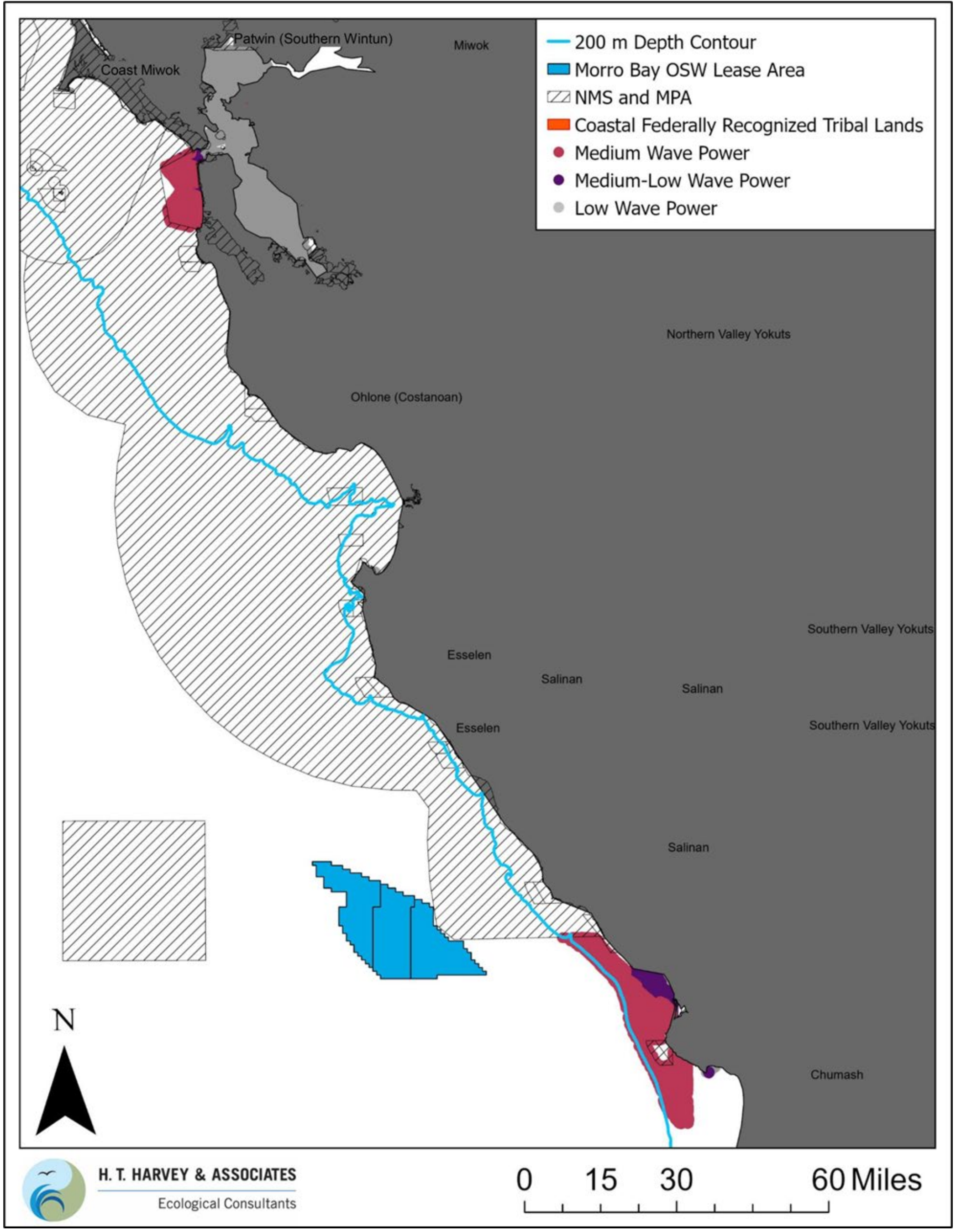


Note in Figure 29 that any potential wave energy deployment sites that overlap with MPAs and NMS, disposal sites, ship traffic lanes, or navigational channels have been removed.

See nahc.ca.gov/cp/references for more information on identified Native lands from the National American Heritage Commission's (NAHC) Digital Atlas.

Source: H. T. Harvey & Associates

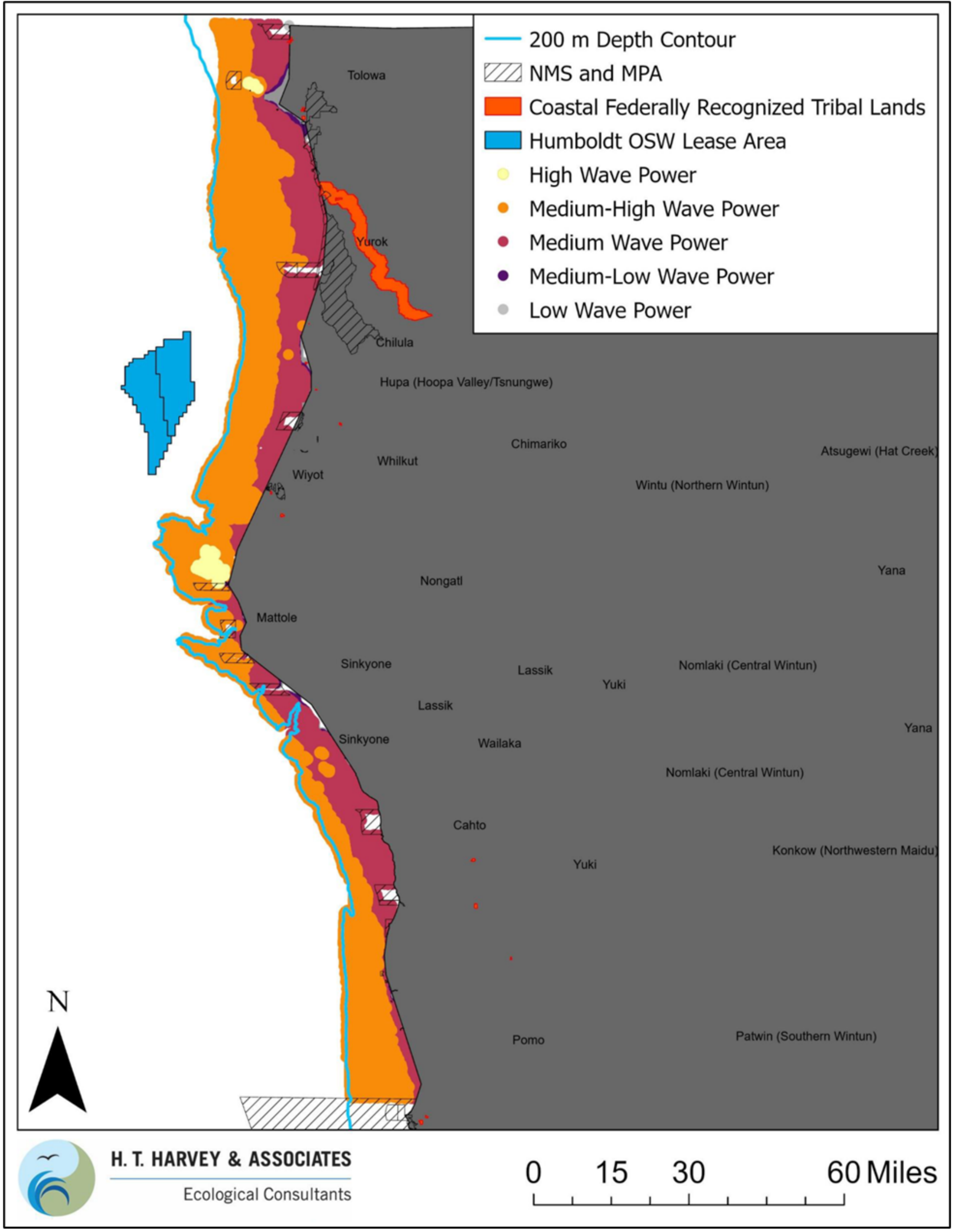
Figure 30: Central California Potential Wave Energy Sites With Coastal California Native American Groups



Note in Figure 30 that any potential wave energy deployment sites that overlap with MPAs and NMS, disposal sites, ship traffic lanes, or navigational channels have been removed.

See nahc.ca.gov/cp/references for more information on identified Native lands from the National American Heritage Commission’s (NAHC) Digital Atlas.

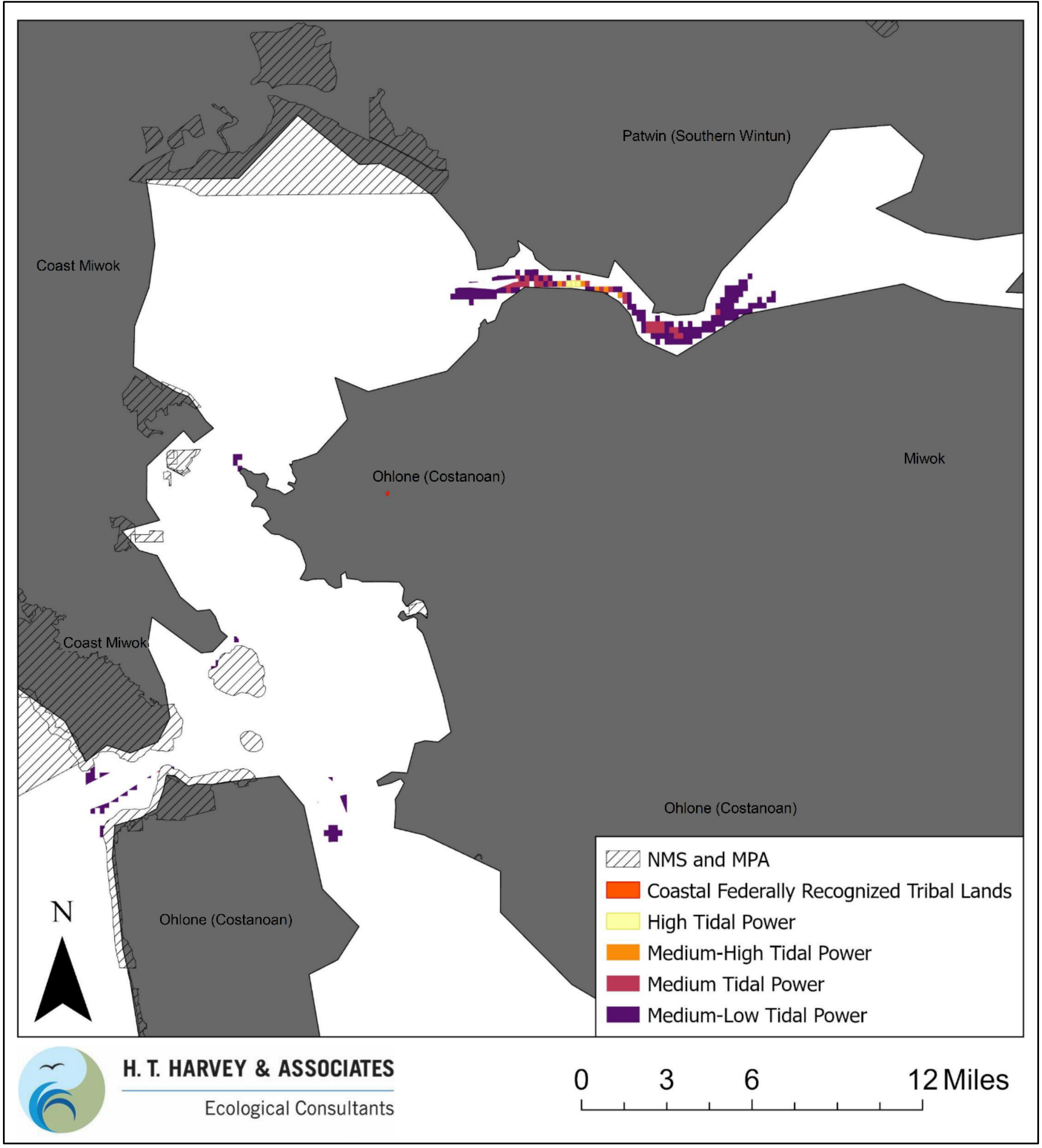
Figure 31: Northern California Potential Wave Energy Sites With Coastal California Native American Groups



Note in Figure 31 that any potential wave energy deployment sites that overlap with MPAs and NMS, disposal sites, ship traffic lanes, or navigational channels have been removed.

See nahc.ca.gov/cp/references for more information on identified Native lands from the National American Heritage Commission’s (NAHC) Digital Atlas.

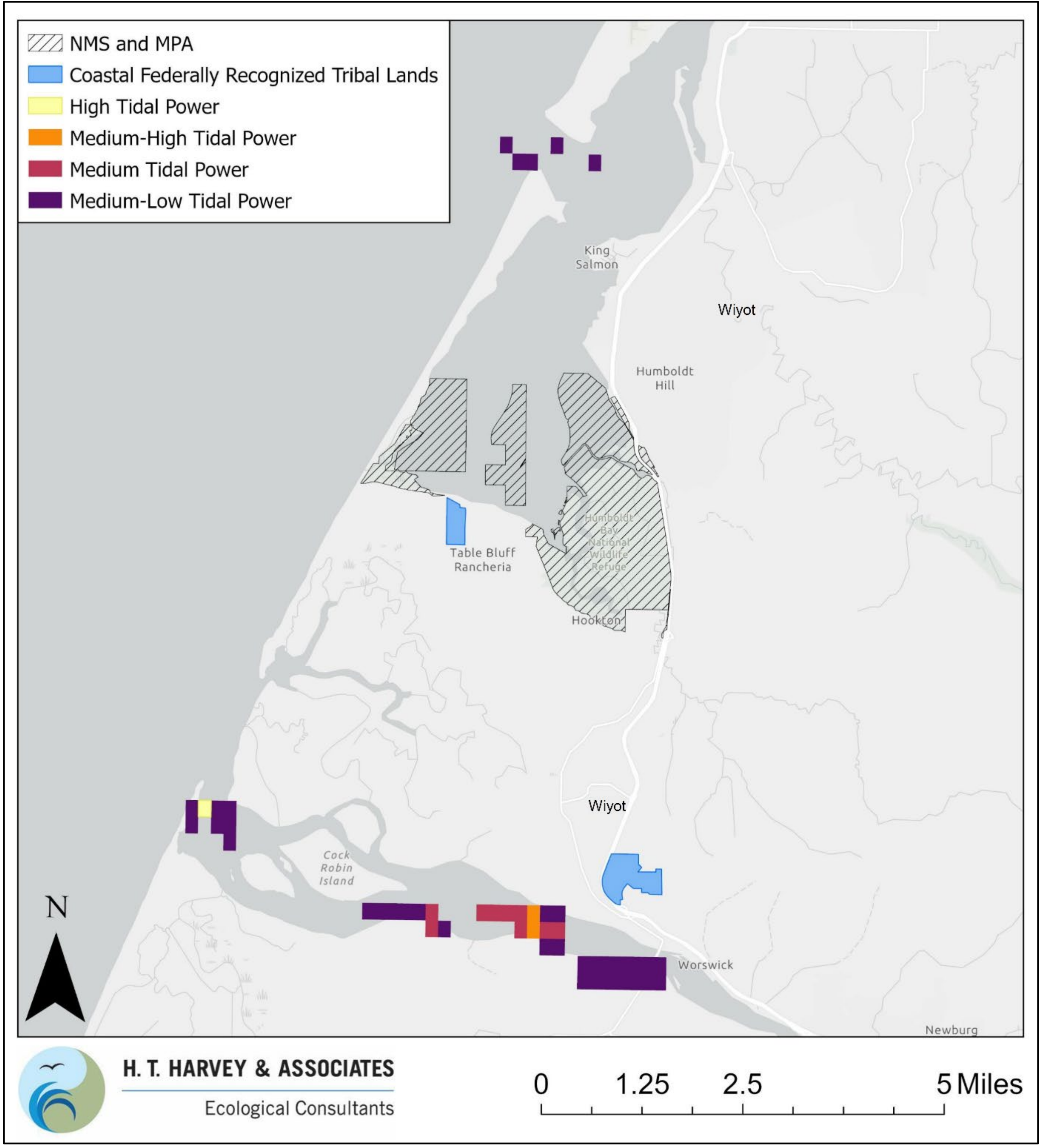
Figure 32: Central California Potential Tidal Energy Sites With Coastal California Native American Groups



Note in Figure 32 that any potential tidal energy deployment sites that overlap with MPAs and NMS, disposal sites, ship traffic lanes, or navigational channels have been removed. Polygons categorized as low potential tidal energy have been removed to highlight the other power categories.

See nahc.ca.gov/cp/references for more information on identified Native lands from the National American Heritage Commission’s (NAHC) Digital Atlas.

Figure 33: Northern California Potential Tidal Energy Sites With Coastal California Native American Groups



Note in Figure 33 that any potential tidal energy deployment sites that overlap with MPAs and NMS, disposal sites, ship traffic lanes, or navigational channels have been removed. Polygons categorized as low potential tidal energy have been removed to highlight the other power categories.

See nahc.ca.gov/cp/references for more information on identified Native lands from the National American Heritage Commission's (NAHC) Digital Atlas.
Basemap Source: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

3.2.2 Shipwrecks and Archaeological Sites

There are more than 1,500 shipwrecks along the California coast, some with exact mapped locations, while others are known to have wrecked but the exact location is approximate or unknown.[92] For example, more than 70 ships are known to have wrecked around the Point Reyes Peninsula before 1940, with 20 of the shipwrecks in unknown locations.[93] Many shipwrecks and other archaeological sites are located within federal marine sanctuaries or state MPAs and are consequently protected from development. Projects located on submerged lands within three nautical miles of the shoreline (that is, within state waters) fall within the jurisdiction of the California State Lands Commission (SLC) and require a tide and submerged lands lease.

The SLC administers the California Shipwreck and Historic Maritime Resources Program, and maintains a list of known shipwrecks in state waters.[94] Any shipwreck sunk for more than 50 years is presumed to be of archaeological or historical significance or both and, thus, is protected under state law. California Public Resources Code Sections 6309, 6313, and 6314 details SLC's authority over shipwrecks and other submerged archaeological sites.[95]

As mentioned in the November 2024 SB 605 report, *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits*, developers looking to deploy wave or tidal energy projects within state waters would need to consult with the SLC. The SLC would assess the potential for impacts to shipwrecks and other historic or archeological sites or both. In addition, a consultation with the Office of Historic Preservation is required to ensure that the proposed deployment/installation area does not include a shipwreck or any other archaeological site. Collecting sonar data of the seafloor around a proposed site as well as along the transmission cable pathway is also recommended to ensure that the area does not include any historical/ archaeological artifacts. If a previously unknown shipwreck or archaeological artifact is found during site characterization surveys, it is recommended that developers maintain a 500-meter perimeter around the shipwreck or artifact to avoid damaging the wreck and debris fields surrounding the wreck. The SLC has permitting authority over geophysical surveys in state waters.

3.3 Commercial and Recreational Fisheries

California's commercial and recreational fishing industries are an important part of the state's economy and the identity of its coastal communities. California is committed to protecting commercial and recreational fisheries and creating a resilient fishing industry. Any future wave

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[92] Foster, J. W. 2016. "A Bubble Slowly Rising: Shipwrecks and the Development of Nautical Archaeology in California." *Proceedings of the Society for California Archaeology* 30:2016, https://www.researchgate.net/profile/John-Foster-2/publication/328007636_A_BUBBLE_SLOWLY_RISING_SHIPWRECKS_AND_THE_DEVELOPMENT_OF_NAUTICAL_ARCHAEOLOGY_IN_CALIFORNIA/links/5bb2a1e2a6fdccd3cb8138f9/A-BUBBLE-SLOWLY-RISING-SHIPWRECKS-AND-THE-DEVELOPMENT-OF-NAUTICAL-ARCHAEOLOGY-IN-CALIFORNIA.pdf.

[93] National Park Service. 2021. "Shipwrecks at Point Reyes." Updated August 22, 2021. Accessed December 2024. https://www.nps.gov/pore/learn/historyculture/stories_maritime_shipwrecks.htm.

[94] California State Lands Commission "Shipwreck Information," https://www.slc.ca.gov/wp-content/uploads/2018/12/ShipwreckInfo.pdf.

[95] California State Lands Commission. "California Shipwrecks," https://www.slc.ca.gov/shipwrecks/.

and tidal energy projects should include early coordination with commercial and recreational fisheries to identify potential conflicts and ways to avoid and minimize those conflicts.

Fishing exclusion areas may need to be established around large wave and tidal projects to protect the energy devices and fishing gear. If avoidance of high-conflict areas is not possible, or if fishing exclusion areas are not an option, developers may be required to enter into collaborative agreements with fishers and fisheries managers (tribal, state, and federal). The purpose of these agreements are to establish communication protocols, compensate for lost gear due to interactions with energy infrastructure, and provide funds to promote resiliency in the commercial and recreational fishing industries.[96] With proper siting, mitigation, compensation, and precaution measures, conflicts between fishermen and energy development can be avoided or reduced.

The project team analyzed commercial and recreational fishing effort data, amount of fishing activity, to identify potential conflict areas for wave and tidal project siting. Due to wave and tidal energy technology constraints, fisheries that primarily operate at water depths deeper than 200 meters were not considered in this analysis. Moreover, this analysis does not consider fishing operational needs or gear types, but rather aims to display where fishing effort takes place offshore California.

3.3.1 Commercial Fishing Effort

California’s nearshore waters, defined in this report as less than 200 meters deep, support a wide variety of commercial fisheries up and down the coast. If wave and tidal energy is found to be feasible and projects are proposed, a full fisheries analysis and fisheries outreach efforts would be conducted to evaluate impacts of every fishery operating in the project area. For this feasibility analysis, the project team used three of California’s most historically valuable nearshore fisheries to identify potential conflict areas. The team defined fisheries value using ex-vessel value, or the dollar amount paid to fishermen at the first point of sale (typically at the dock).

The CDFW collects ex-vessel value for all fish and invertebrates landed commercially in California ports. From 2014 to 2022, Dungeness crab (*Metacarcinus magister*), market squid, and Chinook salmon fisheries were among the highest value fisheries on an annual basis.[97] Of note, the Chinook salmon fishery was closed statewide in 2023 and 2024 because of low population estimates. The maps below display fishing effort or catch densities for these three fisheries along with other constraints, including national marine sanctuaries and marine protected areas.

Fishing effort for Chinook salmon troll and Dungeness crab fisheries was mapped (Figure 34 and Figure 35) using three datasets: fishing effort derived from vessel monitoring system

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[96] Central California Joint Cable/Fisheries Liaison Committee. 2002. Agreement Between Cable Companies And Fishermen, Version 140519. Accessed December 2024, https://climate.law.columbia.edu/sites/climate.law.columbia.edu/files/content/CBAs/Cable%20Companies%20Agreement.pdf.

[97] California Department of Fish and Wildlife. "By the Numbers." California Department of Fish and Wildlife, https://wildlife.ca.gov/Regions/Marine/By-the-Numbers. Accessed December 2024.

(VMS) data,[98] boundaries for community fishing grounds compiled by the North Coast Fisheries Mapping Project,[99] and boundaries for commercial fishing grounds compiled by the Central Coast Fishing Heritage Mapping Project.[100] Figure 34 and Figure 35 show the extent of the study area along with the California Exclusive Economic Zone, California counties, California national marine sanctuaries and marine protected areas, and a 200-meter water depth contour line. As described above, NMS and MPAs are being treated as "no go" zones for this wave and tidal energy feasibility analysis; therefore, fishing data that fall within these areas were not displayed.

The VMS dataset consists of commercial fishing activity from 2010 to 2022 derived from VMS data provided by NMFS and compiled by the Pacific Fisheries Information Network (PacFIN).[101] The Pacific States Marine Fisheries Commission summarized the data using methods developed by California Polytechnic State University, San Luis Obispo, and BOEM. Fishing effort was determined successive vessel positions meeting specified speed criteria that were used to construct estimated fishing tracks. Fishing tracks were then summarized using a one-minute block, and only locations with three or more vessels present were included. The authors emphasize that vessels are only required to carry on-board transceiver units for specific fisheries (for example, federally managed fisheries such as groundfish);[102] therefore, the VMS fishing data represent an incomplete view of actual fishing activity.[103]

The fishing ground boundaries published in the North Coast Fisheries Mapping Project and the Central Coast Fishing Heritage Mapping Project are the result of a collaborative effort led by commercial fishermen in each region, including three Northern Californian commercial fishermen associations and the Morro Bay Commercial Fishermen's Organization. The boundaries present a historically informed snapshot of commercial fishing grounds not limited by regulatory or socioeconomic factors. Data from those mapping efforts were displayed on each map to capture the full extent of possible fishing grounds for each of the analyzed fisheries. These maps do not capture potential future shifts in the location of the fishing grounds due to changing ocean conditions associated with climate change.

The coastwide VMS fishing effort data suggest that higher fishing activity for Chinook salmon and Dungeness crab occurs in the Northern California and Central California regions in

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98 Pacific States Marine Fisheries Commission. 2023. VMS Fishing Effort, Midwater Trawl 2010–2022, https://maps.psmfc.org/metadata/PacFIN/VMS/2010_2022_Summary/PDF/VMS_Fishing_Effort_Midwater_Trawl_2010_2022_metadata.pdf. Data accessed December 2024.

99 Northern California Commercial Fishermen's Associations. 2020. "North Coast Fisheries Mapping Project," https://storymaps.arcgis.com/stories/ec90562aada545acb6bb1bf6f3c8f228.

100 Central Coast Fishing Heritage Mapping Project. (n.d.). "Fisheries Story Map," https://experience.arcgis.com/experience/0aefe2155de3457b9709c9303762664f/page/Fisheries-Story-Map/.

