Test Plan

Environmental Compliance Framework for Floating Tidal Turbines in High Latitude US Waters

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1 Introduction to the Project

Orbital Marine Power (Orbital) is seeking to deploy their floating tidal technology in US waters and has considered the possibility of deploying in temperate waters including the Pacific Northwest (PNW) and the Western Passage, Maine. It has become apparent that some of the most promising tidal sites in the US are located in high latitudes, within the State of Alaska. Within the state, the most likely sites for grid-scale tidal energy are in Cook Inlet, with the largest city (Anchorage) located on the shores, ready and able to absorb the electrical output of a commercial scale tidal development.

Like all potential marine energy deployment sites, characterizing the site, understanding the environmental interactions with floating tidal technology, and mapping a pathway towards regulatory acceptance will be needed to site and permit a tidal development in Cook Inlet.

A previous TEAMER investment allowed Pacific Northwest National Laboratory (PNNL) to develop a framework to select environmentally compliant sites. The same framework is proposed for application here, within the very different environment of Cook Inlet, such as sea ice and seasonal variabilities of sea water temperature.

The report is based on a modeling analysis, a desk-top review and analysis, focusing on the characteristics of the tidal technology and environmental monitoring information on the marine animals and habitats that are specific to high latitudes, particularly those that are endemic to Cook Inlet. The analysis describes the state and federal authorizations required for deploying a floating tidal energy technology, with an emphasis on how they differ from those in Washington/Oregon and Maine. Environmentally compliant sites within Cook Inlet will be selected based on environmental, logistical, and regulatory criteria. Recommendations on monitoring needs and adaptive management practices will be provided. The need to acquire social acceptance for the Orbital technology will also be explored and general recommendations prepared to encourage the best acceptance in the communities of interest. The environmentally compliant sites are overlaid with the tidal currents and logistic details that forms the most likely sites for prospecting for tidal energy deployments.

2 Roles and Responsibilities of Project Participants

2.1 Applicant Responsibilities and Tasks Performed

Orbital provided information relating specifically to the Orbital floating tidal technology to aid with the development of the environmental compliance framework.

2.2 Network Facility Responsibilities and Tasks Performed

PNNL was responsible for the desk-based review of available environmental data and appropriate environmental monitoring and adaptive management options and will examine necessary compliance with authorizations to deploy the tidal technology, driven by the characteristics of the Orbital floating tidal technology. PNNL assessed and made recommendations for acquiring social acceptance for the technology, select environmental compliant sites, and provide recommendations on mitigation and monitoring needs.

3 PROJECT OBJECTIVES

At present there are no consistent methodologies to enable site selection and attain legal and social acceptance for floating tidal turbines in high latitudes in the US. The lack of methodologies can lead to costly development expenditures on projects that do progress due to regulatory issues. This project will follow the previous study that took initial steps in developing a site selection framework based on environmental compliance and recommendations for deploying floating tidal technology projects in the PNW and Western Passage of Maine, with an emphasis on the differences in species and habitats in high latitudes.

Like the previous project, this project considered elements such as tidal resource characteristics (including maximum current, velocity profile, power density, tidal asymmetry, tidal flux, and turbulence), sea ice, turbine length, rotor swept area, tip speed ratio, hub height, mooring configuration, marine mammals, sea birds, fish, and environmental monitoring campaigns. The project provides recommendations on adapting the tidal technology to address environmental compliance; high level design of an environmental data collection campaign to provide further certainty of achieving environmental compliance; and social acceptance.

4 TEST FACILITY, EQUIPMENT, SOFTWARE, AND TECHNICAL EXPERTISE

This project is comprised of a high-resolution tidal hydrodynamic modeling analysis, a desk-based review that will use subject matter expertise at PNNL to achieve the project objectives and provide recommendations to Orbital. The basis for the model simulations and environmental review are drawn from PNNL experience, and previous research developed as part of IEA OES-Environmental (formerly Annex IV) and other marine renewable energy (MRE) projects.

5 TEST OR ANALYSIS ARTICLE DESCRIPTION

Orbital's tidal technology is a floating tidal stream energy generator. A cylindrical floating steel superstructure, which houses power conversion and auxiliary systems, provides reference and attachment for two leg structures with nacelles mounted at their ends. The leg structures have hinge attachments to the superstructure such that, with an actuation system, they can be lowered to position the nacelles and contra-rotating rotors in the optimal part of the tidal stream resource to generate power or be raised to bring the legs, nacelles, and rotors to the surface for the purpose of servicing and turbine towing. Station keeping is provided to the superstructure via a multi-anchor catenary mooring system consisting of rope tethers, mooring chain, and anchors. Power is exported from the turbine via a dynamic cable from the superstructure to the seabed where it connects to seabed static cabling infrastructure that exports power ashore.

The technology has been developed to 2MW, including the world's most powerful tidal turbine, the SR2000 and upcoming O2 2MW.

6 Work Plan

6.1 Experimental Setup, Data Acquisition System, and Instrumentation

Task 1.0: Description of the technology

Based on information provided by Orbital, the characteristics of the Orbital floating tidal technology have been described. Characteristics of interest include the length of the turbine, blade size and width, rotor swept area, tip speed ratio, and configuration of mooring lines. The description of the technology and requirements for deployment (e.g., distance to shore, bathymetry) were documented and used to evaluate the regulatory and environmental mitigation needs in the following tasks, particularly as they apply to the waters and marine environment of Cook Inlet.

Task 2.0: Regulatory context specific to Cook Inlet

To understand the US regulatory context, particularly that which is specific to the State of Alaska, for deploying tidal turbines, pertinent federal, state, and local laws and regulations were reviewed, and strategies developed for addressing them. Applicable laws and regulations were determined as they apply in Cook Inlet. Federal and applicable state laws and regulations were delineated and summarized in a table. While few local ordinances or regulations are likely to apply specifically to tidal energy deployments, a search for applicable requirements was carried out.