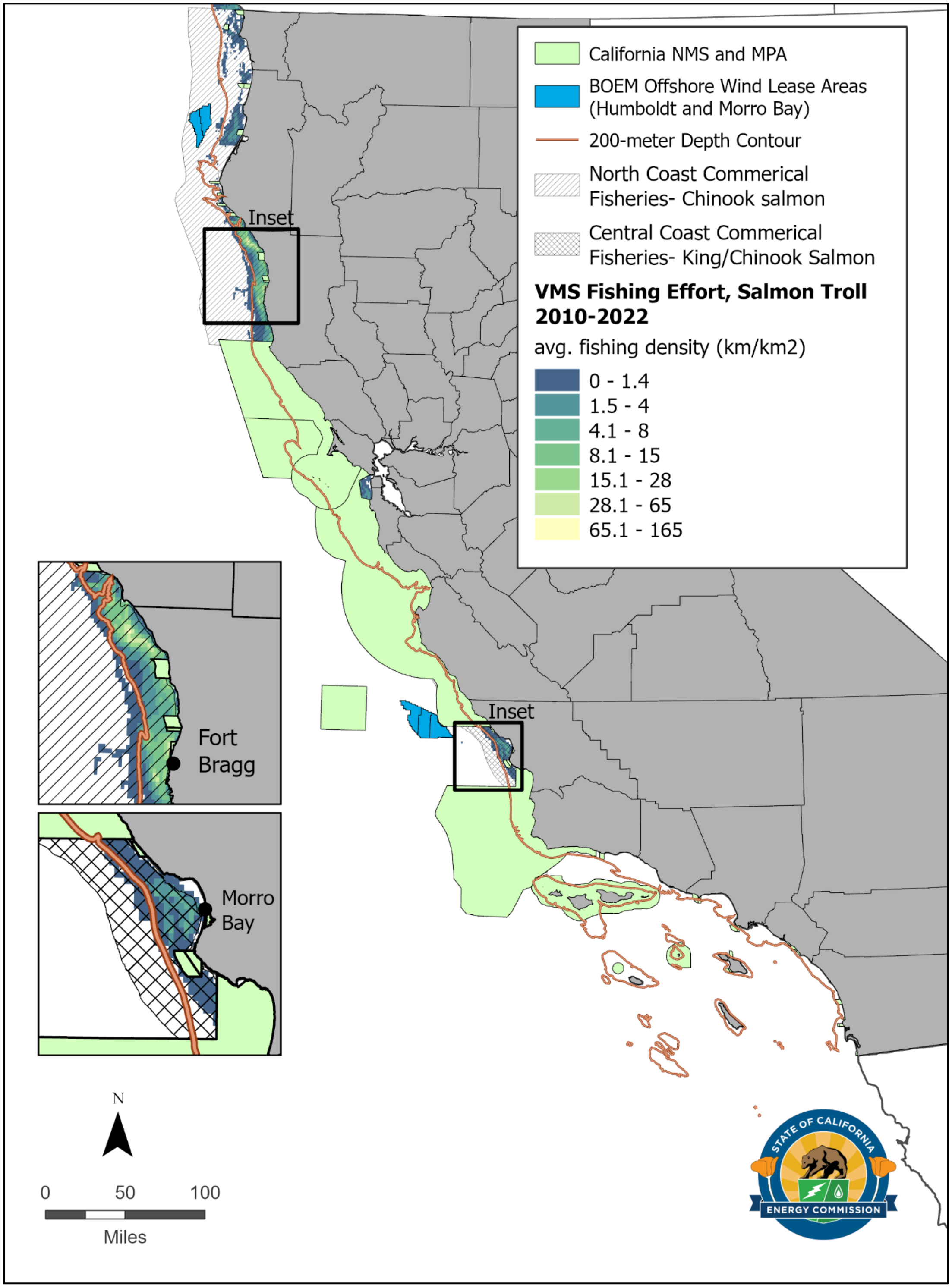
101 The Pacific Fisheries Information Network (PacFIN) is a collaboration between member state and federal fishery agencies that supply the information needed to effectively manage fish stocks on the West Coast of the United States.

102 NOAA Fisheries. "Regional Vessel Monitoring Information," https://www.fisheries.noaa.gov/national/enforcement/regional-vessel-monitoring-information.

103 Pacific States Marine Fisheries Commission. 2023. VMS Fishing Effort, Midwater Trawl 2010–2022. Data accessed December 2024.

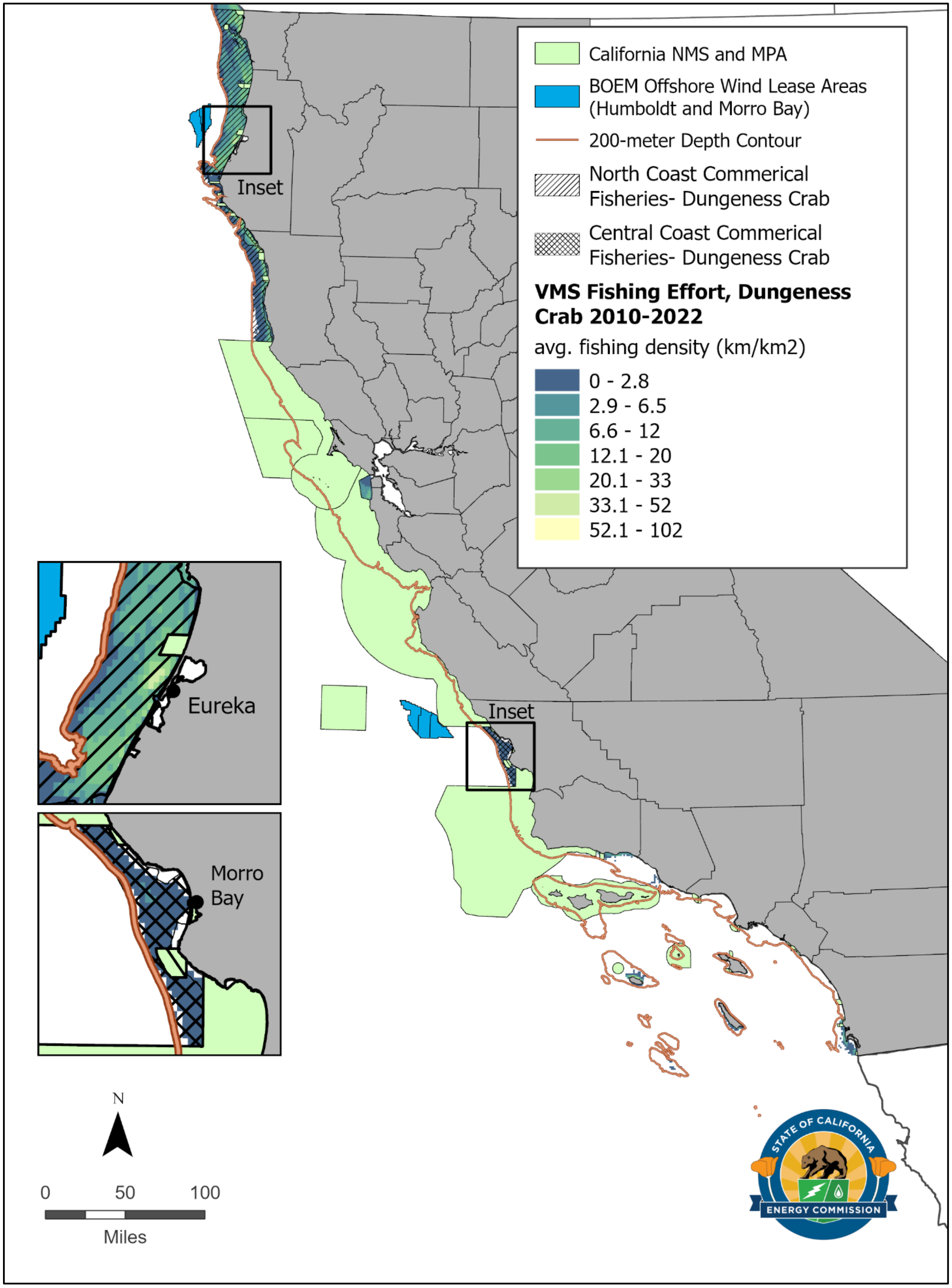
comparison to the Southern California region. For the Chinook salmon fisheries, the highest-density fishing activity outside an NMS/MPA occurs along the North Coast, near Fort Bragg, and off the Central Coast, near Morro Bay. For Dungeness crab, the highest fishing density occurs along the North Coast with an area of high intensity near Eureka, as well as off the Central Coast, near Morro Bay.

Figure 34: Commercial Fishing Effort, Salmon



Source: CEC

Figure 35: Commercial Fishing Effort, Dungeness Crab



Source: CEC

Market squid are also one of California's most valuable commercial fisheries, according to ex-vessel value landed.[104] Market squid depend on nearshore environments with sandy or soft

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[104] California Department of Fish and Wildlife. 2022. *2021 By the Numbers*, https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=198970.

substrates for breeding, making the protection of their habitats a key component to preserving the sustainability of the market squid fishery.

Figure 36 shows relative market squid catch density for 2014 to 2024 calculated using California Department of Fish and Wildlife (CDFW) logbook data for individual net hauls. Each net haul has an estimated catch in tons, and the darker red color indicates a higher catch. Also displayed on the map are shaded regions that show important fishing areas for market squid, according to the North Coast Fisheries Mapping Project[105] and the Central Coast Fishing Heritage Mapping Project.[106] The highest density of market squid fishing catch outside the protected areas occurs along the coast of Southern California (Figure 36). However, market squid fishing grounds were also identified along the North Coast.

Tidal energy projects are unlikely to pose any significant conflicts with commercial fishing since potential tidal energy resources are low in offshore areas where most commercial fishing occurs. One exception is commercial fishing for coastal pelagic species (for example, Pacific herring) that occurs inside bays and estuaries. Since this analysis has a water depth constraint of 200 meters or less, it is less likely that commercial fishing for highly migratory species (for example, albacore tuna [*Thunnus alalunga*], swordfish [*Xiphias gladius*], louvar [*Luvarus imperialis*], opah [*Lampris* spp.]) will be impacted since those species are active in deeper, offshore waters. However, fisheries that operate closer to shore could be impacted by transmission cables coming to shore and increased vessel traffic associated with offshore wave energy construction, operations, and maintenance.

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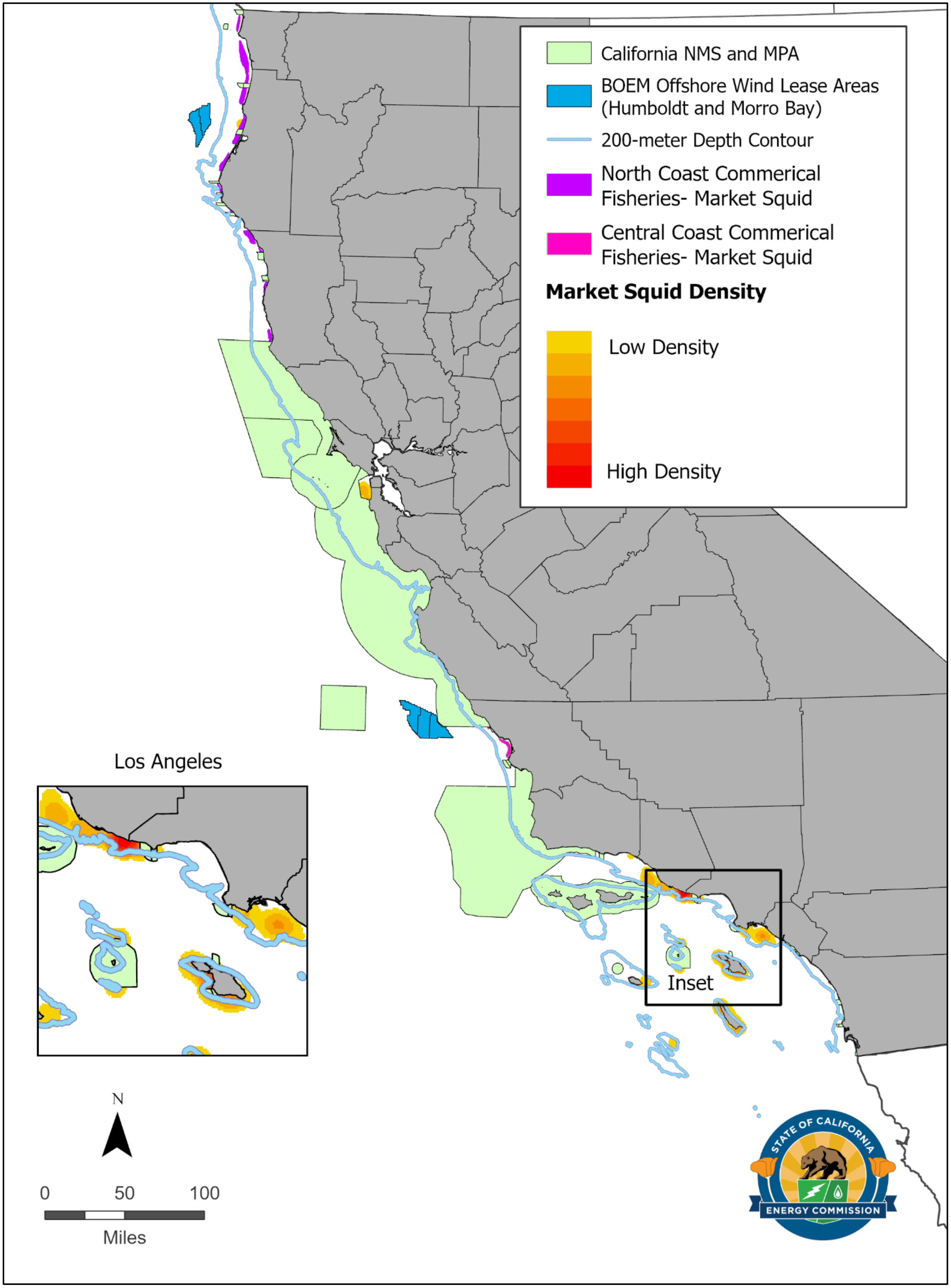
[105] Northern California Commercial Fishermen's Associations. 2020. "North Coast Fisheries Mapping Project."

[106] Central Coast Fishing Heritage Mapping Project. (n.d.). Fisheries Story Map.

Figure 36: Commercial Fishing Effort, Market Squid



Source: CEC

Groundfish fisheries are another important species group in California. Groundfish include more than 90 species of bottom-dwelling marine finfish, such as rockfish, sablefish, lingcod, and flatfishes. These species contribute to the rich biodiversity of the marine ecosystem and have managed populations and habitats (as discussed in Section 3.1). Many groundfish species are important to commercial and recreational fisheries, providing revenue to fishing communities and contributing to local tourism. Marine renewable energy development should be balanced with the needs of marine ecosystems and fisheries.

3.3.2 Recreational Fishing Effort

Recreational fishing effort for California was derived from fishing effort compiled from Commercial Passenger Fishing Vessels (CPFV) and CDFW California Recreational Fishing Survey (CRFS) data.[107] CPFVs, also known as charter boats, are licensed vessels that take paying customers fishing and provide gear, bait, and guidance. CPFVs vary in size and popularity throughout the state. Smaller vessels that host up to six anglers are the most common CPFV in Northern California, whereas larger "party boat" vessels that accommodate 20 to more than100 anglers are more common in Southern California.

Figure 37 shows CPFV fishing effort from January 2014 through September 2024. Fishing effort data were sourced from CDFW's Commercial Passenger Fishing Vessel logbook entries. Effort data are summarized and displayed using the three-digit CDFW commercial fishing blocks. Most CDFW commercial fishing blocks have a spatial resolution of 10 minutes of latitude by 10 minutes of longitude (roughly 10 by 10 nautical miles), with larger blocks farther offshore (30 by 30 nautical miles). CPFV fishing effort is represented by catch per angler-hour, calculated by multiplying the number of total hours fished by the number of anglers that fished in each block. Darker red indicates higher CPFV effort. The hatched blocks that show no data were omitted because of confidentiality reasons. (A block must have logbook data submissions from three or more unique vessels over the time period analyzed to be considered nonconfidential.) Fishing blocks with the highest CPFV effort were typically close to shore near large population centers like the San Francisco Bay Area, Los Angeles, and San Diego.

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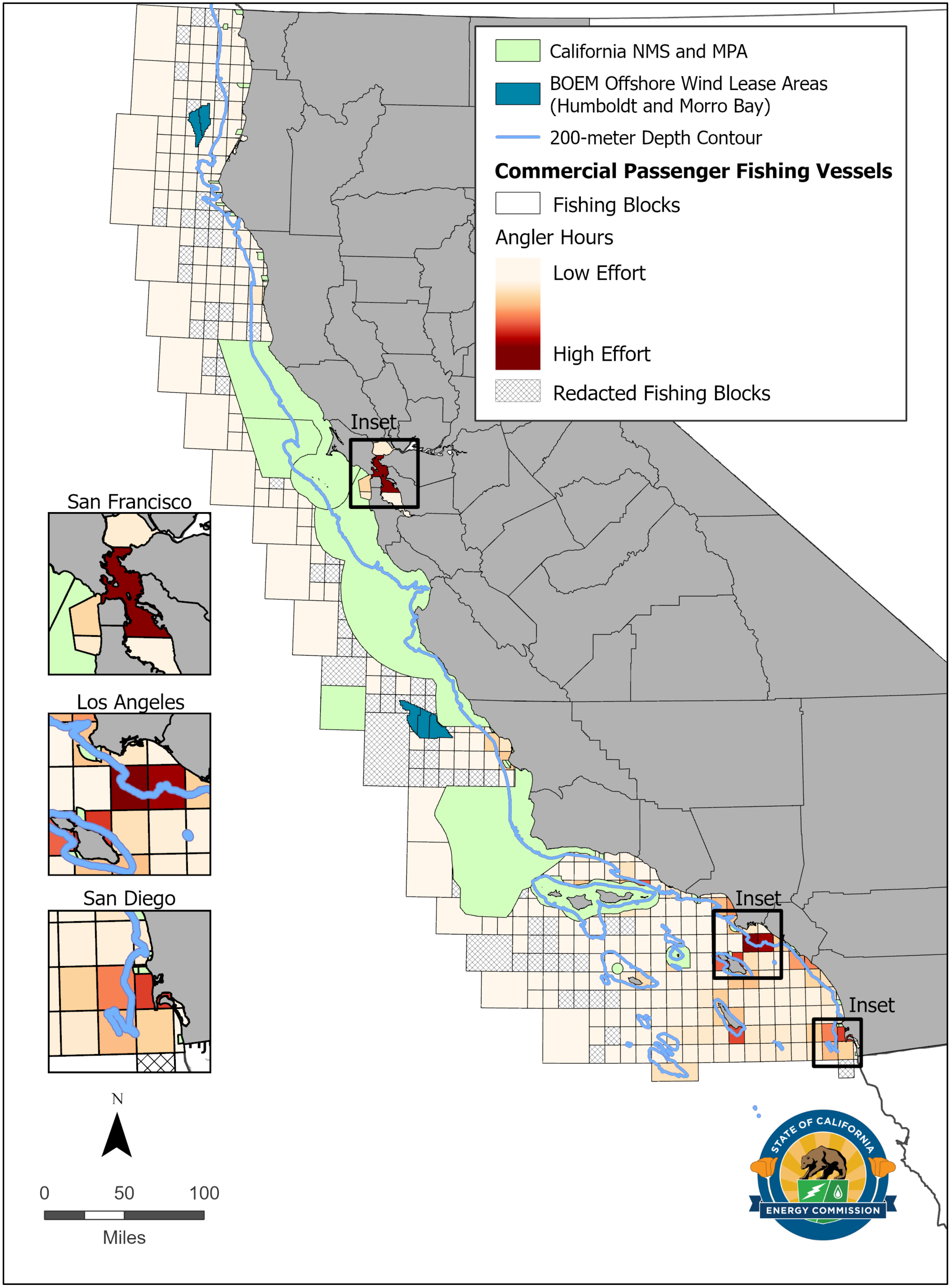
[107] Recreational Fisheries Information Network. 2025. "RecFIN," Pacific States Marine Fisheries Commission, www.recfin.org. Accessed December 2024.

Figure 37: Recreational Fishing Effort, Commercial Passenger Fishing Vessels

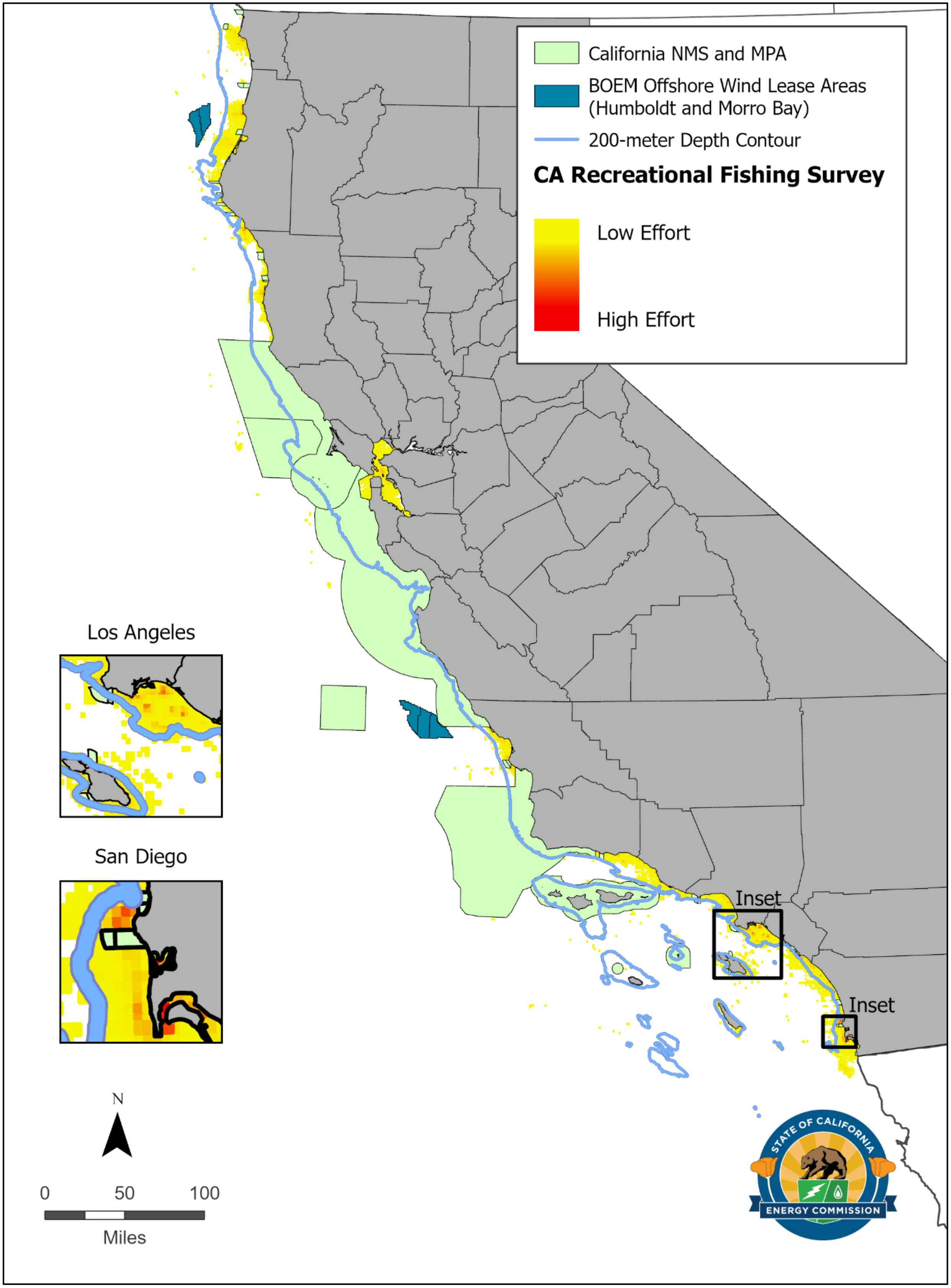


Source: CEC

Figure 38 shows ocean recreational fishing effort data from CDFW's California Recreational Fishing Survey (CRFS) for private and rental boats from 2004 to 2022. CRFS data are collected by conducting interviews with recreational anglers when they return to the dock/boat launch after fishing. CRFS data collectors record the number of fish kept and the number of fish released reported by the angler during a fishing trip, as well as where the angler was fishing. Those data are then ascribed to one-minute fishing blocks (about 1.8 km or 1 nm). Darker red shades in the heat map indicate blocks that had more fishing trips reported.

The highest recreational fishing effort was concentrated outside major ports and coastal population centers along the California coast with decreasing effort as one moves away from those areas. Fishing effort was also concentrated inside bays, channels, and estuaries, as well as around the Channel Islands (Figure 38). Blocks with fewer than three fishing reports were redacted from Figure 38. Higher tidal energy resources are found within bays, channels, and estuaries (such as the Eel River estuary), which could bring recreational fisheries in those areas into conflict with tidal energy projects. Careful planning of such projects would be required to avoid or minimize any conflicts. Fishing activity surrounding the northern Channel Islands falls within the Channel Islands National Marine Sanctuary, so these areas would be protected from wave energy development.

Figure 38: Recreational Fishing Effort, California Recreational Fishing Survey



Source: CEC

3.3.3 Aquaculture

Aquaculture can be energy-intensive, and diesel is often used to power monitoring equipment, circulatory and feeding systems, as well as refrigeration systems.[108] There is growing interest in using renewable energy for powering aquaculture.[109] The U.S. Department of Energy is seeking avenues for the colocation of marine renewable energy and aquaculture as part of its "Powering the Blue Economy™" initiative.[110] In addition to the benefit of providing renewable energy for aquaculture, the colocation of energy systems with aquaculture could provide developers with the opportunity to test their devices. Such collaboration would enable the development of larger devices, which could then be used to power larger aquaculture operations.[111]

At the time of writing, NOAA is working toward identifying suitable areas for offshore aquaculture projects in Southern California, including eight potential areas in the Santa Barbara Channel and two areas in Santa Monica Bay (Figure 39).[112] The "Alternative Boundary" in Figure 39 refers to the study area boundary for potential aquaculture sites. There are also established aquaculture farms that could potentially use wave energy for powering water pumps for tanks and other activities. These aquaculture farms include oyster farms in Humboldt Bay, Tomales Bay, Morro Bay, and San Diego Bay; mussel farms in the Santa Barbara Channel and off the coast of Long Beach; as well as land-based aquacultural sites such as abalone farms in Santa Barbara, Morro Bay, Davenport, and Monterey.[113] Given the potential for colocation of marine renewable energy, current and future aquaculture sites are considered technology-dependent constraints for energy development.

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[108] Freeman, M. C., L. Garavelli, E. Wilson, M. Hemer, M. L. Abundo, and L. E. Travis. April 2022. *Offshore Aquaculture: A Market for Ocean Renewable Energy. Report for Ocean Energy Systems (OES)*, https://www.ocean-energy-systems.org/documents/87797-oes-aquaculture-and-ocean-energy.pdf/.

[109] Gravelli, L., M. C. Freeman, L. G. Tugade, D. Greene, and J. McNally. June 15, 2022. "A Feasibility Assessment for Co-locating and Powering Offshore Aquaculture With Wave Energy in the United States." *Ocean & Coastal Management* 225:106242, https://doi.org/10.1016/j.ocecoaman.2022.106242.

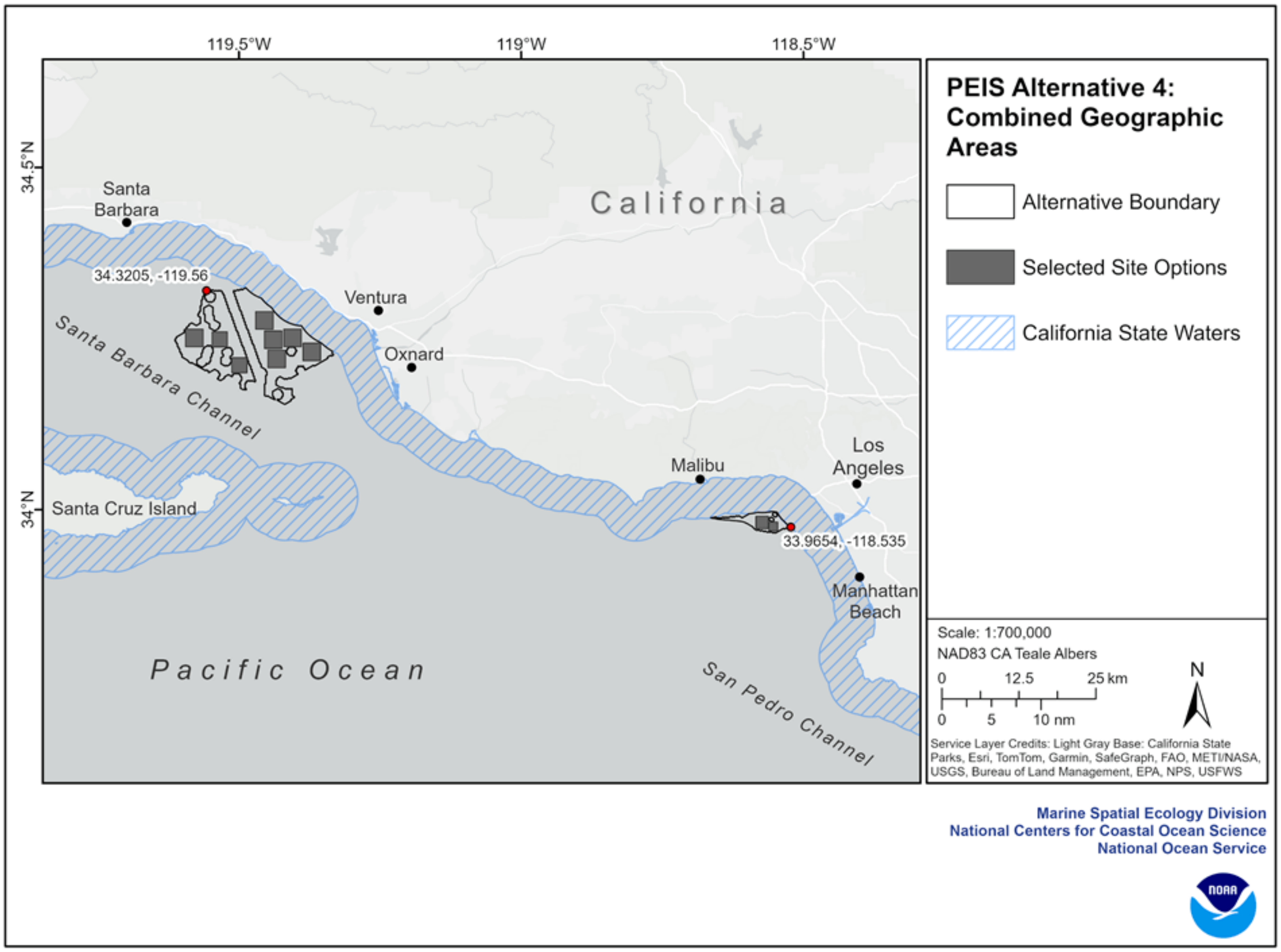
[110] LiVecchi A., A. Copping, D. Jenne, A. Gorton, R. Preus, G. Gill, R. Robichaud, R. Green, S. Geerlofs, S. Gore, D. Hume, W. McShane, C. Schmaus, and H. Spence. 2019. *Powering the Blue Economy; Exploring Opportunities for Marine Renewable Energy in Maritime Markets*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Washington, D.C., https://www.energy.gov/sites/default/files/2019/09/f66/73355-1.pdf.

[111] LiVecchi A., et al. *Powering the Blue Economy; Exploring Opportunities for Marine Renewable Energy in Maritime Markets*.

[112] NMFS West Coast Regional Office. 2024. "West Coast Region Southern California Aquaculture Opportunity Area." Accessed December 2024, https://www.fisheries.noaa.gov/west-coast/aquaculture/west-coast-region-southern-california-aquaculture-opportunity-area.

[113] California Sea Grant. 2024. "Aquaculture in California." Accessed December 2024, https://caseagrant.ucsd.edu/our-work/discover-california-seafood/aquaculture-california.

Figure 39: Combined Geographic Areas Identified in the Programmatic Environmental Impact Statement (PEIS) for Aquaculture Opportunity Areas



Source: NMFS West Coast Regional Office[114]

3.4 Ocean Uses

California has 3,427 miles of coastline that provide important services to about 26.8 million people who live in coastal communities.[115] Minimizing conflict with other ocean users will be vital to the success of wave and tidal energy projects.

3.4.1 Shipping Lanes, Dredged Areas, and Ocean and Sediment Disposal Sites

The most restrictive ocean uses include commercial shipping lanes, ferry routes, areas that are routinely dredged for navigation, and designated ocean disposal sites. Anchoring or stalling a

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[114] NMFS West Coast Regional Office. 2024. "West Coast Region Southern California Aquaculture Opportunity Area."

[115] NOAA Office for Coastal Management. 2024a. "Shoreline Mileage of the United States." Accessed December 2024, https://coast.noaa.gov/data/docs/states/shorelines.pdf; NOAA Office of Coastal Management. 2024b. "Economics and Demographics." Accessed December 2024, https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html#:~:text=Top%20Five%20Coastal%20Populations,and%20Texas%20with%206.9%20million.

vessel within a shipping lane or ferry route is dangerous, making installation and maintenance of a device difficult. In addition, the device(s) could pose a navigational hazard for ships traveling through the lane. Shipping safety fairways specifically prohibit any fixed structures within their boundaries;[116] therefore, a moored device could not be installed in these areas. Any changes to shipping lanes or safety fairways would require negotiations with the U.S. Coast Guard and could delay permitting for a project.

Areas that are routinely dredged for navigation — such as entrance channels, navigational channels, or other dredged areas within harbors and bays — are also likely off limits to moored devices and transmission cables (although WECs built into existing structures such as jetties may be feasible). These areas include federal navigation channels in San Francisco Bay (Main Ship, Pinole Shoal, Outer Richmond, and Suisun Bay);[117] the entrance channels to Marina del Rey,[118] Santa Cruz Harbor and Moss Landing Harbor;[119] Mission Bay;[120] Oceanside Harbor; and the entrance channel of Humboldt Bay,[121] to name a few. Dredging operations could damage energy devices, making these areas unsafe for moored devices. Wave or tidal energy projects looking to deploy devices within a port or harbor should coordinate with the U.S. Army Corps of Engineers (USACE) or local port authorities or both to determine areas to avoid.

In addition to dredging for navigational purposes, offshore areas along the California coast known as “offshore borrow sites” are dredged for sediment that are then used to replenish beaches. Offshore borrow sites are temporary and are typically located close to shore (close to the beach receiving the sediment) or within a bay/harbor. It is recommended that any projects coordinate with the USACE for the most up-to-date information on potential offshore borrow sites within potential project areas, including locations identified within sand scoping studies.

Sediment removed during dredging operations is often dumped out at sea at designated ocean disposal sites. Disposal of other material (for example, vessels, marine mammal carcasses) at sea is also allowed with a Marine Protection, Research and Sanctuaries Act (MPRSA) permit.

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[116] Electronic Code of Federal Regulations. "Title 33: Navigation and Navigable Waters; Chapter I: Coast Guard, Department of Homeland Security; Subchapter P: Ports and Waterways Safety; Part 166: Shipping Safety Fairways; Subpart A: General; Section 166.105." Accessed December 14, 2024. https://www.ecfr.gov/current/title-33/chapter-I/subchapter-P/part-166/subpart-A/section-166.105.

[117] U.S. Army Corps of Engineers, San Francisco District. "Federal Navigation Channels, Final Environmental Assessment and Environmental Impact Report, Finding of No Significant Impact." Accessed December 14, 2024. https://www.spn.usace.army.mil/Portals/68/docs/P%20and%20Programs/Navigation/Fed%20Nav%20Channels_FEAEIR_FONSI%202015.pdf.

[118] Army Corps of Engineers. 2024. “Marina del Rey California.” Accessed December 2024, https://www.spl.usace.army.mil/Missions/Civil-Works/Navigation/Marina-del-Rey/.

[119] National Ocean Service. 2024. “Monterey Bay National Marine Sanctuary: Resource Issues: Dredging and Harbors.” Accessed December 2024, https://montereybay.noaa.gov/resourcepro/resmanissues/dredge.html#:~:text=The%20two%20harbors%20that%20regularly,this%20case%2C%20the%20two%20harbors.

[120] City of San Diego. 2024. “Capital Improvements Program (CIP): Mission Bay Navigational Safety Dredging Project.” Accessed December 2024, https://www.sandiego.gov/cip/projectinfo/featuredprojects/missionbaydredging#:~:text=Mission%20Bay%20Navigational%20Safety%20Dredging%20Project%20%7C%20City%20of%20San%20Diego%20Official%20Website.

[121] Army Corps of Engineers. 2024. “Humboldt Harbor & Bay.” Accessed December 2024, https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Current-Projects/Humboldt-Harbor-Bay--/.

The U.S. Environmental Protection Agency (EPA) is responsible for issuing permits for the disposal of materials other than dredged sediments and manages all MPRSA sites, while the USACE issues permits for dredged materials. All active ocean disposal sites along the California coast are considered as ”no go” zones to energy development, but those areas could be available in the future if they are retired (depending on the material dumped at the site).

3.4.2 Department of Defense Sites and Operations

Developers must address potential conflicts with U.S. Department of Defense (DoD) activities when siting wave and tidal energy near DoD properties and operations, particularly areas critical to national security. DoD conducts extensive training, weapons testing, and other operations off the California coast, which could conflict with wave and tidal energy development. However, the military could have use for marine energy technologies since the devices can be deployed in off-grid locations along the coast. Distributed energy systems can provide decentralized and sustainable power for military bases, installations, and operations in coastal and maritime environments.[122]

To determine if a marine renewable energy project would be compatible with DoD military operations, energy developers would need to submit project information to the DoD Siting Clearinghouse for review, which would then identify any challenges and operational impacts for further discussion. It is recommended that developers request an informal review early in the development process to site renewable energy in a manner that is compatible with military operations.[123]

3.4.3 State/County Beaches and Recreational Areas

A marine renewable energy project or transmission cables or both could be installed near any state beaches, county beaches, or recreational areas that do not fall within the California MPA system. However, the device type(s) and array size of the project may be limited to certain devices and smaller installations, along with other considerations, to avoid conflicts with recreational use of the areas, such as sailing, wind surfing, kayaking, swimming, and surfing. Potential effects of the devices and array size on surfing areas will need to be evaluated before installing a project. Changes to bottom bathymetry, wave form, beach erosion, and sand transport could impact the quality of the surf areas and should be minimized to reduce impacts on surfing areas. Permitting may be a challenge in (and offshore of) these areas; however, more site-specific analysis is required. There are also potential colocation opportunities where a WEC array could be used to reduce wave energy and enhance coastal resilience.[124] Again, more site-specific analyses are required to model the benefits of WEC arrays.

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[122] Lee, Susan and Vida Strong. (Aspen Environmental Group). 2024. *Wave and Tidal Energy: Evaluation of Feasibility, Costs, and Benefits. SB 605 Report*.

[123] U.S. Department of Defense. “DOD Military Aviation and Installation Assurance Siting Clearinghouse,” https://www.dodclearinghouse.osd.mil/.

[124] Ozkan, C., Mayo, T., Passeri, D. L. 2022. “The Potential of Wave Energy Conversion to Mitigate Coastal Erosion From Hurricanes.” *Journal of Marine Science and Engineering* 10(2):143, https://doi.org/10.3390/jmse 10020143.

3.5 Ocean Infrastructure

Ocean infrastructure such as subsea cables and pipelines, oil and gas platforms, planned infrastructure associated with OSW lease areas, and buoys all need to be considered when siting wave and tidal energy development. Moreover, as more infrastructure is built in offshore environments, it will be increasingly important to model the cumulative impacts of ocean infrastructure and consider these impacts when siting marine renewable energy projects.

3.5.1 Subsea Cables and Pipelines

The Pacific Ocean is crisscrossed by thousands of miles of subsea data cables that connect the United States to other Pacific Rim countries. California hosts at least ten landing areas/stations for these cables: San Diego, Redondo Beach, Hermosa Beach, El Segundo, Los Angeles, Santa Barbara, Grover Beach, San Luis Obispo, Morro Bay, and the Eureka Cable Landing Station (https://www.submarinecablemap.com/). Submarine cables require maintenance and repairs, which are performed using large vessels (more than 125 m long).

Cable ships need adequate space to maneuver and structures such as WECs, and their own maintenance vessels could create navigational hazards for these ships. Moreover, grapnels are often used for retrieving faulty cables, which could damage energy devices and transmission cables. Therefore, it is recommended that device deployments and transmission cables associated with wave and tidal energy be located a distance of two to three times the water depth from existing cables, or at least 500 m away from a cable in waters less than 75 meters deep. This recommendation follows the International Cable Protection Committee's (ICPC) recommendation for parallel submarine cables.[125] Furthermore, the ICPC recommends consulting with the manager/operator of the cable to ensure that they agree with the spacing and are aware of the presence of any structures.

The southern coast of California, from Vandenberg Space Force Base to Long Beach, has several old oil pipelines, some of which are no longer in operation and have been abandoned. Other pipelines have been in operation for 30 to 40 years, making them vulnerable to rupture, as evidenced by a 2021 oil spill off the coast of Newport Beach where a ship's anchor is suspected to have dragged and ruptured a pipeline, spilling 25,000 gallons of oil.[126] Given the nascency of the marine renewable energy industry in the United States, there are few recommendations for the installation of marine renewable energy infrastructure around oil and gas pipelines. Therefore, following recommendations for planning renewable energy developments around subsea infrastructure in the United Kingdom,[127] marine renewable

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[125] International Cable Protection Committee. 2013. *ICPC Recommendation #13: The Proximity of Offshore Renewable Wind Energy Installations and Submarine Cable Infrastructure in National Waters*. No. 13, Issue 2C. November 26, 2013, https://downloads.regulations.gov/BOEM-2022-0009-0193/attachment_1.pdf.

[126] California Energy Commission. 2021. "Petroleum Watch." Updated November 2021. Accessed December 2024. https://www.energy.ca.gov/sites/default/files/2021-11/November_Petroleum_Watch_ADA.pdf.

[127] Renewables Sub-Group of Subsea Cables UK. August 2012. *The Proximity of Offshore Renewable Energy Installations & Submarine Cable Infrastructure in UK Waters,* https://www.thecrownestate.co.uk/media/1783/ei-km-in-pc-cables-082012-proximity-of-offshore-renewable-energy-installations-submarine-cable-infrastructure-in-uk-waters-guideline.pdf.

energy devices and cables should be positioned at least one nautical mile (1.85 km) away from pipelines.

3.5.2 Oil and Gas Platforms

The placement of WECs and TECs on existing marine structures, such as a decommissioned oil and gas platform or an active platform, could reduce installation costs and reduce device footprints, thereby reducing the environmental impact of marine energy projects.[128] Oil and gas companies, such as Italy's Eni, have initiated research into integrating WECs into their offshore platforms.[129] Called an Inertial Sea Wave Energy Converter (ISWEC), Eni's device is suitable only for powering offshore infrastructure. However, the device could be further developed to transform old oil platforms into renewable energy platforms.[130] Other projects, such a pilot project between Mocean Energy and Chysaor, are looking to provide wave energy to power remotely operated vehicles (ROVs) used for inspecting pipelines and decommissioning projects.[131]

There are 23 oil and gas platforms in federal waters off the coast of Southern California, 13 of which are still producing, 6 platforms are retiring/retired, 1 platform is used for processing only, and 3 platforms where production is paused (as of 2021).[132] There are three active oil and gas platforms and one retired platform in California waters.[133] Generating renewable energy using existing oil and gas platforms along the California coast could reduce decommissioning costs for oil and gas companies while minimizing installation costs for tidal or wave energy projects. However, designing devices for this purpose could be complex since platforms often act as artificial reefs and fish attractants.[134] Careful analysis of the pros and cons and potential impacts would be required for colocation of devices. Oil and gas platforms are therefore viewed as a technology-dependent constraint for wave and tidal energy development.

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[128] Mustapa, M. A., O. B. Yaakob, Y. M. Ahmed, C. K. Rheem, K. K. Koh, and F. A. Adnan. 2017. "Wave Energy Device and Breakwater Integration: A Review." *Renewable and Sustainable Energy Reviews* 77:43–58, https://www.sciencedirect.com/science/article/abs/pii/S1364032117304409; Nguyen, H. P., C. M. Wang, Z. Y. Tay, and V. H. Luong. 2020. "Wave Energy Converter and Large Floating Platform Integration: A Review." *Ocean Engineering* 213:107768, https://www.sciencedirect.com/science/article/abs/pii/S0029801820307472.

[129] Offshore Energy Today. 2019. "Eni's New Wave Power Device to Convert Mature Offshore Platforms Into Renewable Energy Hubs." Updated March 27, 2019. Accessed December 2024, https://www.offshore-energy.biz/enis-new-wave-power-device-to-convert-mature-offshore-platforms-into-renewable-energy-hubs/.

[130] Ibbetson, C. April 3, 2019. "Engineers Convert Old Oil Rigs Into Wave Energy Sites." *New Civil Engineer.* Updated April 3, 2019. Accessed December 2024, https://www.newcivilengineer.com/latest/engineers-convert-old-oil-rigs-into-wave-energy-sites-03-04-2019/.

[131] Snieckus, D. 2020. "Wave Energy Device to be Tested to Power North Sea Oil and Gas Wells." *Recharge.* Updated February 11, 2020. Accessed December 2024, https://www.rechargenews.com/transition/wave-energy-device-to-be-tested-to-power-north-sea-oil-gas-wells/2-1-753898.

[132] California Energy Commission. 2021. *Petroleum Watch*. Updated November 2021. Accessed December 2024, https://www.energy.ca.gov/sites/default/files/2021-11/November_Petroleum_Watch_ADA.pdf.

[133] Ibid.

[134] Love, M. S. 2019. *An Overview of Ecological Research Associated with Oil and Gas Platforms Offshore California.* U.S. Department of the Interior, Bureau of Ocean Energy Management, Camarillo, California. OCS Study BOEM 2019-052, https://espis.boem.gov/final%20reports/BOEM_2019-052.pdf.

3.5.3 Floating Offshore Wind Installations

In December 2022, the Bureau of Ocean Energy Management (BOEM) awarded five leases for OSW energy development in federal waters along the coast of California: two in Northern California off Humboldt County, and three in Central California near Morro Bay. These lease areas are sited 20–40 miles from shore and in water depths up to 1,300 meters. Although the floating OSW energy projects are planned for deployment in waters greater than 200 meters deep (the water depth constraint for WECs in this report), WECs could be colocated with the turbine platforms. A cost analysis by Kluger et al. (2023) of a standalone wind installation versus a colocated wind-wave power installation found that the colocated wind-wave installation had smoother power supply, less energy curtailment, and higher farm-to-grid efficiency than the stand-alone wind farm.[135]

Coupling wave energy with wind energy allows for better energy yields and higher predictability, with one study finding that combined wind-wave farms in California would have less than 100 hours of no power output in comparison to more than 1,000 hours for standalone wind farms and more than 200 hours for wave installations alone.[136] Combined wind-wave farms also provide cost savings since the projects could share development, maintenance, and transmission costs while consolidating ocean space used for energy generation.[137] The environmental impacts of a combined wind-wave farm require further investigation and would likely differ based on the design of the wind turbines and WECs. While there are opportunities for colocation of WECs with OSW installations, an analysis of potential conflicts with combined wind-wave farms is outside the scope of this document.

WEC developers would need to coordinate directly with OSW lessees and BOEM to determine if colocation of technologies is possible. Further, WEC generation using OSW transmission infrastructure to export generation to the grid would require FERC licensing.

3.5.4 Buoys: Metocean and Navigation

NOAA maintains a network of oceanographic and meteorological (“metocean”) buoys through the National Data Buoy Center (NDBC) throughout the world’s oceans with greater than 80 stations in state and federal waters off the California coast. Integration of WECs with metocean buoys WECs is possible, as evidenced by the partnership between NDBC and Ocean Power Technologies, Inc. (OPT) that involved ocean trials of an APB350 PowerBuoy equipped with an ocean monitoring system.[138] In addition to scientific buoys, there are numerous

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[135] Kluger, J. M., M. N. Haji, and A. H. Slocum. 2023. “The Power Balancing Benefits of Wave Energy Converters in Offshore Wind-Wave Farms With Energy Storage.” *Applied Energy* 331:120389, https://www.sciencedirect.com/science/article/abs/pii/S0306261922016464?via%3Dihub.

[136] Stoutenburg, E. D., N. Jenkins, and M. Z. Jacobson. 2010. “Power Output Variations of Colocated Offshore Wind Turbines and Wave Energy Converters in California.” *Renewable Energy* 35:2781–2791, https://www.sciencedirect.com/science/article/abs/pii/S0960148110002004.

[137] Pérez-Collazo, C., D. Greaves, and G. Iglesias. 2015. “A Review of Combined Wave and Offshore Wind Energy.” *Renewable and Sustainable Energy Reviews* 42:141–153, https://www.sciencedirect.com/science/article/abs/pii/S1364032114008053.

[138] OPT. 2016. “Ocean Power Technologies Partnered With the National Data Buoy Center.” News Release. March 8, 2016. Accessed December 2024, https://investors.oceanpowertechnologies.com/news-releases/news-release-details/ocean-power-technologies-partnered-national-data-buoy-center.

navigational buoys and markers maintained by the U.S. Coast Guard all along the West Coast. Wave and tidal energy developers should be aware of any metocean or navigation buoys within their areas of interest. However, buoys are not viewed as a constraint to development and, instead, may represent colocation opportunities.

3.6 Sea Space Conflict Analysis

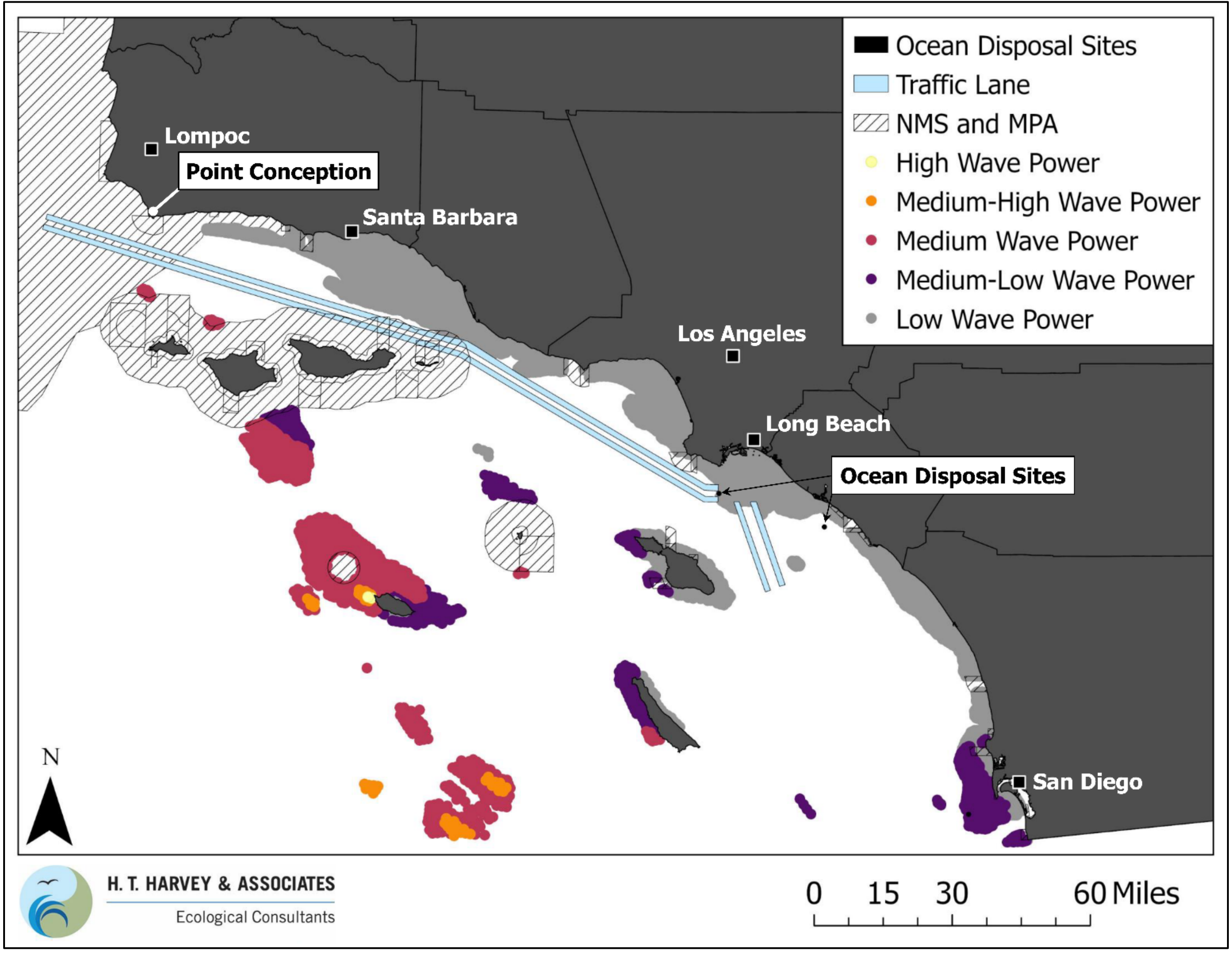
Potential energy deployment sites for each California region identified in Chapter 1 were analyzed for overlap with the "no go" zones identified in the present chapter. Potential deployment sites for wave and tidal energy projects were categorized by energy potential and mapped along with the "no go" zones. Any points/polygons that fell within the "no go" zones were removed. The analysis was sequential, meaning that once points/polygons were removed because of overlap with one zone, they were not replaced. This analysis considered only potential energy sites in water depths less than 200 meters, consistent with the wave and tidal energy resource analysis presented in Chapter 1.

The "no go" zones include:

1. National marine sanctuaries (NMS) and marine protected areas (MPA).
2. Commercial shipping lanes and federal navigational channels ("Traffic Lane").
3. Ocean disposal sites (includes sediment disposal sites).

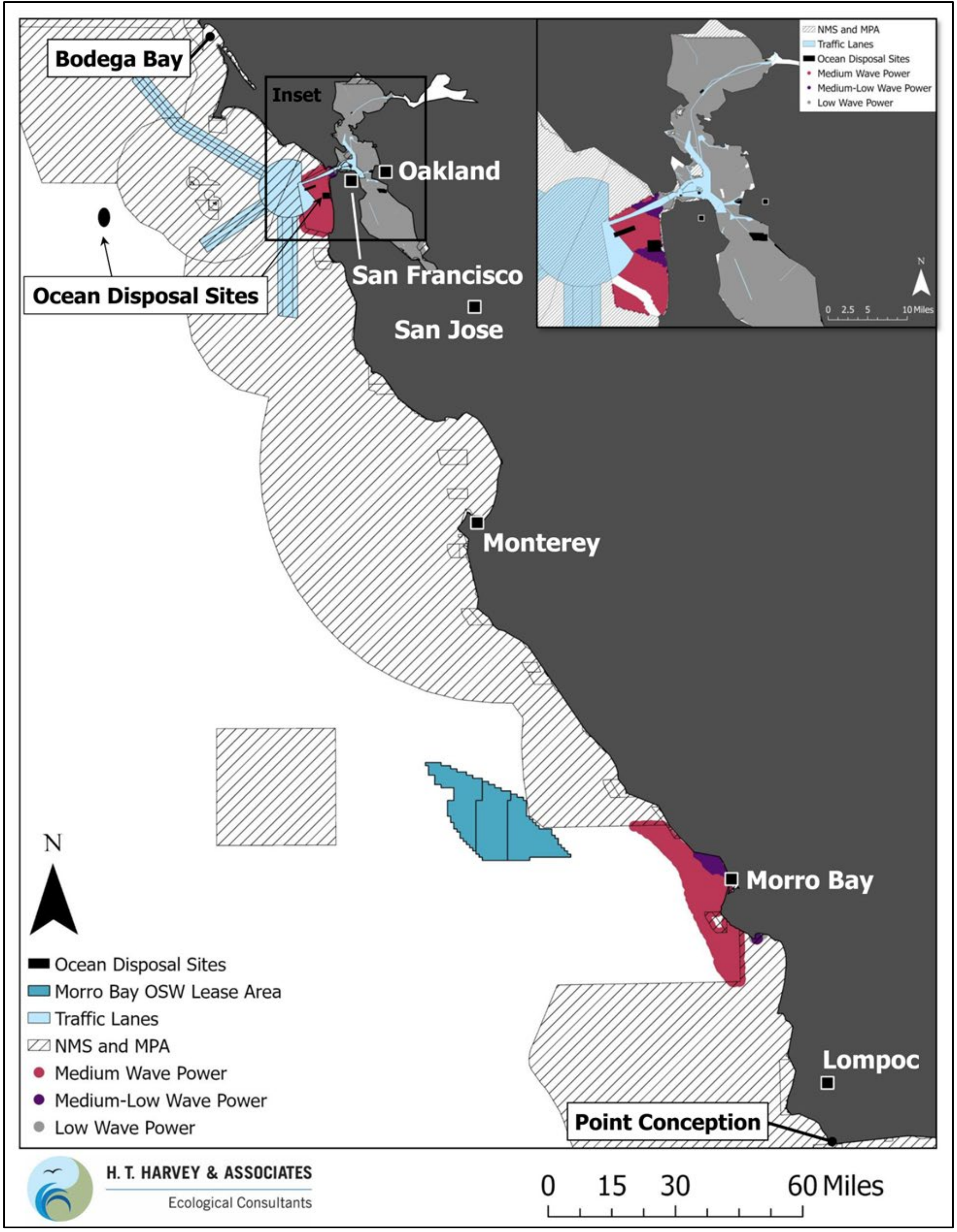
There may be additional "no-go" zones consisting of military operation areas. However, those areas are not readily mappable so any development near DoD properties, and operations would need to be discussed with DoD to ensure compatibility. Some points appear to fall within an NMS/MPA area, but this is due to the scale of the map. The points are outside these areas. The results for the potential wave energy deployment sites are shown in Figure 40 through Figure 42, and Figure 43 through Figure 45 for tidal energy.

Figure 40: Southern California Potential Wave Energy Sites Filtered by "No Go" Zones



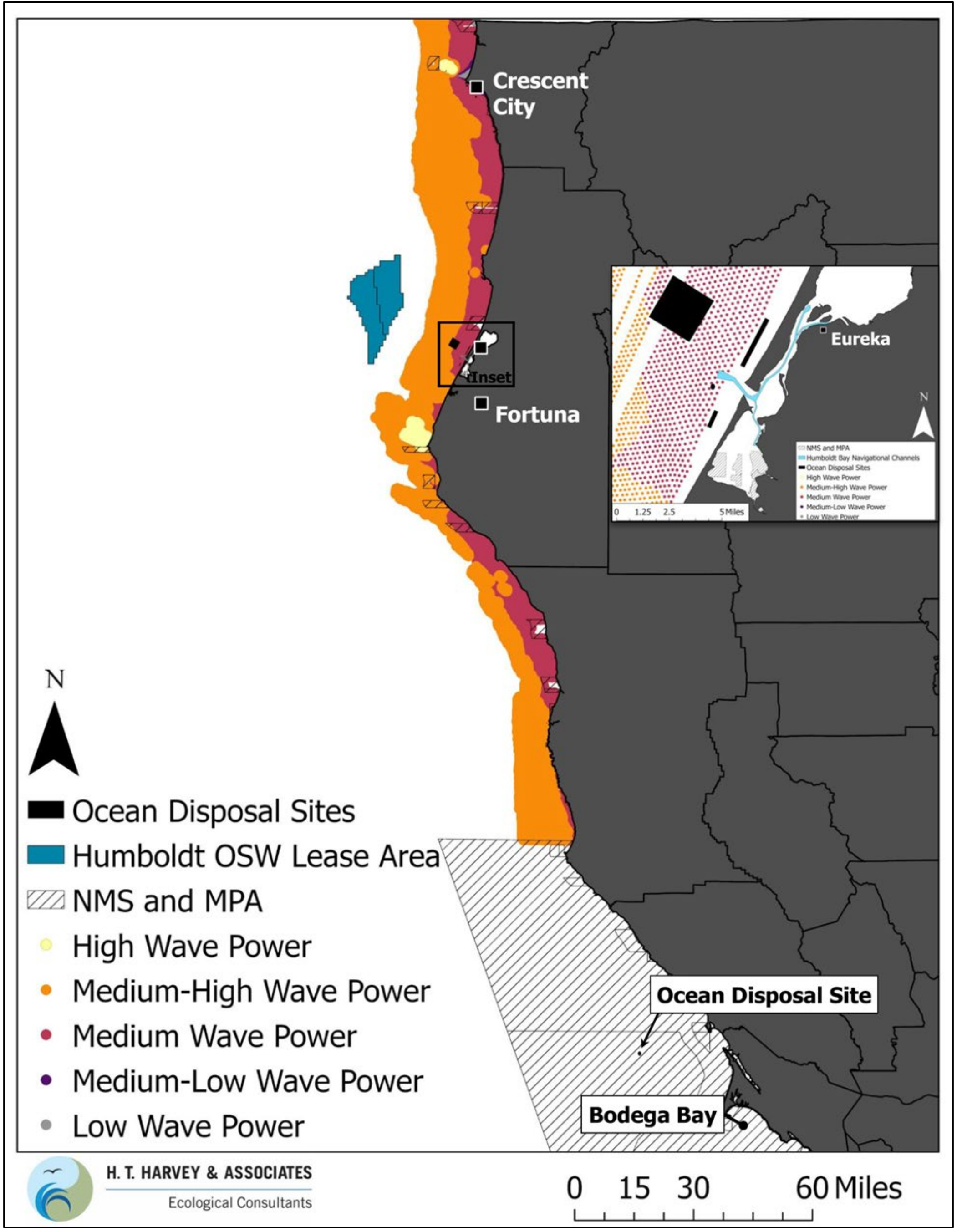
Source: H. T. Harvey & Associates

Figure 41: Central California Potential Wave Energy Sites Filtered by ”No Go” Zones



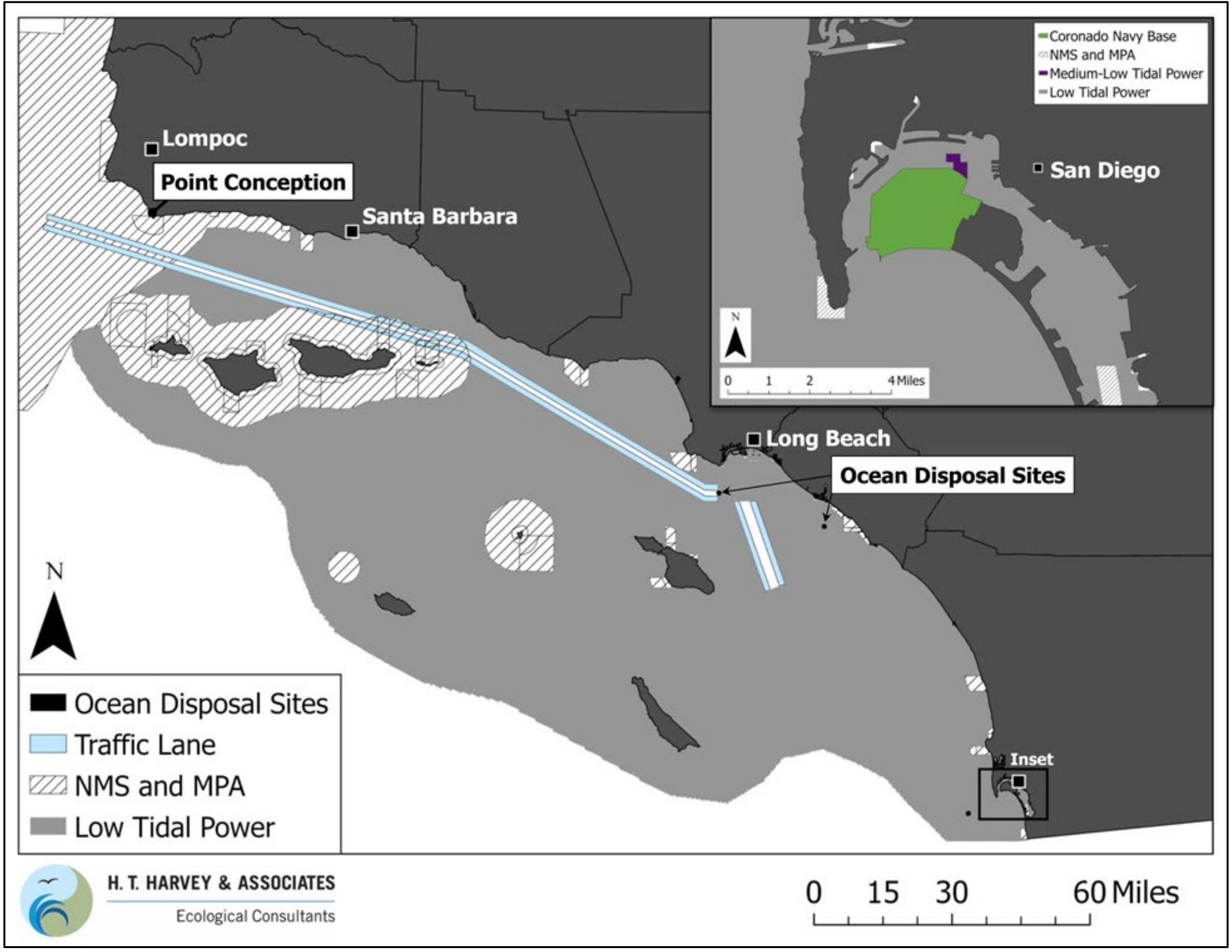
Source: H. T. Harvey & Associates

Figure 42: Northern California Potential Wave Energy Sites Filtered by "No Go" Zones



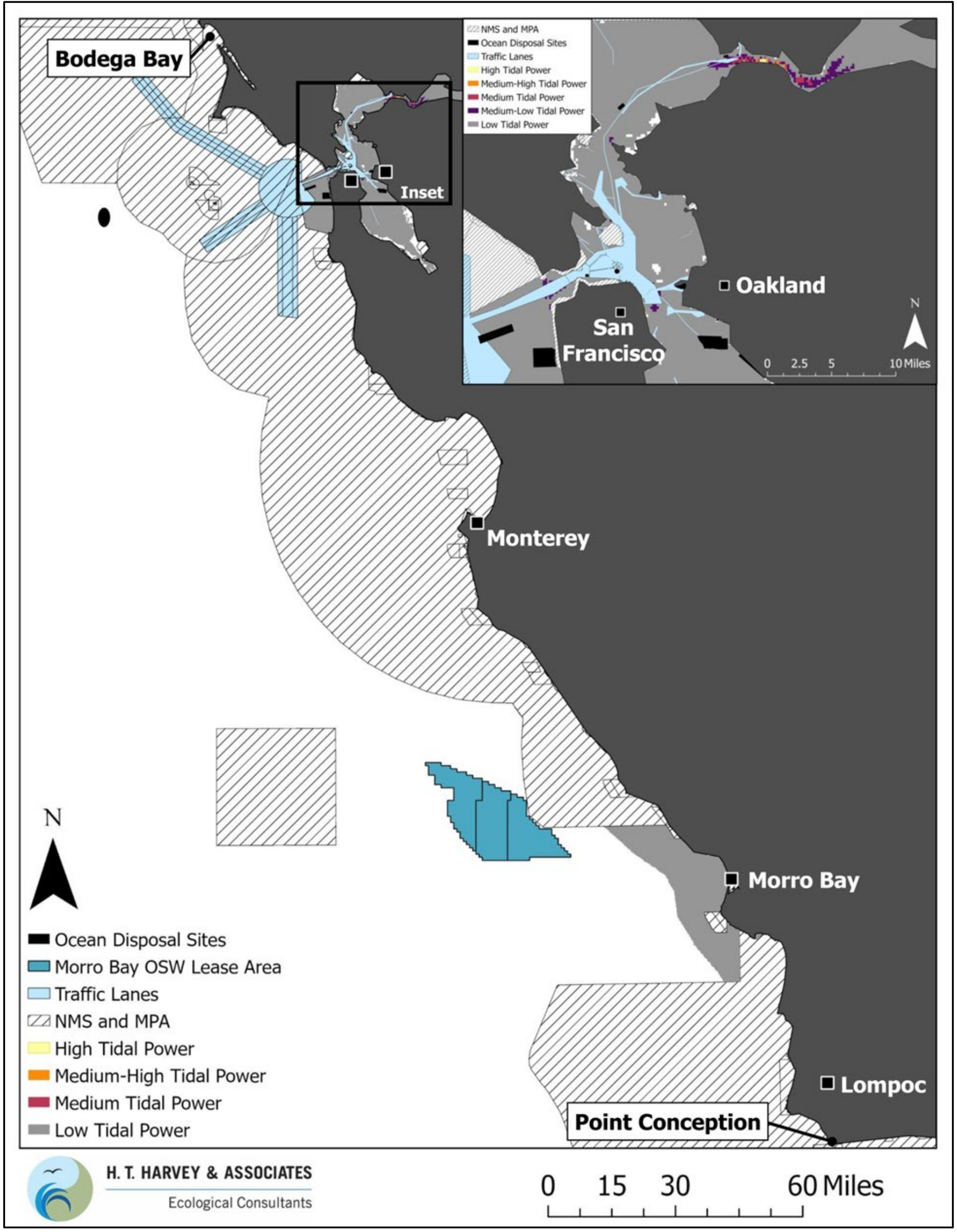
Source: H. T. Harvey & Associates

Figure 43: Southern California Potential Tidal Energy Sites Filtered by "No Go" Zones



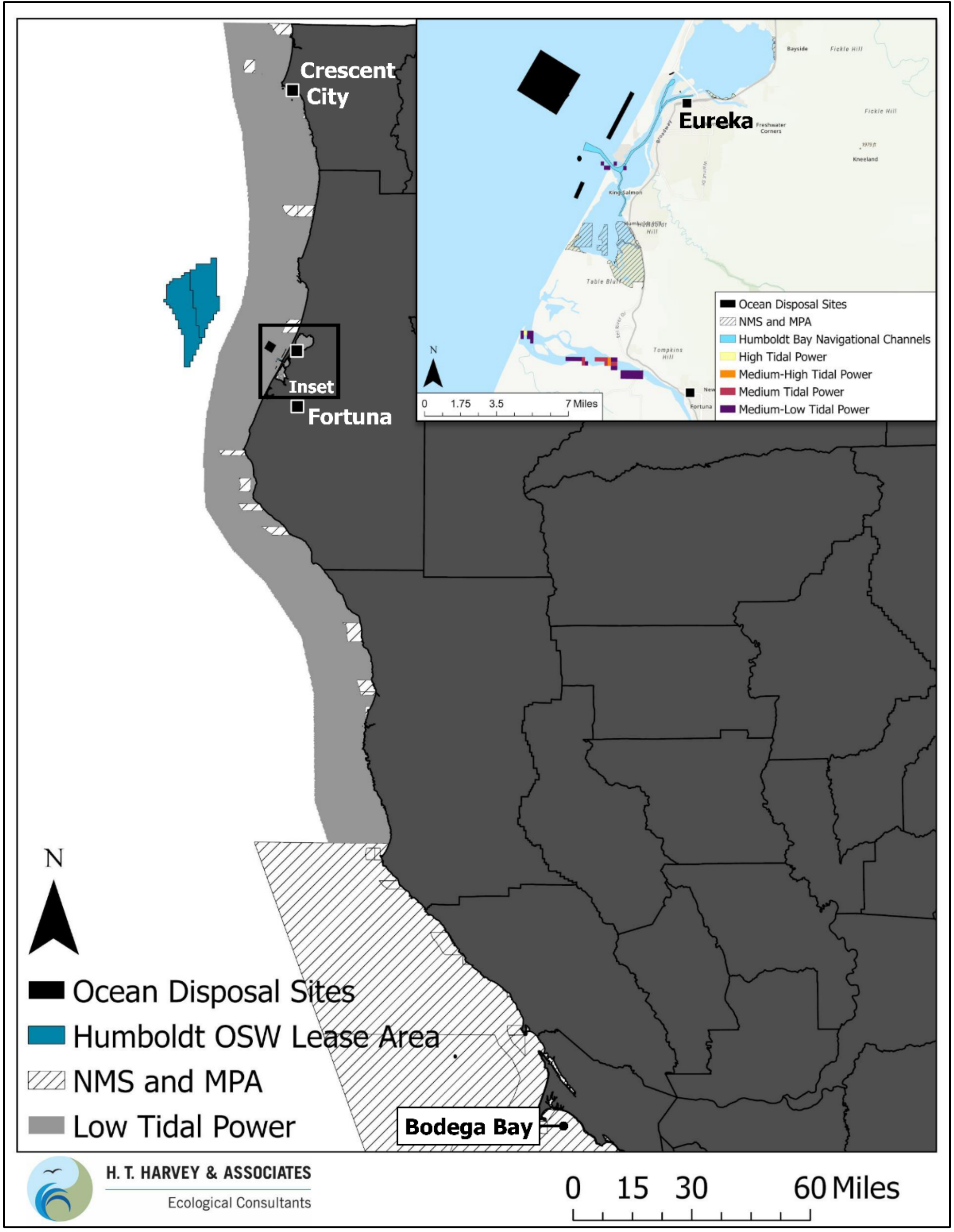
Source: H. T. Harvey & Associates

Figure 44: Central California Potential Tidal Energy Sites Filtered by "No Go" Zones



Source: H. T. Harvey & Associates

Figure 45: Northern California Potential Tidal Energy Sites Filtered by "No Go" Zones



Note that the low tidal power polygons were removed from the inset map to highlight the other power categories.

Source for the basemap in the inset map: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

Source: H. T. Harvey & Associates

3.7 Conclusion

In Southern California, most of the potential wave energy resources are located around the Channel Islands. However, development restrictions in marine sanctuaries and protected areas means that offshore wave energy development is feasible only in the outer Channel Islands, that is, San Nicolas Island, Catalina Island, and San Clemente Island. Potential wave resources are low near the coastline, and developers will need to be careful about siting projects near public beaches. There are opportunities for colocation of WECs with existing structures such as piers, breakwaters, and jetties, as well as oceanographic buoys. Tidal energy resources are low in Southern California; therefore, the region should focus on wave energy projects for its renewable energy portfolio.

Most of the Central California coastline is bordered by marine sanctuaries or protected areas, restricting any potential commercial-scale wave energy developments to two areas: the Morro Bay region and the entrance to San Francisco Bay. Given the potential for colocation with OSW infrastructure and port needs, the area around Morro Bay could be an attractive option for wave energy projects. Development near the entrance to San Francisco Bay may prove challenging as the area has multiple shipping lanes to avoid. Tidal energy resources are restricted to areas within San Francisco Bay, which is similarly restricted by navigational channels and the presence of listed fish species. The higher-potential tidal energy areas are a migration corridor for many listed fish species with designated critical habitat. Therefore, any development within this area will require careful consideration of environmental impacts while avoiding restricting navigation.

Northern California has fewer spatial restrictions and higher potential energy resources for wave and tidal energy projects. The lack of large marine sanctuaries or shipping lanes in the region makes marine energy development in this area more feasible than the other two regions. Wave energy resources are readily available, while the highest tidal energy resources are found within Eel River, which likely presents a host of permitting challenges given that the river is important to local salmon populations, as well as local interested parties and California Native American tribes.

Sea space conflicts could be avoided by careful communication and collaboration with interest groups, regulatory agencies, and tribes. Chapters 5 and 6 discuss protective measures and monitoring strategies for addressing interactions between marine resources and energy developments.

CHAPTER 4:
Electrical Infrastructure

This report considers the locations of existing electric transmission facilities and infrastructure and identifies the additional transmission facilities and infrastructure necessary to accommodate commercial-scale wave and tidal energy development. It is assumed that the locations of electric transmission facilities would be an important consideration for defining suitable sea space for wave and tidal energy deployments. While most marine energy generation is currently small-scale (that is, distributed generation or used in "behind-the-meter"[139] installations), future larger-scale projects will require connection to the electric grid.

This chapter defines electric power terms relevant to wave and tidal energy, provides examples of existing wave and tidal projects, and describes the availability of electrical infrastructure for future wave and tidal projects.

4.1 Power Line Terms and Definitions

4.1.1 Offshore Electrical Cables

New offshore transmission facilities would be needed to access large generators in California's waters. The consulting firm Guidehouse prepared an overview of existing and emerging offshore cable technologies in 2023 as part of the CEC's *AB 525 Offshore Wind Strategic Plan.*[140] This report found that high-voltage alternating current (HVAC) subsea export cables are commonly rated between 132 kilovolts (kV) and 245 kV with an export capacity between 300 and 500 megawatts (MW). However, with improvements in insulation technology, these export cables now exist up to 420 kV, and increased capacity is in development to support up to 1 gigawatt of transmission capacity.

Because wave and tidal generators are small, as defined in Chapter 2, they are supported by electric infrastructure operating at distribution-level voltages. Therefore, this chapter defines needs for "electrical infrastructure" or "power lines" that are at the scale of the distribution system, rather than "transmission."

Electric transmission facilities that interconnect marine energy generation to the onshore grid require licensing through FERC.[141]

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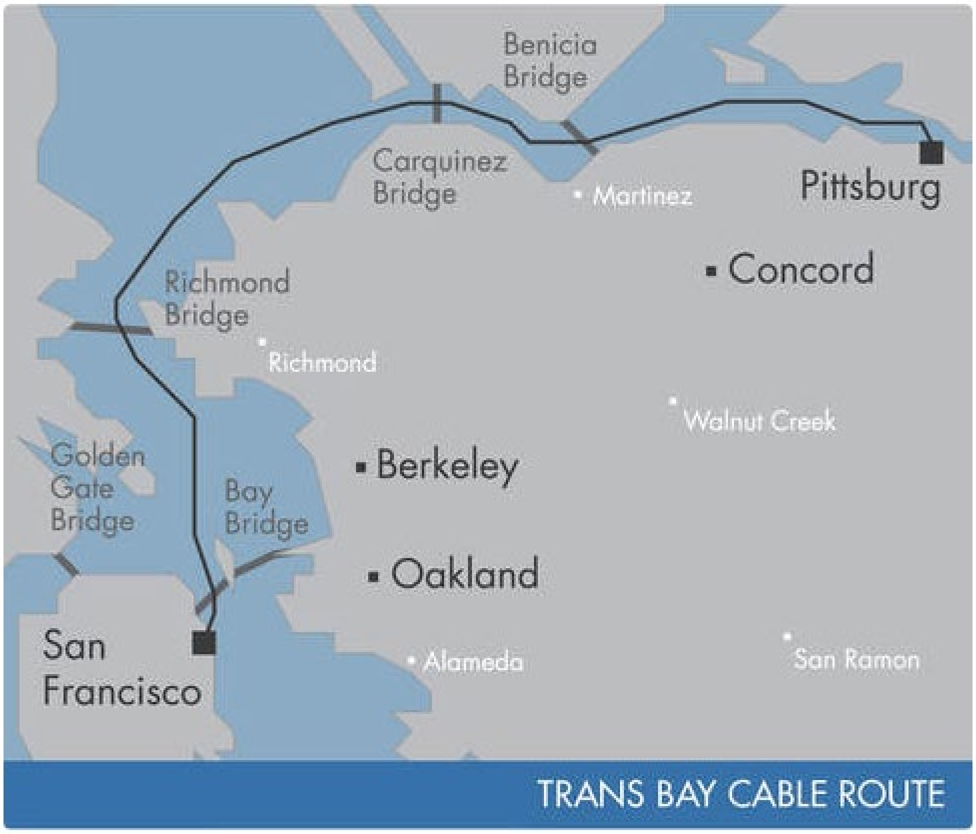
[139] "Behind-the-meter" energy-related activities typically occur within or close to the location the energy is generated and used (for example, rooftop solar at a home).

[140] Huang, Claire, Lily Busse, and Robert Baker. (Guidehouse). June 2, 2023. *Offshore Wind Transmission Technologies Assessment: Overview of Existing and Emerging Transmission Technologies.* Prepared for the California Energy Commission, https://efiling.energy.ca.gov/GetDocument.aspx?tn=250520&DocumentContentId=85289.

[141] Federal Energy Regulatory Commission. "Licensing," https://www.ferc.gov/licensing.

Offshore electric transmission facilities in California include two electrical cables providing power to offshore oil and gas platforms from shore.[142] Cables serving offshore oil and gas activities are designed to resist saltwater corrosion and mechanical stresses. Similar cable types would effectively serve marine energy generators.[143] Another example is the subsea TransBay Cable, a 53-mile direct current electric transmission cable that connects substations in the City of Pittsburg, California, and San Francisco (Figure 46).

Figure 46: TransBay Cable



Source: https://isaacscienceblog.com/2018/09/12/the-trans-bay-cable-and-why-it-is-important/

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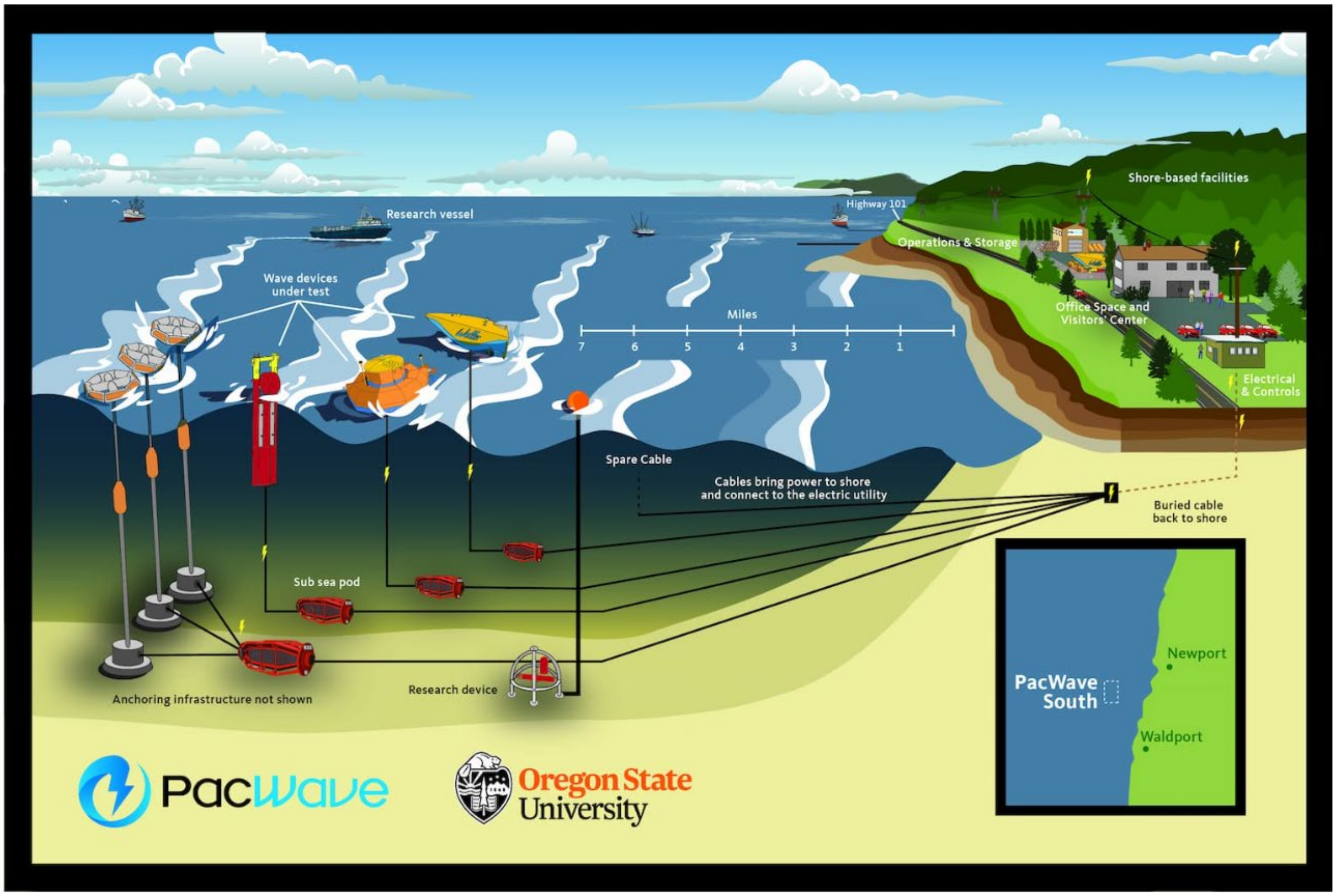
[142] California State Lands Commission. April 2022. *Staff Report 61 (Informational)*. https://slcprdwordpress storage.blob.core.windows.net/wordpressdata/2022/04/04-26-22_61.pdf.

[143] LinkedIn. "Understanding Cable Types in the Oil and Gas Industry". https://www.linkedin.com/pulse/understanding-cable-types-oil-gas-industry-casmo-cable/. Accessed February 2025.

Figure 47 illustrates the electrical cables used to transmit power from the PacWave South test site to shore on the Oregon Coast.

Figure 47: PacWave South



Source: https://pacwaveenergy.org/south-test-site/

4.1.2 Onshore Electricity Transmission

In the context of electric power, a high-voltage transmission system generally operates at voltage levels from 115 kV to 500 kV. Voltages below 100 kV are used for distribution of power through cities and to businesses and homes.[144] Electric utilities regulated by the California Public Utilities Commission (CPUC) are subject to rules for the planning and construction of transmission, power, and distribution line facilities. Under CPUC General Order 131-D, “transmission” refers to lines designed to operate at or above 200 kV. A “power line” is a line designed to operate between 50 kV and 200 kV. A “distribution line” is a line designed to operate under 50 kV. Onshore, examples of transmission structures include lattice steel towers or tubular steel poles that can be up to 200 feet tall.

Onshore power lines are sometimes part of the *subtransmission* system, which carries electricity at lower voltage levels than the high-voltage system. Rural areas and California’s

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[144] Wikipedia. "Electric power transmission." Wikipedia: The Free Encyclopedia, https://en.wikipedia.org/wiki/Electric_power_transmission. Accessed March 2025.

smaller communities are often served by subtransmission systems at voltage levels typically ranging from 66 kV to 200 kV.

The electric *distribution* system extends to the end users of electricity. Distribution circuits are typically energized at between 4 kV and 35 kV. These lower-voltage lines carry electricity to consumers, mainly on wooden poles, or they may be installed underground. Transformers located on distribution poles, on concrete pads on the ground, or underground further step down the voltage before it is ultimately delivered to end users like homes and businesses. In general, the distribution system has the capability of interconnecting smaller electric generating facilities at sizes of 20 MW or less.

4.2 Wave and Tidal Energy: Electrical Cable Requirements

In this discussion of electrical interconnection, nearshore and offshore devices are both considered offshore facilities because the respective interconnection issues are similar. Onshore generators are addressed separately.

This chapter does not address offshore WECs that provide power to connected offshore systems (for example, WECs providing power to data collection buoys) because no electrical interconnection is required.

4.3 Required Electrical Infrastructure for Marine Energy

Table 11 presents examples of existing or planned wave and tidal power facilities around the world. The column "Electrical Connection" shows the range of voltage for interconnection; it is generally from 1 kV to 13 kV. The generation capacity of current wave and tidal generators is relatively small, so distribution-level power lines are typically used. Offshore wave energy converters (WECs) have been located as far as 20 kilometers from shore, while onshore WECs (devices integrated into coastal structures) are projects sited in shallow water at the shoreline.

Table 11: Wave and Tidal Projects and Electrical Connections

Project Name	Location; Water Body	Capacity	Electrical Connection	Generation Description
OFFSHORE	**WAVE**	**POWER**		
Biscay Marine Energy Platform	Armintza, Basque Country, Spain	20 MW	Four 13.2 kV 5 MW subsea cables	Wave energy test site 1.7 km from shore
PacWave (North)	Newport, Oregon Pacific Ocean	n/a	Non-grid connected and exempt from requiring a FERC license	Wave energy test site 3.7 km from shore
PacWave (South)	Newport, Oregon Pacific Ocean	20 MW	Five buried 30 kV subsea transmission cables	Wave energy test site 11 km from shore
EMEC Billia Croo Wave Test Site	Orkey mainland, Billa Croo, UK	7 MW	Each of 6 test berths has an 11 kV cable connected to substation	Wave energy test site 2 km from shore
Lysekil Wave Energy Site	Gothenburg, Sweden North Sea, Atlantic Ocean	1 MW	Power transmitted to shore by a 1 kV subsea cable	Wave energy test site 2 km from shore

Project Name	Location; Water Body	Capacity	Electrical Connection	Generation Description
Wave Hub	Cornwall, UK North Sea, Atlantic Ocean	20 MW	Power from multiple hubs is connected to a single Termination and Distribution Unit, which connects to the onshore infrastructure at 11 kV and 33 kV	Wave energy test site 16 km from shore
ONSHORE	**WAVE**	**POWER**	**(Coastal Structure Integrated)**	
Biscay Marine Energy Platform	Mutriku, Basque Country, Spain	296 kW	Connected with local distribution grid through with a 13.2 kV transformer	Oscillating water column and air turbine (built into harbor breakwater)
Eco Wave Power (EWP) at AltaSea	Los Angeles, California Pacific Ocean	100 kW	Details of electrical interconnection unknown	Single array pilot project
Eco Wave Power Gibraltar Pilot	Gibraltar, UK Strait of Gibraltar, Atlantic Ocean	100 kW	Details of electrical interconnection unknown; power purchase agreement between Eco Wave Power, the Government of Gibraltar and Gibraltar's Electric Authority	Single array pilot project (This device has been moved to AltaSea, Port of Los Angeles)
Eco Wave Power EDF One Pilot	Jaffa, Israel Mediterranean Sea	100 kW	Details of electrical interconnection unknown; connected to Israel's national electric grid through a Feed-In Tariff	Single array pilot project
TIDAL	**POWER**			
EMEC Fall of Warness Test Site	Island of Eday, Scotland North Sea,	10 MW	Each test bay has an 11 kV seabed cable. Onshore, the cables feed into a substation and terminate at an 11 kV substation circuit breaker.	Tidal energy test site 20 km from shore
MeyGen Tidal Energy Project	Inner Sound, Pentland Firth, Scotland North Sea	6 MW installed, 398 MW capacity	Each turbine has a dedicated 4 kV subsea array cable, which is converted to 33 kV for export into the local distribution network	Three-bladed, horizontal-axis tidal turbines, submerged and mounted on foundations resting on the seabed; 2 km from shore
Verdant Power Roosevelt Island Tidal Energy Project	East River, New York City	1.05 MW	Each turbine had a dedicated 480 volt underwater cable connected to five shoreline switchgear vaults. A transformer stepped up power to 4 kV for underground interconnection to the local utility feeder line.	5 meter diameter axial flow turbines
Fundy Ocean Research Centre for Energy (FORCE)	Bay of Fundy	64 MW	Four subsea 34.5 kV cables over 11 kilometers, grid-connected t 69 kV transmission line at the Parssboro Substation	Tidal generation test facility available for research and to evaluate monitoring methods

Source: Aspen Environmental Group

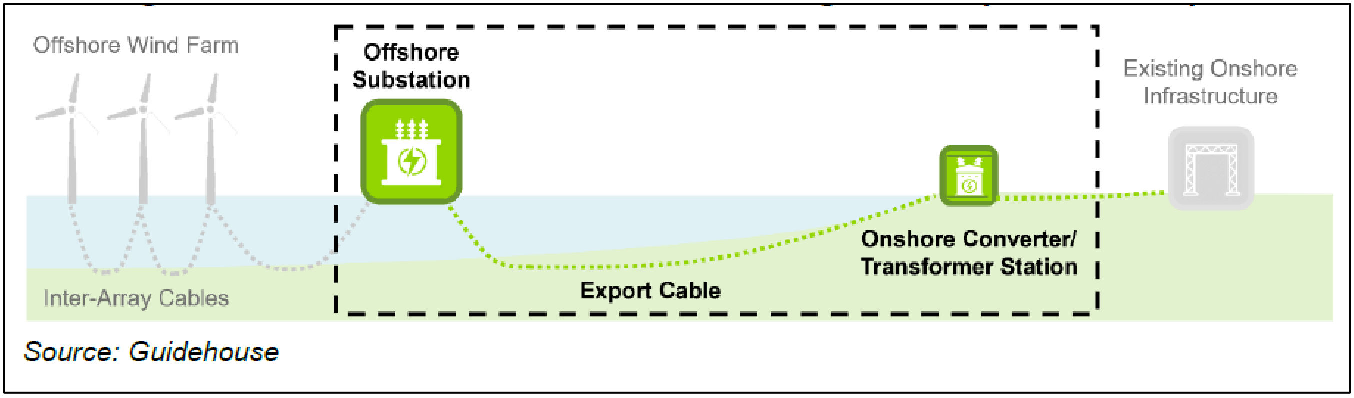
4.4 Offshore Wave and Tidal Energy

Wave and tidal energy generators located offshore both require undersea power lines to carry generated electricity to shore, unless the energy is used to power at-sea devices (for example, ocean observing systems, aquaculture, or military installations). Generators that are shore- or coast-mounted are addressed in the next section.

All sizes of offshore power lines would use a general arrangement such as those shown in Figure 47 and Figure 48. While Figure 48 illustrates generation from offshore wind, the same type of system would be used for a larger wave or tidal generation facility. Generation would be gathered at one cable node or, for a large project, at an offshore substation. Then a single export cable would carry the generated power to shore. Offshore substation equipment cooling systems would need to be environmentally and regulatorily compliant to not negatively impact the seabed or marine life.

As shown in Figure 48, *export cables* are buried deep to avoid disturbing ocean users and wildlife and to transmit power from the offshore collection station or substation to an onshore substation.[145] The *landing of the cable* at the shore is generally completed using horizontal directional drilling to minimize environmental impacts and disruption of beaches and the shoreline. The *onshore connection* occurs at a substation; from this point, electricity is transferred to the existing distribution or transmission network.

Figure 48: Offshore Export Cable and Onshore Connection



Source: Aspen Environmental Group

4.5 Onshore Wave Generators

Onshore wave power systems can eliminate the need for electrical cables because they are attached to onshore facilities like breakwaters or seawalls. This approach can reduce environmental impacts (cable installation and operation can damage marine habitat) and reduce the cost of electrical interconnection.

As an example, EcoWave Power has operated facilities in Portugal, Jaffa Port (Israel), and at Gibraltar (Figure 49) and has recently received permits for installation of a shore-mounted

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[145] New York State Energy Research and Development Authority. "Offshore Wind 101." NYSERDA, https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/About-Offshore-Wind/Offshore-Wind-101. Accessed March 2025.

facility at the Port of Los Angeles.[146] EcoWave Power's "EWP EDF One Pilot" Project in Israel generates up to 100 kW and is connected to Israel's national electrical grid. In August 2022, the Israeli Electric Authority set an official feed-in tariff, or FIT, for the pilot project at Jaffa Port. The FIT enabled the EWP-EDF One project to officially connect to Israel's energy grid. EcoWave Power has also recently announced approval for the development of a breakwater facility that will include an underwater wave energy education center open to the public.[147] This facility in Porto, Portugal, will have a nameplate capacity up to 20 MW when fully operational.

Figure 49: EcoWave Power at Gibraltar

Source: EcoWave Power

Another example of a shore-mounted facility is the Mutriku site in the Bay of Biscay (Basque Country), Spain. Built into the breakwater at the harbor in Mutriku, the plant generates power with air turbines attached to the breakwater. It has a total generating capacity of 296 kW and has been supplying electricity to the grid since 2011.

Tidal barrages can also be used to generate electricity. These systems use a structure similar to a dam, installed across an inlet of an ocean bay or lagoon that forms a tidal basin. These systems generate electricity from the incoming and outgoing tides.[148] The largest is the Sihwa Lake Tidal Power Station in South Korea, with 254 MW of generating capacity. The oldest and second-largest operating tidal power plant is in La Rance, France, with 240 MW of electricity-generation capacity. Smaller tidal power plants are in Canada, China, Russia, and South Korea.

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[146] Eco Wave Power. "Port of Los Angeles Project." Eco Wave Power, https://www.ecowavepower.com/port-of-la/. Accessed March 2025.

[147] Eco Wave Power. "Eco Wave Power Officially Kicks Off the First MW-Scale Wave Energy Project in Portugal." Eco Wave Power, https://www.ecowavepower.com/eco-wave-power-officially-kicks-off-the-first-mw-scale-wave-energy-project-in-portugal/. Accessed March 2025.

[148] U.S. Energy Information Administration. "Hydropower Explained," https://www.eia.gov/energyexplained/hydropower/tidal-power.php.

These shore-mounted facilities can be directly connected to a utility's electric distribution or transmission grid (Figure 48).

4.5.1 Coastal Electrical Infrastructure

As shown in Table 11, the size of existing wave and tidal generators ranges from a few hundred kW to about 20 MW (where multiple generators are installed in an array). Generators of this size require cable connection to shore, and then a distribution-level substation or transformer is needed to feed into the existing distribution-level electric grid. High-voltage transmission lines extend to the California coast in only a few places, but distribution-level power exists everywhere that there are homes or commercial facilities (such as groups of homes, ports, restaurant piers, or tourism sites).

Because of the widespread presence of distribution-level power lines that are adequate to support existing wave and tidal generators, the location and proximity of existing high-voltage transmission lines are not constraints to the development of these generators.

4.6 Wave Energy Converters Combined With Offshore Wind

The high cost of stand-alone wave energy conversion development has been an obstacle for large-scale application. However, costs could be reduced by combining WECs with other structures farther offshore than the scope of this analysis (in water depths greater than 200m), like cables that connect to offshore wind turbines. This combination could also optimize use of marine space. The main advantage of integrated wind power generation is shared infrastructure costs, especially foundations and grid connections. Figure 48 shows how power generated at offshore wind turbines can be gathered at an offshore substation, then transmitted to an onshore substation or AC/DC converter station.

Hybrid power generation architectures that integrate WECs with offshore wind turbine generators or energy storage systems might allow for power quality improvement and sustainable electric power production. However, the costs per kilowatt-hour (kWh) produced are still higher with a combined wind-wave application than with wind energy alone given current WEC capital and operating costs.[149] Synergy benefits can also be sought through improved stability of the structure, for example, in the case of an oscillating water column WEC integrated into the foundation of a floating offshore wind turbine. Stability improvement can be a major benefit for designs in which the interaction between the wind and wave substructures is strong, as in the case of a WEC combined with a floating wind turbine. Proposals to combine WECs with floating offshore wind infrastructure would require coordination with OSW developers, state and federal regulators, tribes, and stakeholders, as appropriate.

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[149] Coastal Wiki. "Wave Energy Converters," https://www.coastalwiki.org/wiki/Wave_energy_converters.

CHAPTER 5: Protective Measures for Potential Environmental and Ocean User Impacts

After assessing potential sea space conflicts, this report analysis provides a high-level discussion on the identification of protective measures that would avoid, minimize, and mitigate any adverse environmental impacts and conflicts with other ocean users.[150] In addition to identifying some potential environmental impacts, this chapter also identifies protective measures for addressing potential ocean use conflicts such as impacts to viewsheds, recreation, aquaculture, commercial and recreational fishing, navigation, cultural resources, and tribal cultural landscapes and uses. This analysis is not intended to replace a formal environmental review that would be required for any prospective project.

This chapter includes the following sections:

- Section 5.1: Environmental impacts
- Section 5.2: Protective Measures
- Section 5.3: Conclusion

5.1 Potential Environmental Effects

Environmental effects related to wave and tidal projects can be categorized based on the following:

1) Likelihood of an impact occurring.
2) Whether the effect will impact individuals, populations, or important habitats or a combination.
3) What phase of the project the effect(s) occurs in (that is, surveys conducted for site characterization, project construction and installation, operation and maintenance, or decommissioning).
4) Duration of the effect (i.e., short-term vs. long-term).

Moreover, the feasibility of mitigating, or addressing, potential impacts should be considered. Once prioritized, potential environmental effects of wave and tidal energy projects can be assessed using the framework of stressors and receptors. Stressors are the marine renewable energy (MRE) components that may harm the marine environment (in other words, the devices, arrays, and related components). Receptors are the marine species, habitats, and the

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[150] For this report, the term *mitigate* is not meant to replace the necessary California Environmental Quality Act (CEQA) process. Any potential project would have to go through a formal CEQA analysis to determine potential impacts and mitigation measures.

biotic and abiotic components of marine ecosystems that could be affected by the stressors.[151] Key stressor-receptor interactions related to wave and tidal energy projects were identified (Figure 50):[152]

1. **Collision, entrainment, impingement, and entrapment** — Risk of marine animals colliding with or being pulled into or onto screens, rotating turbine blades, and other moving parts of wave energy converter/tidal energy converter (WEC/TEC) devices.
2. **Underwater noise** — Disruption of marine animal communication and behavior due to noise produced during installation or operation of WEC/TEC devices or both.
3. **Electromagnetic fields (EMFs)** — Disruptions to marine animal movement and behavior due to EMF radiation from energized power export cables.
4. **Changes in habitats** — Alterations in benthic or pelagic habitats that support marine animals from the installation, presence, and operation of WEC/TEC devices.
5. **Entanglement** — Risk of large marine animals becoming entangled in mooring lines or cables, or entangled secondarily with materials such as lost fishing gear that entangles on devices or moorings, in the water column.
6. **Changes in oceanographic systems** — Decreased wave heights or changes in ocean water circulation (and related effects) due to the presence and operation of WEC/TEC devices.
7. **Displacement** — Changes in the migratory pathways or other movements of marine animals due to the installation, presence, and operation of WEC/TEC devices.
8. **Water quality** — Changes to the chemical characteristics of the water, including the release of contaminants or chemicals.

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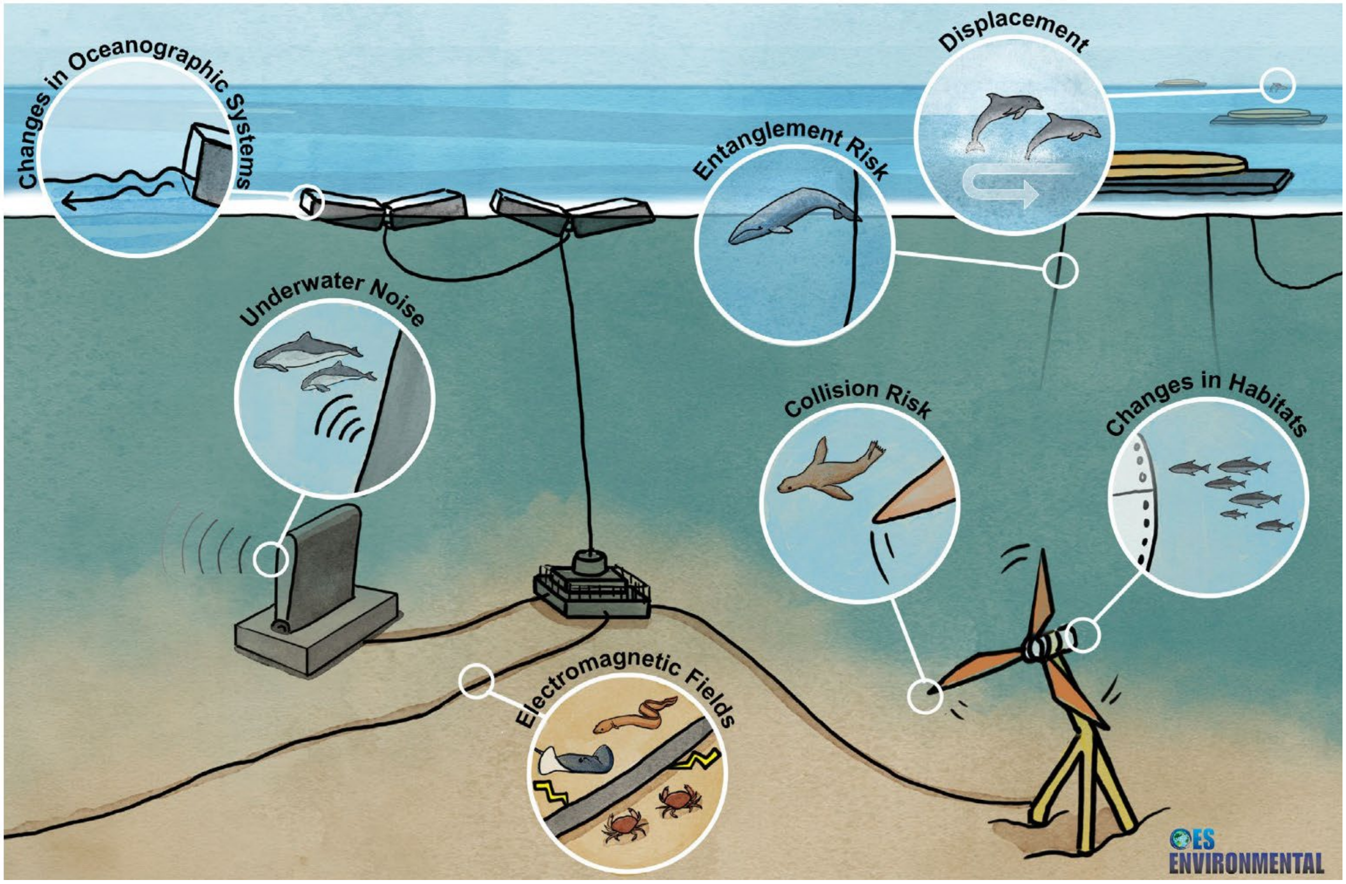
151 Copping, A. E. 2024. "Marine Renewable Energy and Ocean Energy Systems-Environmental." In L. Garavelli, A. E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), OES-Environmental *2024 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World.* Report for Ocean Energy Systems (OES). (pp. 1–7), https://tethys.pnnl.gov/publications/2024-state-science-report-chapter-1-marine-renewable-energy-ocean-energy-systems; Garavelli, L., Hemery, L. G., Rose, D. J., Farr, H., Whiting, J. M., and Copping, A. E. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions." In L. Garavelli, A.E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), OES-Environmental *2024 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES).* (pp. 26–102). doi:10.2172/2438589, https://tethys.pnnl.gov/publications/2024-state-science-report-chapter-3-marine-renewable-energy-stressor-receptor.

152 Ibid.

Figure 50: Stressor-Receptor Interactions and Marine Renewable Energy Installations



Potential stressor-receptor interactions between various marine renewable energy devices and marine organisms.

Source: Copping et al. (2024)

Sources consulted for this chapter include the OES-Environmental State of the Science 2024 report,[153] the Marine Energy Environmental Toolkit,[154] and the Management Measures Tool for Marine Energy.[155] The Management Measures Tool for Marine Energy provides actual protective measures and mitigation strategies applied to past and present wave and tidal projects in the United States and Europe, whereas the Marine Energy Environmental Toolkit provides measures prescribed during permitting for projects in the United States. Though these sources provide helpful insights into what protective measures could be taken for various interactions, the high-level of uncertainty of this nascent technology may require site-specific monitoring and adaptive management strategies (Chapter 6).

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[153] Garavelli, L., L. G. Hemery, D. J. Rose, H. Farr, J. M. Whiting, and A. E. Copping. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions." In L. Garavelli, A.E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), OES-Environmental 2024 State of the Science report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 26-102). doi:10.2172/2438589

[154] Marine Energy. "Reporting Tool," https://marineenergy.app/.

[155] https://tethys.pnnl.gov/management-measures

Many of these stressor-receptor interactions can be avoided or reduced through appropriate project siting to avoid areas of high marine species occurrence/importance. Avoidance of important habitats and ecosystems should be prioritized when siting a project, followed by minimization and mitigation efforts. In addition, proposed projects would undergo analysis of effects under CEQA to determine the specific environmental impacts and identify mitigation measures to avoid or minimize the impacts.

5.2 Protective Measures

5.2.1 Collision, Entrainment, Impingement, and Entrapment

Collision (physical contact with moving components), impingement (trapped by intake flows against screens or WEC components), and entrainment (being drawn into the flow path) with some types of TECs (for example, axial-flow and crossflow turbine blades, Archimedes screw, tidal kites) create the risk of injury or mortality to individuals. These risks could lead to long-term impacts on populations of marine mammals, fish, and diving seabirds, though the degree of impact is uncertain.[156] Laboratory and field studies using single devices and small arrays have improved understanding of collision risk and avoidance behaviors; however, applicability to future larger arrays is uncertain. Also, collision risk and avoidance models used for wind projects (for example, standard three-bladed wind turbines) are less applicable to wave or tidal projects due to the wide range of converter designs.

Impingement, as defined for hydropower, is when fish or other aquatic organisms become trapped against a barrier structure, such as a screen, because of high water velocities. Entrapment (marine organisms that get entrapped within the air chambers of oscillating water column WECs and in reservoirs of overtopping devices) could result in mortality or injury if an organism becomes trapped within a device with no escape or bypass options, or entrained and passed through turbines. Potential protective and management measures to address these impacts include:

- Minimizing the area influenced by moving parts when designing devices.
- Installing guards for moving turbine blades.
- Minimizing the potential for entrapment/entrainment by providing adequate entering and exiting, escape pathways.
- Reducing turbine speed or pause operations when species of concern are present.
- Monitor devices to detect collision events and to understand the conditions under which collisions occur.
- Testing different color patterns, acoustic deterrents, or other deterrence methods, such as acoustic pingers and electromagnetic protective fields that could improve detectability and avoidance.

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[156] Garavelli, L., Hemery, L. G., Rose, D. J., Farr, H., Whiting, J. M., and Copping, A. E. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions."

5.2.2 Underwater Noise

Underwater noise generated during the site characterization surveys, project installation, operation, or decommissioning of WECs and TECs could affect individuals and populations of marine organisms through displacement, masking of important sounds, habituation, or temporary/permanent reduction in hearing sensitivity.[157] The frequency, amplitude, directionality, and propagation range of sounds from individual devices and arrays need to be considered relative to ambient sound levels, sensitive species' hearing thresholds, and documented noise responses when evaluating the risk of an installation to marine animals.[158]

Underwater noise measurements taken to date for small arrays of wave and tidal devices (fewer than six) indicate that the devices produce sound levels below those that could cause injury or harm to marine animals. However, there are still uncertainties because of the numerous WEC and TEC device types.[159] It will be important to measure sound levels produced by different types devices, as well as by larger arrays, and characterize behavioral responses of marine animals to these devices to improve understanding of the acoustic impact of wave and tidal energy projects.[160] Potential protective and management measures for addressing acoustic impacts include:

- Scheduling installation of devices when sensitive species are unlikely to be present.
- Avoiding pile driving, if possible, for installing devices.
- Using underwater sound attenuation measures such as bubble curtains during installation to decrease sound propagation, especially if pile driving is required.
- Modeling and monitoring noise levels and sound propagation during installation (for example, for pile driving or other noise-producing installation methods) to determine the impact area around a device where sounds levels meet or exceed disturbance and injury thresholds for relevant marine species.
- Modeling and monitoring noise levels and sound propagation during operation to provide understanding of device noise relative to ambient conditions.

5.2.3 Electromagnetic Fields (EMFs)

Ambient electromagnetic fields (EMFs) in the ocean are produced by Earth's geomagnetic field, electric fields induced by the movement of charged objects (for example, currents/waves, organisms) through a magnetic field, and bioelectric fields produced by organisms.[161] EMF

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[157] Ibid.

[158] Ibid.

[159] Ibid.

[160] Ibid.

[161] Normandeau Associates Inc, Exponent Inc., T. Tricas, and A. Gill. May 2011. *Effects of EMFs From Undersea Power Cables on Elasmobranchs and Other Marine Species*. U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, California. OCS Study BOEMRE 2011-09, https://tethys.pnnl.gov/publications/effects-emfs-undersea-power-cables-elasmobranchs-other-marine-species; Gill, A. B., I. Gloyne-Phillips, J. Kimber, and P. Sigray. 2014. *Marine Renewable Energy, Electromagnetic (EM) Fields and EM-Sensitive Animals*. In M. A. Shields and A.I.L. Payne (Eds). Marine renewable energy

includes the electric field and the magnetic field. EMFs can be generated by WECs and TECs, the umbilical cables (connecting the WECs to the subsea connectors), the subsea connectors, and the subsea cables to the shore. The primary sources of anthropogenic EMFs are the subsea power cables used to transmit electricity produced by the devices to shore, which are either high voltage alternating current (AC) or direct current (DC). Cables can produce localized heat as well as EMFs.[162] Many marine species sense and respond to E-fields or B-fields or both. However, the species that are of the greatest concern for interactions with EMFs are bony fish (teleosts and chondrosteans), crustaceans (crabs, lobsters, and prawns), elasmobranchs (sharks, skates, and rays), mollusks (snails, bivalves, cephalopods), marine mammals (cetaceans and pinnipeds), and sea turtles.[163]

EMFs from devices or arrays may disrupt animal movement and behavior, although laboratory and field studies have indicated that effects from small-scale developments (one to six devices) do not pose a risk to marine animals and should not prevent small-scale wave or tidal energy development nor require extensive monitoring.[164] High uncertainty remains regarding the effects of larger wave or tidal energy projects and the cumulative effects of multiple marine energy projects (that is, offshore wind energy projects in combination with wave energy installations). Improved understanding of species-specific dose-response thresholds for EMF, or the level of EMF exposure at which different species exhibit biological responses, is required for more effective prevention and management measures.

Potential protective and management measures for addressing EMFs include:

- Installing protection/shielding around cables.
- Using existing offshore infrastructure for routing transmission cables such as other cable corridors (for example, follow offshore wind cable corridors) or structures such as pipelines to reduce spatial extent of impact.
- Burying (trench) cables or using directional drilling for installing transmission cables.
- Using models to evaluate potential EMF levels relative to ambient condition and monitor to validate models.

5.2.4 Changes in Habitat

The introduction of hard structures to benthic and pelagic environments may result in habitat disturbance or habitat loss due to devices changing water flow patterns or both, which, in turn, could result in scouring or trapping of benthic sediments. Also, colonization of structures associated with the devices by sessile organisms (that is, biofouling), including nonnative species, could result in the creation of artificial reefs or fish-aggregating devices, which could attract fish and other marine predators to the devices and associated mooring

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technology and environmental interactions. Springer, Dordrecht, Netherlands. Pages 61–80, https://link.springer.com/chapter/10.1007/978-94-017-8002-5_6; Garavelli, L., Hemery, L. G., Rose, D. J., Farr, H., Whiting, J. M., and Copping, A. E. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions."

[162] Ibid.

[163] Ibid.

[164] Ibid.

infrastructure.[165] Dead biofouling organisms would then slough off the devices, affecting benthic habitats below the devices. Finally, the devices themselves could be used as haul-out platforms for seals and sea lions or as perches for seabirds if the device has a surface above water.

Although many of these interactions have been documented for MRE devices or similar structures, uncertainties still exist for larger arrays and effects on populations.[166] Potential protective and management measures to address changes to habitats include:

- Designing devices and moorings to minimize interactions such as biofouling, perching, and haul-out.
- Minimizing the benthic footprint of devices (for example, anchors, mooring lines, foundations).
- Minimizing the introduction and colonization of nonnative invasive species on hard surfaces through the use of antifouling measures such as specialized coatings or paints or frequent cleaning. In addition, vessels installing or servicing the devices should be from the local area or undergo cleaning.
- Monitoring benthic, pelagic, and above water (if there is a surface expression) areas around the devices to verify interactions.

5.2.5 Changes in Oceanographic Systems

Wave and tidal energy devices can change flow patterns and wave climates (that is, the distribution of wave characteristics averaged over a period).[166] Changes to tidal flow, localized current patterns (for example, turbulence, eddies, wakes), and wave energy could, in turn, have cascading effects on habitats (particularly intertidal and surf-zone habitats) and marine food webs. The extent of these interactions depends on the scale and number of devices (that is, the array size).[167]

Moreover, changes to flow patterns could affect biological and chemical processes, marine organism larval transport, shoreline processes, sediment transport, and depending on the scale of the installation, entire marine communities and habitats. Based on current understanding of small wave and tidal energy deployments (one to six devices), changes to oceanographic systems will be within the range of natural variability.[168] However, as wave and

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[165] Kramer, S. H., C. Hamilton, G. Spencer, H. Ogston. 2015. *Evaluating the Potential for Marine and Hydrokinetic Devices to Act as Artificial Reefs or Fish Aggregating Devices, Based on Analysis of Surrogates in Tropical, Subtropical, and Temperate U.S. West Coast and Hawaiian Coastal Waters* (Report No. OCS Study BOEM 2015-021), https://tethys.pnnl.gov/publications/evaluating-potential-marine-hydrokinetic-devices-act-artificial-reefs-or-fish.

[166] Garavelli, L., L. G. Hemery, D. J. Rose, H. Farr, J. M. Whiting, and A. E. Copping. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions;" Nelson, P. A., D. Behrens, J. Castle, G. Crawford, R. N. Gaddam, S. C. Hackett, J. Largier, D. P. Lohse, K. L. Mills, P. T. Raimondi, M. Robart, W. J. Sydeman, S. A. Thompson, S. Woo. October 2008. *Developing Wave Energy In Coastal California: Potential Socio-Economic and Environmental Effects*. California Energy Commission, PIER Energy-Related Environmental Research Program & California Ocean Protection Council. Publication Number: CEC-500-2008-083, https://tethys.pnnl.gov/sites/default/files/publications/Nelson_2008.pdf.

[167] Ibid.

[168] Ibid.

tidal energy projects scale up, there is greater uncertainty around how larger arrays will affect the hydrodynamics of the surrounding area. Therefore, monitoring and model validation are necessary.[169,170] Potential measures that address changes to oceanographic systems include:

- Modeling changes in tidal and current flows, flux, and turbulence to predict potential effects to marine habitats and organisms.
- Designing structures to minimize turbulence.
- Monitoring the tidal and marine hydrodynamic flow regimes before and after installation to improve understanding of the effects of devices on these regimes.
- Monitoring and modeling interaction between wave energy and indicator species or assemblages (for example, benthic communities).

5.2.6 Entanglement

Entanglement of marine mammals, sea turtles, fish, and birds with WECs and associated moorings (primary entanglement), with fishing gear ensnared around the WECs and associated moorings (secondary entanglement), or between the WECs and animals that are already entangled with gear (tertiary entanglement) are potential high-risk, long-term interactions with high uncertainty. Although risk of entanglement appears to be low for single devices and small arrays, the risk for larger arrays is unknown.[171] Potential measures to address entanglement include:

- Minimizing the number of mooring lines for WECs.
- Using taut mooring line designs for WECs.
- Installing real-time technologies that could detect gear/debris entanglement by monitoring mooring line strain.
- Routinely inspecting mooring lines for entangled fishing gear or marine debris and rapid removal.
- Limiting deployments in popular fishing areas. Create fishing exclusion zones around devices and arrays to minimize gear entanglement (may require review by California Department of Fish and Wildlife or other entities).

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[169] Jones, C., G. Chang, K. Raghukumar, S. McWilliams, A. Dallman, and J. Roberts. 2018. "Spatial Environmental Assessment Tool (SEAT): A Modeling Tool to Evaluate Potential Environmental Risks Associated With Wave Energy Converter Deployments." *Energies* 11, 2036, doi:10.3390/en11082036, https://www.mdpi.com/1996-1073/11/8/2036; Chang, G., K. Ruehl, C. A. Jones, J. Roberts, and C. Chartrand. 2016. "Numerical Modeling of the Effects of Wave Energy Converter Characteristics on Nearshore Wave Conditions." *Renewable Energy* 89:636–648, https://www.sciencedirect.com/science/article/abs/pii/S0960148115305528; Nelson, K., S. C. James, J. D. Roberts, and C. Jones. 2017. "A Framework for Determining Improved Placement of Current Energy Converters Subject to Environmental Constraints." *International Journal of Sustainable Energy,* 37(7), 654-668. DOI:10.1080/14786451.2017.1334654, https://www.tandfonline.com/doi/full/10.1080/14786451.2017.1334654.

[170] Garavelli, L., Hemery, L. G., Rose, D. J., Farr, H., Whiting, J. M., and Copping, A. E. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions."

[171] Ibid.

- Improving cost effectiveness and efficiency for detection and retrieval of lost fishing gear.
- Burying transmission cables.

5.2.7 Displacement

Large arrays may result in the displacement of marine animals (for example, avoidance and exclusion) as a response to stressors. Displacement primarily occurs at the individual level, but it could affect populations of marine organisms depending on the scale of arrays. Stressors that cause displacement include noise, EMF, habitat changes, physical presence of devices, device movement, and changes to hydrodynamics. Displacement could occur at a variety of temporal scales, ranging from short-term avoidance or exclusion from an area to long-term or permanent displacement from an area.

The consequences of displacement can include bioenergetic effects (such as changes in feeding behavior and energy expenditure of the displaced species), increased susceptibility to predation, changes in competition, and changes to essential habitats (that is, breeding, feeding, rearing habitats, and migration corridors). Displacement is unlikely for small wave and tidal energy projects (one to six devices). However, there is high uncertainty on the mechanisms and importance of displacement for larger wave and tidal energy projects.[172] Potential measures that address displacement include:

- Avoiding migratory routes or important/sensitive habitats when selecting deployment sites and determining the configuration of the array and moorings.
- Scheduling installation and maintenance to avoid sensitive periods (for example, gray whale migration).
- Minimizing lighting needed to reduce potential interference with migration.

5.2.8 Water Quality

Impacts on water quality may occur during the installation, maintenance, or removal of WEC/TEC devices (for example, release of chemicals, oils, lubricants) and from antifouling coatings. Accidental spills of lubricants, fuels, or other substances from vessels used for construction, maintenance, or decommissioning or from malfunctioning devices could occur. Potential remobilization of contaminants in sediment could occur during transmission cable burial. Potential measures to avoid impacts on water quality include:

- Preventing spills through WEC/TEC design, minimizing amounts of spillable fluids in WEC/TECs and on support vessels.
- Having spill response plans, which should include reporting protocols, prevention measures for avoiding spills, and response actions for the timely identification of accidental releases, as well as rapid containment and clean-up procedures.
- Implementing operation plans, should include appropriate training and response practices.

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172 Polagye, B., B. Van Cleve, A. Copping, and K. Kirkendall (editors). 2011. *Environmental Effects of Tidal Energy Development*. U.S. Dept. Commerce, NOAA Tech. Memo. F/SPO-116, 181 p., https://tethys.pnnl.gov/publications/environmental-effects-tidal-energy-development-proceedings-scientific-workshop.

- Routinely inspecting and monitoring WEC/TECs and vessels for leakages or potential accidental spills.

5.2.9 Ocean Uses

Consideration of mitigation measures for other ocean uses is challenging due to lack of convergence on technologies and project precedence. However, protective measures for avoiding ocean-use conflict exist and are case-specific, and further site-specific analysis will be required.

Visual Impacts

Devices, whether shore-based, nearshore or offshore, may impact a scenic vista or culturally significant viewsheds and landscapes for California Native Americans. Potential measures that address visual impacts include:

- Locating devices where visual impacts are minimized.
- Selecting types of devices that minimize visual impacts on scenic resources.
- Engaging early and often with interested parties and California Native American tribes to understand potential impacts and seek strategies to address them.

Impacts on Recreation

Safety hazards posed by the hard structures, moving parts, and size of the devices, as well as changes to wave climates from devices, could reduce or degrade recreational opportunities, such as sailing, surfing, kiteboarding, kayaking, swimming, and diving, in deployment areas. To reduce potential impacts, devices should be positioned away from popular recreational areas, and if avoidance is not possible, the deployment area should be clearly marked on local maps and signs. Communication with recreational advocacy groups and interested parties will be key to identifying and minimizing conflicts.

Impacts on Aquaculture

A multidevice wave or tidal energy project could potentially impact aquaculture resources by reducing the kinetic energy and circulation patterns available to areas with aquaculture operations. Decreased wave and tidal energy may then impact water circulation, food availability, and pollutant concentrations in nearshore aquaculture operations on the California coast. These impacts could, in turn, decrease the commercial value, food safety, or viability of the product. Reducing tidal energy may change sediment deposition, depth of light penetration, and pollutant concentrations,[173] which may impact aquaculture. Potential measures to avoid or minimize impacts include consideration of circulation patterns when siting to minimize impacts on existing aquaculture operations.

Impacts on Commercial and Recreational Fishing

Projects should be located outside established, high-use fishing grounds as much as possible to avoid space-use conflicts. The compatibility of offshore wave or tidal energy projects with fishing activities is contingent upon the layout and footprint of the project relative to fishing

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173 Polagye, B., B. Van Cleve, A. Copping, and K. Kirkendall (editors). 2011. *Environmental Effects of Tidal Energy Development*.

practices in the area. Siting projects at a high density may prevent fishing in certain areas. Procedures for mitigation and compensation need to be developed in collaboration with recreational and commercial fishing associations, fisheries managers (tribal, state, and federal), and other relevant groups. BOEM developed the following guidelines for OSW developers for avoiding conflict with fisheries that are pertinent to marine renewable energy projects:[174]

- Reduce the size of the project footprint.
- Do not site in established, high-use fishing grounds.
- Bury transmission cables to a minimum depth of three to six feet below the seabed. (If burial is not possible or cable protection is required or both, make the protection compatible with trawls.)
- Design facilities to maximize existing access to fisheries.
- Use designs that improve habitat for fish.
- Schedule installation and maintenance during time windows that minimize disruption to fishing activities.
- Update all navigational charts with the project facilities and provide updates to NOAA and the U.S. Coast Guard.

Navigational Hazards

An array of wave or tidal energy devices in the water may create new navigational hazards for vessels. As a result, new Coast Guard aids to navigational hazards may need to be installed near deployment sites (e.g., navigational marker buoys that may include sound and lighting). To reduce potential impacts, projects need to coordinate with the U.S. Coast Guard during siting and development to consider the location of shipping lanes, entrances to ports and harbors, and other potential navigational hazards.

Impacts on Cultural Resources and Tribal Uses

Projects located nearshore and offshore may impact cultural resources and traditional activities of California Native American tribes and communities. Since most wave and tidal energy devices will require a safety buffer zone, a project may impact the ability for tribes and tribal communities to engage in subsistence activities, as well as religious and spiritual activities. Impacts to tribes will be discussed further in the CEC’s final report to the Governor and Legislature in 2025. To reduce potential impacts:

- Site projects away from cultural sites.
- Communicate and coordinate closely with potentially impacted tribes.

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[174] BOEM. 2025. *Guidelines for Providing Information for Mitigating Impacts to Commercial and For-Hire Recreational Fisheries on the Outer Continental Shelf Pursuant to 30 CFR Part 585*. 41 p., https://www.boem.gov/sites/default/files/documents/renewable-energy/Fisheries%20Mitigation%20Guidance_Final_011625_for%20posting.pdf.

5.3 Conclusion

The nascent marine renewable energy industry is growing, and the project team's understanding of the uncertainties surrounding environmental impacts will advance, along with it as projects come on-line.[175] The simplest and most effective protective measure for avoiding conflict is to avoid developing in areas that would result in conflict (Chapter 3).

If avoidance is not possible, the next step is to put protective measures in place for reducing conflict. Such measures include design considerations for devices and associated components, procedures to follow during construction and operation, modeling to predict and detect impacts, and monitoring, to name a few. Clear communication and collaboration with managers and stakeholders will be essential for preventing conflict and ensuring the success of energy projects. Projects should budget and plan for data collection when planning projects to further elucidate interactions and help prevent impacts. Enhanced knowledge of these interactions would allow for some risks to be retired and refine monitoring protocols and allow for adaptive management (Chapter 6).

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[175] Barr, Z., J. Roberts, W. Peplinski, A. West, S. Kramer, and C. Jones. 2021. "The Permitting, Licensing and Environmental Compliance Process: Lessons and Experiences Within U.S. Marine Renewable Energy." *Energies* 14(16):5048, https://doi.org/10.3390/en14165048.

CHAPTER 6:
Monitoring and Adaptive Management Strategies

Monitoring and adaptive management strategies will be critical for addressing potential interactions where uncertainty is high and risks to individuals, populations, or important/ sensitive habitats are not well understood. Monitoring is important for detecting the frequency and magnitude of interactions while adaptive management may allow for projects to implement appropriate measures and determine whether continued monitoring is necessary, or if risks can be retired.[176]

Adaptive management offers a pathway for regulators to approve marine renewable energy developments while ensuring that environmental interactions are monitored and addressed. While this report provides a high-level discussion of monitoring and adaptive management strategies as required in SB 605 statute, all adaptive management plans will need to be evaluated through existing laws and regulations (for example, CEQA). It will be crucial to identify the resources required to implement these strategies successfully while maintaining a balance between economic viability and environmental protection.

An adaptive management approach can also include phasing projects, starting with smaller pilot-scale deployments and collecting data to characterize interactions. This approach can guide decision-making to safely allow projects to scale up to larger commercial arrays while minimizing environmental impacts.

As identified in Chapter 6 of the IEA-OES *State of the Science Report*,[177] several wave and tidal projects have adopted adaptive management strategies, most recently by Oregon State University (OSU) for its PacWave South wave energy test site. Specific adaptive management strategies include:

- Evaluating baseline environmental conditions at the proposed project site and identifying high-risk, high-uncertainty issues.
- Determining critical information gaps from a baseline evaluation, as well as other wave and tidal energy projects and comparisons and similarities between familiar forms of energy.
- Developing targeted studies to address data gaps and identify thresholds of concern.
- Developing communication protocols for providing study findings to adaptive management decision-makers in a timely manner.

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[176] Freeman, M.C. 2024. "Strategies to Aid Consenting Processes for Marine Renewable Energy." In L. Garavelli, A. E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), *OES-Environmental 2024 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World.* Report for Ocean Energy Systems (OES). (pp. 170-203). doi:10.2172/2438595, https://tethys.pnnl.gov/publications/2024-state-science-report-chapter-6-strategies-aid-consenting-processes-marine.

[177] Ibid.

- Identifying protection, mitigation, and enhancement measures and actions that would be used if thresholds of concern are exceeded. Laying out a clear path for decision-making for regulatory agencies, energy developers, and stakeholders (for example, if A happens, then B. If C happens, then D).
- Agree on a monitoring timeline and mileposts (for example, monitor for one year and then re-evaluate).

This section is organized as follows:

- Section 6.1: Strategies for Monitoring Success
- Section 6.2: Examples of Wave and Tidal Projects With Adaptive Management Strategies Applied
- Section 6.3: Conclusions

6.1 Strategies for Successful Monitoring

Given that the wave and tidal energy industry is still emerging, many real-world projects to learn from are small scale with only a few devices deployed at a time. Smaller projects are less likely to have measurable effects on the surrounding environment. However, there is greater uncertainty for scaling up projects. The following discussion is referring to what is known for successful monitoring of MRE projects and acknowledges that further studies and research are needed for risks of commercial-scale projects.

The key to a successful monitoring and adaptive management strategy is to identify the interactions that require additional information to permit and evaluate whether those interactions have been "retired," as defined by Freeman (2024):[178]

> "A process for facilitating consenting for MRE [marine renewable energy] developments whereby each potential environmental risk need not be fully investigated for every project. Instead, regulators, advisors, developers, and consultants can rely on what is known from consented MRE projects, related research studies, or findings from analogous offshore industries to help determine which interactions are better understood and can be considered retired or low risk. If new information becomes available, a retired risk can (and should) be re-examined and a new decision made about risk retirement."

For example, two stressor-receptor interactions, EMFs and underwater noise, were identified as candidates for risk retirement for projects with few devices.[179] More recently, three additional stressor-receptor interactions were identified as candidates for risk retirement for projects with few devices: changes in habitat, changes in oceanographic systems, and

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[178] Ibid.

[179] Copping, A. E., M. Freeman, A. Gorton, and L. Hemery. 2020. "Risk Retirement and Data Transferability for Marine Renewable Energy." In A. E. Copping and L. G. Hemery (Eds.), *OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World* (pp. 263–279). https://www.ocean-energy-systems.org/news/oes-environmental-2020-state-of-the-science-report/.

entanglement.[180] However, the effect of increasing the number of devices on these stressor-receptor interactions, as well as other environmental interactions, such as collision risk and displacement, require more evaluation, and are likely device- and site-specific.

Interactions that cannot be "retired" are candidates for monitoring and adaptive management. A thorough analysis of risks should include:

1. The data analyzed and reasons why risks continue to have high uncertainty and therefore cannot be retired.
2. Thresholds of concern for the level of interaction between the stressor and receptor.
3. Potential impacts of exceeding thresholds on receptors.
4. Identification of specific study/monitoring goals and objectives.
5. Identification of methods, equipment, and study designs to evaluate goals and objectives.
6. Analytical metrics for determining if thresholds are met or exceeded
7. Constraints and limitations.
8. How results will be used in an adaptive management framework to make decisions.

Ideally, the adaptive management strategy would identify the types of actions that would occur when thresholds are exceeded. For example, if thresholds are exceeded, it could trigger the need for additional monitoring, scheduling device maintenance, changing project layout, or other project operations. In this way, developers can factor in the potential range of decisions that could occur in the future, based on findings from monitoring. Studies within an adaptive management framework should be adaptable as well. Methods, technologies, protocols, and analytical approaches may change over time, and information from other installations or monitoring or both may indicate that additional risks can be retired and further monitoring is not warranted, or risks remain or new risks are found, requiring additional monitoring or other project modifications.

6.2 Examples of Wave and Tidal Projects With Adaptive Management Strategies Applied

Two wave energy projects that have included adaptive management strategies in permitting and licensing but have not yet applied them include Ocean Power Technologies' (OPT) Reedsport Wave Park and Oregon State University's (OSU) PacWave South.[181] The settlement agreement for OPT's traditional FERC license included adaptive management intended to support the implementation of monitoring studies, and to identify and adjust measures required to address any unanticipated effects of the project and its potential expansion.

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[180] Garavelli, L., Hemery, L. G., Rose, D. J., Farr, H., Whiting, J. M., and Copping, A. E. 2024. "Marine Renewable Energy: Stressor-Receptor Interactions."

[181] Le Lièvre, C. 2020. "Adaptive Management Related to Maritime Renewable Energy." *In A.E. Copping and L.G. Hemery (Eds.), OES Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World*. Report for Ocean Energy Systems (OES). (pp. 242–261), doi:10.2172/1633206.

Detailed environmental studies were included for pinnipeds and cetaceans, EMFs, fish, and seabirds, as well as changes in waves, currents, and sediment transport.

Adaptive management was not implemented because OPT surrendered the FERC license two years after the project was approved. PacWave South is still under construction, but the associated adaptive management strategy is included in its FERC license and is a means to addressing uncertainties and allow developers to test specific WEC types (for example, point absorber, oscillating water column) at the PacWave South site. The strategy includes commitments by OSU to implement monitoring programs for underwater noise, habitat changes, and EMFs to confirm assumptions about the levels and durations of potential effects. The plan also includes processes for taking corrective actions in consultation with regulatory agencies as part of an Adaptive Management Committee that included the state and federal agencies and OSU.

Current plans for floating offshore wind energy development off California could guide wave and tidal energy project planning. While floating OSW facilities will be farther from shore and in deeper waters, many of the same environmental monitoring and adaptive management strategies could also apply to wave and tidal projects. Projects such as the Ocean Protection Council's "comprehensive offshore wind environmental monitoring guidance"[182] to properly monitor, evaluate, and mitigate environmental impacts of offshore wind facilities could be applicable to wave and tidal projects.

6.3 Conclusion

Permitting challenges for marine renewable energy projects presented by environmental uncertainties and risks may be addressed by developing a monitoring and adaptive management strategy. Over time, as the industry develops and as understanding of environmental interactions advances, the uncertainties that result in long permitting time frames and high costs may decrease.[183] Marine renewable energy developments will be guided by lessons learned from adaptive management and monitoring until many of the risks are better understood or can potentially be retired. Lessons learned from adaptive management and monitoring need to be communicated to developers, regulatory agencies, stakeholders, and California Native American tribes through outreach and existing knowledge bases (for example, PRIMRE).[184]

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[182] California Marine Sanctuary Foundation. "Offshore Wind Environmental Monitoring Guidance," https://www.californiamsf.org/offshorewind.

[183] Peplinski, W.J., J. Roberts, G. Klise, S. Kramer, Z. Barr, and A. West. 2021. "Marine Energy Environmental Permitting and Compliance Costs." *Energies* 14:4719. https://doi.org/10.3390/en14164719.

[184] Portal and Repository for Information on Marine Renewable Energy, https://openei.org/wiki/PRIMRE.

CHAPTER 7:
Outreach and Engagement

Meaningful outreach and engagement are important in assessing marine renewable energy technologies. SB 605 directs the CEC to identify suitable sea space, mitigation measures, and monitoring and adaptive management strategies for wave and tidal energy. This work is to be done in coordination and consultation with state and local government agencies, California Native American tribes, commercial and recreational fisheries, nongovernmental organizations, offshore wave and tidal energy developers, and other interested stakeholders. This chapter outlines engagement activities conducted for this report (Section 7.1) and strategies for successful future engagement on marine renewable energy (Section 7.2).

7.1 Outreach and Engagement Activities

Per statute, the CEC has conducted outreach with the groups mentioned above to disseminate information on SB 605 efforts and gather feedback on suitable sea space, identification of mitigation measures, and monitoring and adaptive management strategies. Outreach efforts are ongoing and will be covered in more detail within the CEC report to be submitted to the Legislature and Governor in 2025. Below is a summary of engagement to date.

7.1.1 California Native American Tribes

The CEC engaged in tribal consultations with California Native American tribes to discuss the wave and tidal energy resources, their feasibility, and the development of the 2024 Integrated Energy Policy Report Update. Request for consultation letters were sent in May 2024, and specific to suitability of sea space and this report, in January 2025, to all California Native American tribes across California. Workshop and related draft materials for the draft *2024 IEPR Update* were shared with tribes for review, input, and consultation offered. Moreover, the CEC and partnering state and federal agencies meet monthly with an intertribal working group to continue conversations regarding the impacts of ocean renewable energy resource such as offshore wind and wave and tidal resources.

The CEC held two tribal listening sessions February 19, 2025, and February 26, 2025, related to SB 605 sea space identification for wave and tidal energy discussed within this consultant report. The tribes that attended expressed concern about continued potential for development within the ocean and unceded ancestral territories. They expressed concern about future research being completed by developers and the need for research to be unbiased and from trustworthy sources. They asked about the permitting process for prospective projects in state waters and the role that local governments would have in the permitting process. They asked about the process for selecting renewable resources for inclusion into the state’s resource planning for the electric grid.

Additionally, some tribal representatives pointed to a recently designated Indigenous Marine Stewardship Area (IMSA). Tribal marine stewards typically represent a coalition of sovereign nations, who work together to support co-management of their ancestral coast and ocean territories. In 2023, the Pulikla Tribe of Yurok People, the Tolowa Dee-ni' Nation, and the

Cher-Ae Heights Indian Community of the Trinidad Rancheria designated the Yurok-Tolowa Dee-ni' IMSA, which is a defined geography in ocean and coastal waters that are designated by a tribal nation to achieve long-term stewardship, management, and co-management of ecosystem services and support cultural lifeways and economies.[185] CEC staff expect to provide additional information on the IMSA in the final version of this consultant report.

Additional outreach and consultation is expected as the final CEC report is developed later this year. Future materials and workshop notices will be shared with tribes in advance. Lastly, the CEC and agencies involved in preparing the SB 605 reports are thankful for the time and information shared by tribal leaders, staff, and tribal members.

7.1.2 Commercial and Recreational Fisheries

The CEC held a fishing community engagement webinar with commercial and recreational fisheries January 9, 2025. Fishermen concerns included the cumulative impacts to fishing communities from all offshore development (offshore wind, aquaculture, and so forth), which compound restrictions to fishermen. Fishermen expressed a desire for compensation for participating in public processes, as they are concurrently participating in planning processes for offshore wind energy development.[186] CEC staff presented on SB 605 sea space identification at a Pacific Fisheries Management Council meeting January 30, 2025. Fishermen acknowledged that while salmon, squid, and Dungeness crab are important fisheries to consider in this sea space analysis, there are many more fisheries that could be impacted by marine renewable energy development. Additional fisheries analysis and outreach would need to be conducted for potential projects.

7.1.3 Environmental Nongovernmental Organizations

The CEC met with environmental nongovernmental organizations regarding SB 605 sea space identification January 27, 2025. Participants acknowledged the nascency of this industry and emphasized that future planning efforts should ensure minimal impact on marine ecosystems. In addition, the CEC has conducted outreach on work related to SB 605 via email to provide updates on SB 605 efforts.

7.1.4 Wave and Tidal Energy Developers

The CEC held a wave and tidal industry engagement webinar January 16, 2025. The webinar included discussion on wave and tidal resource availability, constraints to technology deployment, and marine energy applications in California. Additional engagement was conducted via meetings and emails to inform technology deployment feasibility and provide updates on SB 605 efforts.

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[185] Tolowa Dee-ni’ Nation. “Yurok & Tolowa Dee-ni’ Indigenous Marine Stewardship.” Tolowa Dee-ni’ Nation. https://tolowa-nsn.gov/341/Yurok-Tolowa-Dee-ni-Indigenous-Marine-St. Accessed February 2025.

[186] In accordance with Condition 7c of the California Coastal Commission’s concurrence with offshore wind lease areas and Senate Bill 286, the California Coastal Commission established and leads the California Offshore Wind Energy Fisheries Working Group. The working group seeks to develop a statewide strategy for avoidance, minimization, and mitigation of impacts to fishing and fisheries that prioritizes fisheries productivity, viability, and long-term resilience.

For this report, outreach was conducted to help inform the findings in this consultant report. Additional outreach will occur as the CEC uses this consultant report and other relevant information to prepare a final report on wave and tidal energy to be delivered to the California Legislature.

7.2 Future Engagement

Outreach and engagement efforts will continue after this consultant report publication. A next step in this work is submission of a written report to the Governor and Legislature that will include a summary of the *Final 2024 IEPR Update* findings and a summary of the sea space identification findings. That report will include considerations that may guide legislative and executive actions to address barriers and support development of feasible wave and tidal energy technologies, infrastructure, and facilities in California. Outreach and engagement with California Native American tribes, commercial and recreational fisheries, nongovernmental groups, industry, and other interested stakeholders will be conducted to inform the formal report to the Governor and Legislature, as required in SB 605 statute.[187]

Future engagement strategies with relevant government agencies, tribal governments, and interested parties on wave and tidal energy should consider starting with education and information sharing of the technologies and potential effects. The marine renewable energy industry is still emerging with few commercial-scale projects in operation, so the public's knowledge on these topics is limited. Key stakeholders to engage in future outreach on marine renewable energy include federal, state, and local government agencies; California Native American tribes; commercial and recreational fishing industry; maritime industry; environmental groups; academic and research institutions; coastal communities; and energy developers. Additional recreational stakeholder groups include the Surfrider Foundation and regional groups for recreational activities such as sailing and diving.

The OES State of the Science Report highlights recommendations for developing engagement approaches to marine renewable energy. These recommendations can be applied to future outreach and engagement efforts and include:

1. Tailoring engagement for each project based on different contexts, communities, or locations.
2. Clarifying responsibilities and setting expectations, including defining who is responsible for which aspects of engagement goals and ideal outcomes of engagement efforts.
3. Conducting stakeholder engagement and information-sharing activities early and regularly, ideally before key decisions being made to allow stakeholder input to be incorporated or changes made based on suggestions or concerns.
4. Moving beyond informing to participatory approaches that build trust and listening to stakeholders and communities.

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[187] "Senate Bill No. 605 (Padilla, Chapter 405, Statutes of 2023." California Legislative Information, 2023, leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB605.

5. Including equity and social and energy justice considerations throughout engagement and in all project phases — planning, development implementing, operation, and decommissioning.[188]

Meaningful engagement with coastal communities, indigenous peoples, and stakeholders supports California's future vision for marine energy, which ensures that projects are developed collaboratively, transparently, and equitably.

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[188] Rose, D. J., and Freeman, M. C. 2024. "Stakeholder Engagement for Marine Renewable Energy." In L. Garavelli, A. E. Copping, L. G. Hemery, and M. C. Freeman (Eds.), *OES-Environmental 2024 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World*. Report for Ocean Energy Systems (OES). (pp. 144-169). doi:10.2172/2438593.

APPENDIX A: Glossary

Alternating current (AC): Electrical current that changes direction periodically. Most transmission lines in the United States transport AC power because electricity is generated and used as alternating current.[1]

Angler: An angler represents a single person fishing in a block on a single day.

Attenuator: A single surface-floating bodies or multiple connected bodies that rise and fall with wave motion, and electricity is generated through mechanical turbine rotation or hydraulic pumps that are driven by the flexing motion of the device.

Aquaculture: The breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments.[2]

Axial-flow turbines have spinning blades whose axis of rotation is oriented with the direction of the current. They mimic wind turbines in shape and energy extraction method.

Bathymetry: The study of seabed topography, or the depths and shapes of underwater terrain.

Bureau of Ocean Energy Management (BOEM): The federal agency under the U.S. Department of Interior that manages development of U.S. Outer Continental Shelf energy and mineral resources. BOEM manages overall offshore wind processes, which include four phases: planning and analysis, leasing, site assessment, and construction and operation.

California coastal zone: A legislatively defined geographic region that establishes the area regulated under the Coastal Act encompassing the land and water areas along the length of the California coastline from the Oregon border to the border of Mexico, extending seaward to the state's outer limit of jurisdiction, including all offshore islands, and extending inland generally 1,000 yards from the mean high tide line of the sea.

Commercial fishing blocks: The California Department of Fish and Wildlife (CDFW) uses a system of commercial fishing blocks to manage and report commercial fishing activities along the California coast. These blocks are essentially a grid system that divides the ocean waters into sections, each approximately 10 minutes of latitude by 10 minutes of longitude (roughly 10 square miles).[3]

Consistency certification: Under the federal Coastal Zone Management Act (CZMA), coastal states with an approved coastal management plan are able to review federal permits and

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1 CPUC. *Electric Transmission Fact Sheet.* Accessed at https://ia.cpuc.ca.gov/Environment/info/aspen/cltp/archive/Files_8_26_14/_2ElectricTransmissionFactSheet.pdf. January 16, 2025.

2 NOAA. 2025. "What Is Aquaculture?" Accessed at https://oceanservice.noaa.gov/facts/aquaculture.html. January 16, 2025.

3 CDFW. "Commercial Fishing Blocks — Pre Jan. 1, 2025 - R7 – CDFW." Accessed at https://data-cdfw.opendata.arcgis.com/datasets/CDFW::commercial-fishing-blocks-pre-jan-1-2025-r7-cdfw-ds3093/about. March 2025.

activities to determine if they are consistent with the state's management plan. They can either "concur" or "object" to the consistency certification.

Consistency determinations (CDs): A consistency determination is submitted to the California Coastal Commission when a federal agency activity affects the coastal zone. It is a project description and analysis of the coastal zone effects of the activity based on the policies of the Coastal Act.

Crossflow turbines have a set of blades that spin in the direction of flow and can be mounted horizontally or vertically. As these turbines spin, the design of the blades must minimize the flow across the blade as it returns to face the flow.

Demand-side resources: Demand-side resources serve resource adequacy needs by reducing load, which reduces the need for additional generation. Typically, these resources result from energy efficiency or demand response and load management.

Desalination: The process of removing dissolved salts form saline water to produce freshwater.[4]

Direct current (DC): Electrical current that flows in one direction and is useful to transmit electricity over very large distances and between asynchronous grids.[5]

Distributed energy resources (DER): Typically smaller generation units that are on the consumer's side of the meter or providing generation to serve nearby load.

Distribution lines: These electric power lines cover much shorter distances, and are typically energized at 16 kV, 12 kV, or 4 kV. Distribution lines carry electricity to neighborhoods on shorter wooden poles or underground.[6]

Embayment: A coastal recess that forms a bay.

European Marine Energy Centre (EMEC): Marine technology test facility located in the United Kingdom.

Evolutionary significant unit (ESU): A population of organisms that is considered distinct for the purposes of conservation.

Farm-to-grid efficiency: The effectiveness with which energy generated by marine energy projects (wave, tidal, or offshore wind) is converted into useable electricity and delivered to the grid.[7]

Floating offshore wind: Offshore wind turbines deployed in water depths that necessitate floating structures and are stabilized by moorings and anchors. Floating offshore wind

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[4] USGS. 2019. "Desalination." Accessed at https://www.usgs.gov/special-topics/water-science-school/science/desalination. January 16, 2025.

[5] CPUC. *Electric Transmission Fact Sheet.*

[6] Ibid.

[7] Kluger, J. M., M. N. Haji, and A. H. Slocum. 2023. "The Power Balancing Benefits of Wave Energy Converters in Offshore Wind-Wave Farms With Energy Storage." *Applied Energy* 331:120389, https://www.sciencedirect.com/science/article/abs/pii/S0306261922016464?via%3Dihub.

technology allows offshore wind to be deployed in deeper waters where fixed-bottom offshore wind is not feasible. Due to the nearshore water depth of the Pacific Continental Shelf, floating offshore wind is the only feasible option for California.

Gigawatt (GW): One thousand megawatts (1,000 MW) or 1 million kilowatts (1,000,000 kW) or 1 billion watts (1,000,000,000 watts) of electricity. One GW is enough to supply the electric demand of about 1 million average California homes.

High voltage (HV): Any voltage above 1000 volts for alternating current (AC) and 1500 volts for direct current (DC).[8]

Incident energy: The amount of energy, at a prescribed distance from the equipment, generated during an electrical arc event. It increases as the magnitude of current flowing in the fault and clearing time increase.

Kilovolt (kV): One-thousand volts (1,000). Distribution lines in residential areas are usually 12 kV (12,000 volts).

Kilowatt (kW): One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of 4 kW each hour.

Kilowatt-hour (kWh): The most commonly used unit of measure telling the amount of electricity consumed over time. It means 1 kilowatt of electricity supplied for 1 hour. In 1989, a typical California household consumes 534 kWh in an average month.

Levelized cost of energy (LCOE): The average total cost of an energy generation project per unit of total electricity generated. Also referred to as the levelized cost of electricity, LCOE is a measurement to assess and compare alternative methods of energy production.

Marine protected areas (MPA): A named, discrete geographic marine or estuarine area seaward of the high tide line or the mouth of a coastal river, including any area of intertidal or subtidal terrain, together with its overlying water and associated flora and fauna that has been designated by law, administrative action, or voter initiative to protect or conserve marine life and habitat.[9]

Megawatt (MW): One thousand kilowatts (1,000 kW) or 1 million (1,000,000) watts. One MW is enough electrical capacity to power 1,000 average California homes. (Assuming a loading factor of 0.5 and an average California home having a 2 kilowatt peak capacity.)

Morphology: The morphology of the shoreline refers to the study of the shape, structure, and landforms that make up coastal systems or subsystems.

Nameplate capacity: The total manufacturer-rated capacities (or full-load sustained energy generation output) of equipment such as turbines, generators, condensers, transformers, and

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[8] The Electricity Forum. 2025. "What Is Considered High Voltage?" Accessed at https://electricityforum.com/what-is-considered-high-voltage. January 16, 2025.

[9] CDFW. 2025. "Marine Protected Areas: Definitions." Accessed at https://wildlife.ca.gov/Conservation/Marine/MPAs/Definitions. March 10, 2025.

other system components. Wave and tidal energy converter nameplate capacities are rated in megawatts (MW).

National Environmental Policy Act (NEPA): A federal law that requires federal agencies to assess the environmental effects of proposed actions requiring a discretionary action prior to making decisions.

National Marine Sanctuaries (NMS): Protected waters that include habitats such as rock reefs, kelp forests, deep-sea canyons, and underwater archaeological sites.[10]

National Oceanic and Atmospheric Administration (NOAA): A federal agency whose mission is to understand and predict changes in climate, weather, ocean, and coasts, share that knowledge and information, and conserve and manage coastal and marine ecosystems and resources.[11]

National Renewable Energy Laboratory (NREL): A federal laboratory that performs research, development, and deployment of renewable energy and energy efficiency technologies.[12]

Nearshore wave energy converter (WEC): Deployed within a few hundred meters (m) of shore, in water depths of 10–25 m. They are generally mounted directly to the seafloor; however, some devices have floating, semisubmerged, or submerged components as well.

Offshore wave energy converter (WEC): Deployed in waters deeper than 25 m. These devices may float at the surface, be near the surface (semisubmerged), or be submerged. As such, they require moorings and anchors to hold them in place.

Onshore wave energy converter (WEC): Typically, fixed structures that are deployed on coastal structures or in shallow water. These can be integrated into breakwaters or piers or built as stand-alone structures.

Oscillating water column wave energy converters generate electricity by using the oscillating motion of water within a chamber as waves pass by. These WECs typically consist of a partially submerged chamber open to the sea.

Oscillating wave surge converters: Oscillating wave surge converters consist of a buoyant structure that moves back and forth (surges) in response to the passing waves to create energy.

Outer Continental Shelf (OCS): Includes the submerged lands between state jurisdiction (3 miles from shore) to 200 nautical miles (nm) from shore. The OCS is the portion of the internationally recognized continental shelf of the United States, which does not fall under the jurisdictions of the individual U.S. states.

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[10] NOAA. 2025. "What Is a National Marine Sanctuary?" Accessed at https://oceanservice.noaa.gov/facts/nms.html#:~:text=National%20marine%20sanctuaries%20are%20protected%20waters%20that%20include,located%20off%20the%20northern%20and%20central%20California%20coast. January 16, 2025.

[11] NOAA. 2025. "About Our Agency." Accessed at https://www.noaa.gov/about-our-agency. January 16, 2025.

[12] NREL. 2025. "About NREL." Accessed at https://www.nrel.gov/about/. January 16, 2025.

Overtopping wave energy converters (WEC) generate electricity across a sloping structure or a seawall with a reservoir behind it. As waves approach the structure, they climb up and spill over the crest, filling the reservoir with water. Being impounded, the water accumulated in the reservoir is at a higher elevation than the surrounding ocean. The water collected in the reservoir is then released through turbines or sluice gates. This controlled release of water drives turbines or generators, converting the potential energy of the stored water into electricity.

Point absorbers typically involve a floating buoy or platform that moves up and down or back and forth in response to the motion of passing waves. This movement, relative to a fixed structure (like an anchor), is then converted into mechanical energy using a power take-off mechanism, such as hydraulic pistons or linear generators.

Power matrix defines the expected energy output of a specific technology at varying resource levels.

Powering the Blue Economy involves using marine energy technologies to support and enhance various sectors and activities within California’s rich ocean economy.

Pressure differential wave energy converter generates electricity by harnessing the difference in pressure between two points caused by the motion of ocean waves, the crest, and trough.

Project developer (or developer): A project developer is responsible for developing and managing the project, including activities required to secure financing and permits, determine the project design and engineering aspects, and engage with partners, agencies, and stakeholders. A developer may also be the owner and operator of the energy project.

Port: This term is used both for the harbor area where ships are docked and for the agency (port authority), which administers use of public wharves and port properties. Offshore wind will require ports and waterfront facilities to support a range of activities, including construction and staging of floating platform foundations, manufacturing and storage of components, final assembly, and long-term operations and maintenance.

Project phase(s): Wave and tidal project activities can be categorized into chronological phases. Key workforce and supply chain development phases include supply chain and manufacturing, integration and assembly, and operations and maintenance. These project phases overlap with the BOEM renewable energy program phases: planning, leasing, site assessment, and construction and operations. Project developers incorporate both categories of project phases into a project timeline.

Raster graphic: A graphic made up of a collection of tiny, uniformly sized pixels, which are arranged in a two-dimensional grid made up of columns and rows. Each pixel contains one or more bits of information, depending on the degree of detail in the image.

Senate Bill 605 (SB 605): The law requires that the CEC evaluate the feasibility, costs, and benefits of using wave energy and tidal energy as forms of clean energy in California’s state and federal coastal waters.

Substation connects two or more transmission lines and transforms voltage from higher to lower. Substations may contain high-voltage switches that allow lines to be connected or isolated for maintenance. Substations can have transformers to convert between two transmission voltages, or equipment such as phase angle regulators to control power flow between two adjacent power systems. A large transmission substation can cover 50 or 100 acres, including multiple voltage levels, and a large amount of protection and control equipment (capacitors, relays, switches, breakers, voltage, and current transformers).[13]

Technology readiness level (TRL): A metric used for describing technology maturity. It is a measure used by many U.S. government agencies to assess maturity of evolving technologies (materials, components, devices, and so forth) before incorporating that technology into a system or subsystem.[14]

Tidal energy converters (TEC): Technologies that create electricity using tidal or current movement.

Terawatt-hour (TWh): A unit of energy that represents 1 trillion watts of power used for one hour.

Transmission lines carry electricity over long distances, from the generating facility to areas of demand. The electricity in transmission lines is transported at voltages of more than 200 kV to maximize efficiency. Voltages of 220 kV to 500 kV are typical. Transmission lines are usually attached to large lattice steel towers or tubular steel poles.[15]

Volt (V): A unit of electromotive force. It is the amount of force required to drive a steady current of 1 ampere through a resistance of 1 ohm. Electrical systems of most homes and office have 120 volts.

Water Power Technologies Office (WPTO): A group within the U.S. Department of Energy that enables research, development, and testing of emerging technologies to advance marine energy, as well as hydropower and pumped storage systems.[16]

Wave energy converter (WEC): Technologies that use wave movement to create electricity. These can be both onshore and offshore installations.

Workforce: All the workers needed to support a project or industry. The workforce for wave and tidal energy consists of workers needed to perform all types of jobs related to the wave and tidal energy ecosystem for all project phases.

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[13] CPUC. *Electric Transmission Fact Sheet*.

[14] DOE. "Technology Readiness Level." Accessed at https://www.directives.doe.gov/terms_definitions/technology-readiness-level. January 23, 2025.

[15] CPUC. *Electric Transmission Fact Sheet*.

[16] US DOE. 2025. "Water Power Technologies Office." Accessed at https://www.energy.gov/eere/water/water-power-technologies-office. January 16, 2025.

APPENDIX B: Wave and Tidal Generation Project Examples

This appendix presents examples of existing wave and tidal projects, the following technologies:

- Section B.1: Hydrokinetic Tidal Generation Projects
- Section B.2: Hydrokinetic Wave Generation Projects

B.1 Hydrokinetic Tidal Generation Projects

Dent Tidal Energy Project (British Columbia, Canada, Bute Inlet)

Dates of Operation: 2012 – ongoing

Capacity: 500 kW

Description: Extracts energy of the tidal currents in a constricted channel. Floating tidal turbine connected via a 900-meter submarine cable to the Dent Island microgrid and energy storage system.

La Rance Tidal Barrage (France, Rance River)

Dates of Operation: 1966 – ongoing

Capacity: 240 MW

Description: 24 bulb tidal turbines mounted onto a dam. Generates power from tidal flow in an estuary and supplies 0.012% of the power demand of France.

Living Bridge (New Hampshire, Piscatauqa River)

Dates of Operation: 2017 – ongoing

Capacity: 25 kW

Description: Single tidal turbine mounted onto a bridge with multi-directional flow capabilities. Provides baseload power to sensors that collect data on measuring bridge conditions (structural health monitoring), traffic management, and estuarine water quality to assist in environmental stewardship.

Bourne Tidal Hydrokinetic Test Site (Massachusetts, Cape Cod Canals)

Dates of Operation: 2024 – ongoing

Capacity: 50 kW

Description: Test site with an 8-year FERC license for a pilot project. Collects marine, coastal, and engineering data to determine the feasibility of tidal turbines in the Cape Cod Canal.

MeyGen Tidal Energy Project (Pentland Firth, Scotland, North Sea, Atlantic Ocean)

Dates of Operation: 2010 – ongoing

Capacity: 6 MW

Description: Array of seafloor mounted tidal turbines. Connected via seafloor cable to a substation that is part of the national grid. The MeyGen project is the largest planned tidal energy project in the world, with up to a 398 MW generation capacity.

European Marine Energy Centre (EMEC) Fall of Warness Grid Connected Tidal Test Site (Orkney Island, Scotland North Sea, Atlantic Ocean

Dates of Operation: 2005 – ongoing

Capacity: 10 MW

Description: Axial flow turbines that harness tidal currents. Power generated travels via subsea cable to a substation and transformer and feeds into the national grid or is directed to an electrolyzer to generate hydrogen.

Nova Innovation Shetland Tidal Array (Shetland, Scotland, Bluemull Sound, Atlantic Ocean

Dates of Operation: 2016 – ongoing

Capacity: 600 kW

Description: Seabed mounted axial flow turbines that harness tidal currents of a constricted channel. Exports power to the local grid.

Sihwa Lake Tidal Power Station (South Korea, Pacific Ocean)

Dates of Operation: 2011 - ongoing

Capacity: 254 MW

Description: Built into an artificial reservoir. Generates one-way power twice a day at high tide. Sluice gates are closed as the tide comes in, which isolates the reservoir at its lowest level. When the tide is high, water flows into the reservoir, generating electricity.

LHD Tidal (China, East China Sea)

Dates of Operation: 2016 – ongoing

Capacity: 3.4 MW

Description: Platform based tidal turbines extracting power from tidal current. Connected to the local grid.

Minesto Holyhead Deep Array (Wales, UK, Holyhead Bay, Atlantic Ocean

Dates of Operation: 2018 – ongoing

Capacity: 500 kW

Description: Single device, tidal kite that harnesses low-velocity tidal energy. Supplies power to a self-contained microgrid used for analyzing the electricity generated.

Roosevelt Island Tidal Energy (RITE) Pilot Project (New York City, NY, East River)

Dates of Operation: 2012 - 2021

Capacity: 1.05 MW

Description: Operated under a pilot project license from FERC. Array of three axial flow turbines that generated power for the local grid. The project was successfully decommissioned having achieved a Technology Readiness Level 9.

Spiralis Energy Axial Skelter (Poole Harbor, UK, English Channel)

Dates of Operation: 2024 - ongoing

Capacity: 500 kW

Description: Biomimetic design based on the Turritella seashell. Made from recyclable 3D-printed segments with a repurposed steel frame. As tidal currents flow through the seashell-shaped design, it naturally rotates to generate power.

Fundy Ocean Research Centre for Energy (Nova Scotia, Canada, Bay of Fundy, Atlantic Ocean)

Dates of Operation: 2009 - ongoing

Capacity: 64 MW

Description: Test center for tidal energy. Supplies power to the provincial power gird.

B.2 Hydrokinetic Wave Generation Projects

AltaSea EcoWave Power Gibraltar Pilot (Gibraltar, UK, Strait of Gibraltar)

Dates of Operation: 2016 - 2022

Capacity: 100 kW

Description: Onshore point absorber attached to an existing jetty. Consists of floaters, which rise and fall with the up and down motion of ocean waves. Connect to the floaters is a linear hydraulic actuator which when moved pressurizes hydraulic fluid. This pressurized fluid is sent to a shoreside power station where it is used to drive a rotary generator to produce electricity. Supplied power to the national grid. The Gibraltar floaters have been moved to Los Angeles.

AltaSea Eco Wave Power (Port of Los Angeles, California, Pacific Ocean)

Dates of Operation: 2020 - ongoing

Capacity: 100 kW

Description: Pilot project to install eight wave energy floaters on the piles of an existing concrete wharf. System includes an energy conversion unit, which converts wave energy into hydraulic cylinder motion, producing pressurized fluid used to drive a generator and produce electricity.

PacWave South (Oregon, Pacific Ocean)

Dates of Operation: 2021 - ongoing

Capacity: 20 MW

Description: Grid-connected wave energy test facility operating under a FERC license. Able to accommodate up to 20 wave energy converters.

Penghu Aquaculture and Wave Energy Platform (Guangdong, China, Pacific Ocean)

Dates of Operation: 2019 - ongoing

Capacity: 60 kW

Description: Combined point absorber and aquaculture platform. Power generated supports the aquaculture operation.

Biscay Marine Energy Platform, Mutriku Area (Mutriku, Basque Country, Spain, Atlantic Ocean)

Dates of Operation: 2011 - ongoing

Capacity: 296 kW

Description: Oscillating water column wave energy converter mounted into a harbor breakwater. Supplies electricity to the local grid.

Lysekil Wave Energy Site (Lysekil, Sweden, North Sea, Atlantic Ocean)

Dates of Operation: 2004 - ongoing

Capacity: 1000 kW

Description: Wave energy test site that accommodates up to 20 wave energy converters. Supplies power to the local grid.

Wave Hub (Cornwall, UK, Atlantic Ocean)

Dates of Operation: 2010 - 2021

Capacity: 2 MW

Description: Wave energy test site that supported commercial-scale wave energy converter demonstration. Power generated was supplied to the regional and national grid.

U.S. Navy Wave Energy Test Site (WETS) (Hawaii, Pacific Ocean)

Dates of Operation: 2021 - ongoing

Capacity: 100 kW

Description: Grid-connected wave energy test facility supporting commercial point absorber and oscillating water column devices. Power generated supports project operations.

CalWave X1 (California, Pacific Ocean)

Dates of Operation: 2021 - 2022

Capacity: 1 kW

Description: Single device pilot project. Fully autonomous and submerged point absorber. Power generated supported project operations.

AW-Energy Simple Underwater Generation of Renewable Energy (SURGE) 2 (Peniche, Portugal, Atlantic Ocean)

Dates of Operation: 2015 - 2021

Capacity: 350 kW

Description: Offshore single device, oscillating wave surge converter. Supplied power to the local grid via an onshore substation.

Mocean Wave Energy Converter: Blue X (Orkney Island, Scotland, North Sea, Atlantic Ocean)

Dates of Operation: 2021 - 2024

Capacity: 100 kW

Description: Wave forcing and the converters' dynamic responses leads to a motion about the hinge (called flex), which drives a power take-off mechanism that converts the kinetic energy into electricity. The WEC was successfully tested with an underwater battery storage system. Power generation stopped due to completion of the testing program for the Renewables for Subsea Power Project.

NoviOcean Hybrid Offshore Energy Converter (Sweden)

Dates of Operation: 2016 - ongoing

Capacity: 1 MW

Description: Hybrid combined wave, wind, and solar energy converter. The wave energy converter is comprised of a rectangular float and inverted hydropower plant. The inverted hydropower plant utilizes a water turbine and hydraulic cylinder to pump high-pressure water towards the turbine.

C-Power SeaRAY (Hawaii, Pacific Ocean))

Dates of Operation: 2023 - ongoing

Capacity: 1 kW

Description: Fully autonomous surface attenuator. Provides in-situ power, energy storage, and real-time data and communications. Tested to investigate at-sea charging of uncrewed underwater vehicles.

CorPower Ocean C4 (Agucadoura, Portugal, Atlantic Ocean)

Dates of Operation: 2023 - ongoing

Capacity: 300 kW

Description: Point absorber that operates with a phase control, which allows the structure to move in phase with incoming waves during operational sea states, amplifying the device motion and power capture. Power generated is exported to the national grid.

APPENDIX C:
Geodatabase Metadata

The table below provides a summary of the base layers and synthesized layers used in the geodatabase.

Layer Name	Category	Description	Link
*Base Layers**			
Annual (2017) Wind – Point	Colocation and Conflict	Offshore wind resource potential, averaged over 2017; point form Results in the geodatabase are reported on the existing 1.2 km x 1.2 km aliquot grid defined by BOEM for the Pacific coastal region. Wind speed statistics are reported at the center point of each aliquot grid. The data set delivered to BOEM is a geodatabase consisting of 14 layers. Variables starting with 'WS' are wind speeds in meters per second, those starting with 'WK' are Weibull k parameters (dimensionless), and those starting with 'WC' are Weibull c (scale) parameters [sic] in meters per second. Source: MarineCadastre	https://metadata.boem.gov/geospatial/NREL_HourlyWind_WestCoast_polysandpoints.xml
Annual (2017) Wind - Poly	Colocation and Conflict	Offshore wind resource potential, averaged over 2017; polygon form Polygons were created by creating a raster grid of the point files using the closest approximate x,y distance for a BOEM aliquot block of 0.0175 degrees, reclassifying the raster into wind classes and generating a polygon file from the reclassified raster. Source: MarineCadastre	
OceanDisposalSite_CA	Colocation and Conflict	These data show the location of available and discontinued ocean disposal sites within California state waters. Contemporary ocean disposal sites generally accept clean dredged material (sediment) collected during navigation channel improvement projects. These projects are sponsored and-or regulated by federal and state agencies. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/54193
BOEM_Pacific_Leases_CA	Colocation and Conflict	This data set contains BOEM Planning Area outlines for the BOEM Pacific Region. This layer uses the NAD 83 coordinate system. Source: BOEM	https://www.boem.gov/oil-gas-energy/mapping-and-data/pacific-cadastral-data
BeachNourishment_CA	Colocation and Conflict	Beach Nourishment projects occur throughout California. These projects can be privately, federally or state funded. This GIS dataset combines historical data compiled in the Western Carolina University Beach Nourishment Viewer database, as well as the National Beach Nourishment Database generated by the American Shore and Beach Preservation Association. The data contain attribute information on the general location of sand placement, primary funding source and funding	https://www.fisheries.noaa.gov/inport/item/66107

Layer Name	Category	Description	Link
		type, volume of sediment emplacement (in cubic yards), length of beach nourished (in feet) and cost and inflated cost for over 2,000 beach nourishment episodes dating back to 1923. Source: MarineCadastre	
Substations_CA	Colocation and Conflict	This feature class represents known electric power substations within California that are located within 20 miles of the coastline. Substations are facilities and equipment that switch, transform, or regulate electric voltage. This data set includes taps, a location where power on a transmission line is tapped by another transmission line. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66139
OilandGasPlanningAreas_CA	Colocation and Conflict	This product resulted from merging four regional datasets containing BOEM Planning Area outlines. The Submerged Lands Act (SLA) boundary, along with the Continental Shelf Boundary (CSB), the Limit of Protraction were used to complete the polygons for the Planning Areas. They are projected in WGS_1984_World_Mercator. Source: Marine Cadastre	https://www.fisheries.noaa.gov/inport/item/66160
OffshoreOilGasResourcePotential_CA	Colocation and Conflict	These data show the location of probable oil or gas geologic structures (plays) mapped within the outer continental shelf of the United States. Plays are groups of known or postulated subsurface hydrocarbon accumulations that share common geologic, geographic, and temporal properties, such as history of hydrocarbon generation, migration, reservoir development, and entrapment. Plays are displayed as two-dimensional features but may overlap vertically allowing for multiple plays in the same area. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66164
PowerPlant_CA	Colocation and Conflict	These data represent operable electric generating plants within the vicinity of the California coastline by energy source. This includes all plants that are operating, on standby, or short or long-term out of service with a combined nameplate capacity of 1 megawatt or more. The presence of a facility may indicate that power transmission infrastructure exists nearby. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66174
Wind_Planning_Areas_CA	Colocation and Conflict	This data set shows the lease blocks and sub-blocks which represent the current investigations by BOEM for new areas of interest in offshore wind energy development. For a general outline version of this layer, go to the Wind Planning Area Outlines layer. Source: MarineCadastre	https://hub.marinecadastre.gov/datasets/ad4e83ed78d24319b641ebbaf1f7298e_7/explore?location=24.536098%2C-113.514528%2C4.11
Wrecks_and_Obstructions_CA	Resources	These data are a synthesis of two sources - the NOAA Office of Coast Survey's 2016 Automated Wreck and Obstruction Information System (AWOIS), and the NOAA Electronic Navigational Charts (ENC). Features are recorded as either a wreck, wreck area, obstruction, or unknown. Source: NOAA National Ocean Service, Coastal Services Center	https://www.fisheries.noaa.gov/inport/item/70439

Layer Name	Category	Description	Link
Wastewater_Outfall_Pipes_CA	Resources	This feature class contains integrated location, identification, and permit and discharge monitoring information from the EPA Facility Registry Service (FRS) for the subset of facilities that link to the Permit Compliance System (PCS)for a subset of for coastal facilities permitted under the National Pollutant Discharge Elimination System (NPDES) module of the Integrated Compliance Information System (ICIS). Coastal proximity was determined by selecting facilities located within 20 miles of submerged areas established in the Submerged Lands Act (SLA, 43 U.S.C. sect. 1301 et seq.), 48 U.S.C. sect. 1705, or that overlapped the Exclusive Economic Zone (EEZ) for facilities in regions outside the SLA. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66210
Submarine_Cables_CA	Resources	These data depict the occurrence of submarine cables in and around California navigable waters. These data are derived from NOAA and NASCA Submarine Cable records. Cables segments logically assumed to be parts of a single cable have been combined into a single feature in this dataset. Source: MarineCadastre	https://hub.marinecadastre.gov/datasets/noaa::submarine-cables
Pipeline_Areas_CA	Resources	These data show the general location of pipelines within California state waters. In the nearshore, pipelines are routinely buried below the seabed. In the offshore, they are placed directly on the seabed. A pipeline area may contain one or more physical pipelines. 30 CFR 585.301 defines a minimum 100-foot-wide right of way grant on each side of a pipeline. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66170
OffshoreOilGasPlatform_CA	Resources	Bureau of Ocean Energy Management Pacific OCS Platforms off the coastline of California as of August 24, 2010 Source: BOEM	https://metadata.boem.gov/geospatial/pc_plat.xml
Munitions_and_Explosives_of_Concern_CA	Resources	Unexploded ordnances (UXO) are explosive weapons (bombs, bullets, shells, grenades, mines, etc.) that did not explode when they were employed and still pose a risk of detonation. This dataset represents known or possible former explosive dumping areas and UXOs. This is NOT a complete collection of unexploded ordnances on the seafloor, nor are the locations considered to be accurate. Two related datasets should be viewed in tandem: Unexploded Ordnance Locations displays known/possible individual or tightly grouped unexploded ordnances on the ocean floor and Formerly Used Defense Sites (FUDS) displays areas identified by the United States Army Corps of Engineers where unexploded ordnances may exist. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66206
Danger_Zones_and_Restricted_Areas_CA	Resources	These data represent the location of Danger Zones and Restricted Areas within coastal and marine waters, as outlined by the Code of Federal Regulations (CFR) and the Raster Navigational Charts (RNC). The CFR defines a Danger Zone as, 'A defined water area (or areas) used for target practice, bombing, rocket firing or other especially hazardous operations, normally for the armed forces. The danger zones may be closed to the public on a full-time or intermittent basis, as stated in the regulations.' The CFR defines a Restricted Area as, 'A defined water area for the	https://www.fisheries.noaa.gov/inport/item/48876

Layer Name	Category	Description	Link
		purpose of prohibiting or limiting public access to the area. Restricted areas generally provide security for Government property and/or protection to the public from the risks of damage or injury arising from the Government's use of that area.' Other features in this dataset include: Danger Area, Missile Testing Area, Naval Operations Area, Prohibited Area, Restricted Airspace, Test Area, and Torpedo Testing Area. Source: MarineCadastre	
Aquaculture_CA	Resources	These data show the location of aquaculture operations within coastal and offshore waters of California. Aquaculture types may include aquatic organisms such as fish, crustaceans, mollusks, and aquatic plants. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/53129
Principal_Ports_CA	Resources	Principal Ports are the top 150 U.S. ports based upon total annual tonnage. Variation in annual tonnage at a port may result in exclusion or inclusion on the Principal Port list. The Principal Port data contain port code, port name, and values for total, domestic, foreign, import and export tonnage. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/56124
Ocean_Observing_Sites_CA	Resources	These data show the location of ocean observing assets within California state waters, and the physical parameters generally collected at each platform or gauge. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/67000
ProtectedArea_CA	Resources	These data represent the geographic boundaries of marine and terrestrial protected areas in California. Marine features are shown for U.S. state and federal waters as well as those located within 20 miles of coastal submerged lands including hydrologically related rivers and bays. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/66176
CA_State_UTM	Boundaries	California state boundaries projected in the Universal Transverse Mercator coordinate system (UTM) Zone 10 Source: California Open Data Portal	https://data.ca.gov/dataset/ca-geographic-boundaries
Exclusive_Economic_Zone	Boundaries	Exclusive Economic Zone boundary (200 nm from shore)	
FederalandStateWaters	Boundaries	These data show the geographic representation of Federal and State Waters for the purpose of display in the MarineCadastre.gov OceanReports application. The boundary between state and federal waters was determined by consulting The Submerged Lands Act (43 U.S.C. §§ 1301 et seq.), 48 U.S.C. §§ 1705 and The Abandoned Shipwreck Act (43 U.S.C. §§ 2101). Source: Marine Cadastre	https://www.fisheries.noaa.gov/inport/item/54383
CoastalPopulatedPlaces	Boundaries	These data show the local of well-known places along the coast of the United States and its territories. Source: NOAA Office for Coastal Management	https://www.fisheries.noaa.gov/inport/item/66114

Layer Name	Category	Description	Link
IndianLand	Boundaries	This dataset depicts feature location, selected demographics, and other associated data for American Indian Reservations, Alaska Native Villages, Federally Recognized Tribal Entities, Public Domain Allotments, and off-reservation trust lands. Source: NOAA Office for Coastal Management	https://www.fisheries.noaa.gov/inport/item/48860
CoastalCounty	Boundaries	This dataset represents US counties and independent cities which have at least one coastal border and select non-coastal counties and independent cities based on proximity to estuaries and other coastal counties. Source: U.S. Census Bureau	https://www.fisheries.noaa.gov/inport/item/66112
CongressionalDistrict	Boundaries	These data depict the 117th Congressional Districts and their representatives for the United States. The boundaries and numbers shown for the congressional districts are those specified in the state laws or court orders establishing the districts within each state. Source: NOAA Office for Coastal Management	https://www.fisheries.noaa.gov/inport/item/56122
Anchorage	Transportation	Anchorages are well-defined navigable waters where a vessel may safely drop anchor. The size, shape, and conditions for use of these areas can vary widely. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/48849
TidalPowerDensity_ NorthCA_UTM	Energy	Vector of annual, depth-averaged tidal power density (W/m^2) Source: NREL's Marine Energy Atlas	https://maps.nrel.gov/marine-energy-atlas/
TidalPowerDensity_ CentralCA_UTM	Energy	Vector of annual, depth-averaged tidal power density (W/m^2) in Central California, projected in UTM Zone 10	
TidalPowerDensity_ SouthCA_UTM11	Energy	Vector of annual, depth-averaged tidal power density (W/m^2) in Southern California, projected in UTM Zone 11	
omnidirwavepower_ 2010_NorthCA_UTM	Energy	Point layer of 2010 average omnidirectional wave power (W/m), projected in UTM Zone 10 Omni-directional wave power is the energy flux arriving at a point from all directions. The units are power per unit length of wave-crest (i.e., kW/m). This data was generated using WaveWatch III and SWAN for 2010. The data was developed with funding from the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Water Power Technologies Office to improve our understanding of the U.S. wave energy resource and to provide critical information for wave energy project development and wave energy converter design. Source: NREL's Marine Energy Atlas	https://maps.nrel.gov/marine-energy-atlas/
omnidirwavepower_ 2010_CentralCA_UTM	Energy	Point layer of 2010 average omnidirectional wave power (W/m), projected in UTM Zone 10 Source: NREL's Marine Energy Atlas	
omnidirwavepower_ 2010_SouthCA_UTM11	Energy	Point layer of 2010 omnidirectional wave power (W/m), projected in UTM Zone 11 Source: NREL's Marine Energy Atlas	

Layer Name	Category	Description	Link
GSHHS_Shoreline_CA	Bathymetry	California shoreline	
BathymetryContours	Bathymetry	These data show bathymetric contours (isobaths) that help characterize the general physiographic patterns of the seafloor. Contour intervals are every 10 m from zero to -100 m, every 25 m from -100 m to -500 m, and every 100 m from -500 m to full depth. The DEM utilized was the Global Multi-Resolution Topography Synthesis which is a multi-resolution gridded global Digital Elevation Model that includes cleaned processed ship-based multibeam sonar data at their full spatial resolution (approximately 100 m in the deep sea. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/54364
Gebco_bathy_clipped	Bathymetry	Global raster layer of water depths Source: The General Bathymetric Chart of the Oceans	https://download.gebco.net/
*Synthesized Layers**			
CA_Boundaries_UTM	Boundaries	California waters, split into three sections, north to south, and projected in UTM Zone 10	
North_Central_EZ	Conflict and Colocation	Combined potentially constrained area for North and Central California, projected in UTM Zone 10	
South_EZ	Conflict and Colocation	Combined potentially constrained area for Southern California, projected in UTM Zone 11	
TidalPowerDensity_NorthCA_Binned_UTM	Energy	Polygon feature of tidal power groupings by power density for Northern California in UTM Zone 10	
TidalPowerDensity_CentralCA_Binned_UTM	Energy	Polygon feature of tidal power groupings by power density for Central California in UTM Zone 10	
TidalPowerDensity_SouthCA_Binned_UTM11	Energy	Polygon feature of tidal power groupings by power density for Southern California in UTM Zone 11	
omnidirwavepower_2010_NorthCA_Binned_UTM_Area_Clip	Energy	Polygon feature of wave power groupings by power density for Northern California projected in UTM Zone 10	
omnidirwavepower_2010_CentralCA_Binned_UTM_Area	Energy	Polygon feature of wave power groupings by power density for Central California projected in UTM Zone 10	
omnidirewavepower_2010_SouthCA_Binned_UTM11_Area	Energy	Polygon feature of wave power groupings by power density for Southern California projected in UTM Zone 11	

Layer Name	Category	Description	Link
Additional Context Layers (in Geodatabase but not mapped)*			
AIS Vessel Tracks	Conflict and Colocation	A vessel track shows the location and characteristics of commercial and recreational boats as a sequence of positions transmitted by an Automatic Identification System (AIS). AIS signals are susceptible to interference, and this can result in a gap within a vessel track. The distribution, type, and frequency of vessel tracks are a useful aid to understanding the risk of conflicting uses within a certain geographic area. The vessel track positions in this data set are collected and recorded from land-based antennas as part of a national network operated by the U.S. Coast Guard. Source: MarineCadastre	https://www.fisheries.noaa.gov/inport/item/72958