Information collected under this project describes the required authorizations (law or regulation) and the cognizant government agencies for deployment of a floating tidal energy technology. Each of the laws or regulations were assessed in the context of floating tidal technologies in Cook Inlet, relevance of the authorization to MRE, and an interpretation made of how those requirements will apply specifically to Orbital devices in high latitudes.

Task 3.0: Additional requirements for floating tidal turbines, including social license

Recommendations for identifying and engaging relevant communities, including tribes, and stakeholder groups (e.g., fishers, recreational/tourism, etc.) were made, based on an assessment of the situation in Cook Inlet.

Task 4.0: Tidal modeling support of resource characterization

Cook Inlet is identified as the top tidal site for tidal energy development because of its large tidal range and strong currents in the narrow channels. The Turnagain Arm near the upper inlet has the largest tidal range in the U.S., with a mean of 9.2 m during spring tide, as well as strong currents near the entrance. The Foreland near the mid-inlet shows a large area of strong tidal currents and suitable water depth for turbine deployment. To understand the tidal hydrodynamics and assess the effects of tidal energy extraction on oceanographic processes and environmental interactions with floating tidal technology in Cook Inlet, high-resolution hydrodynamic model data for the Cook Inlet are required. Supported by DOE WPTO, PNNL has developed a preliminary tidal hydrodynamic model for the Cook Inlet. However, the model was validated with limited water level and current data for a selected simulation period (Wang and Yang, 2020). The model was forced with tides only, and other forcing mechanisms, such as wind and river discharge were not considered. Furthermore, high model grid resolution was mainly considered in the Foreland area. Therefore, it was necessary to refine the model with higher grid resolution covering areas that have potential for floating tidal technology. Wind and river discharge were included in the model refinement. Multiple model simulations were conducted for the time periods corresponding to NOAA's Acoustic Doppler Current Profilers (ADCPs) data collected in the summer months between 2005 and 2012. Extensive model validation was conducted using all 39 ADCP stations inside Cook Inlet. Model outputs will include total water level, 3D velocity field and turbulence parameters. Further data analysis, such as power density, tidal asymmetry, volume flux at selected locations calculated and analyzed to support the environmental review study and analysis.

Task 5.0: <u>Delineating areas in Cook Inlet for floating tidal technologies (including bathymetry, tidal resources, protected species and habitats)</u>

Publicly available data on bathymetry, tidal resources, sea ice, and species that are under protected status or are commercially/recreationally/culturally significant were assembled. Specific logistical constraints (such as distance to ports, distance to grid connections, or the presence of navigation channels and other infrastructure) were noted. These data were used to delineate areas of potential floating tidal technology deployment.

<u>Task 5.0</u>: <u>Assessment of environmental effects from development of marine energy devices on marine animals, seabirds, and critical habitats in Cook Inlet</u>

Regulatory processes that address the safety of marine animals and seabirds from development projects are based on the risk to those animals that may result from construction and operation of floating tidal devices. These risks were evaluated for likely deployment areas in Cook Inlet and compared to the available data.

Task 6.0: <u>Environmental data collection for initial development of floating tidal turbines, post-installation monitoring, and adaptive management</u>

Regulators may require that applicants for marine energy projects provide baseline data before construction, as well as potentially requiring environmental monitoring data around the device after construction but before operation begins. In addition, all projects will be required to carry out some level of compliance monitoring during operation. Each of these types of data collection that is likely to be required is briefly addressed here, as well as the role that adaptive management may play in acquiring regulatory approval for floating tidal turbines.

<u>Task 7.0</u>: Project management and coordination.

The project was managed under PNNL processes and standards. PNNL staff checked in with Orbital periodically, and with TEAMER representatives every two months, to report on progress and any challenges encountered.

Deliverable: A final report was developed describing what is needed to permit/license a floating tidal technology project and how those needs apply specifically to Orbital's application of their floating tidal technology in Cook Inlet.

6.2 Numerical Model Description

Model performance for simulated water level and velocity were evaluated using a set of commonly used error statistics, such as root-mean-square-error (*RMSE*), scatter index (*SI*), Bias and linear correlation coefficient (*R*).

The *RMSE* is defined as

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - M_i)^2}{N}}$$

where N is the number of observations, M_i is the measured value, and P_i is the model-predicted value.

The scatter index (*SI*) is the normalized *RMSE* with the average magnitude of measurements:

$$SI = \frac{RMSE}{\overline{|M|}}$$

The bias (*Bias*) is defined as the mean difference between model predictions and the measurements:

$$Bias = \frac{\sum_{i=1}^{N}(P_i - M_i)}{N}$$

The linear correlation coefficient (*R*) is a measure of the linear relationship between model predictions and measurements:

$$R = \frac{\sum_{i=1}^{N}\left(P_i - \overline{P}\right)\left(M_i - \overline{M}\right)}{\sqrt{\left(\sum_{i=1}^{N}\left(M_i - \overline{M}\right)^2\right)\left(\sum_{i=1}^{N}\left(P_i - \overline{P}\right)^2\right)}}$$

Water level and 3D velocity, turbulence parameters, including turbulence intensity, turbulence kinetic energy and dissipation rate were directly outputted from the model.

Because model data are available throughout the numerical domain, additional quantities of interest for tidal energy development can be calculated, including power density and vorticity (for tidal asymmetry analysis). Instantaneous tidal power density (P_t) is given as

$$P_t = \frac{1}{2}\rho U^3$$

where ρ is the water density and U is the horizontal current speed.

Vorticity is defined as the curl of the depth-average or layered horizontal velocity (u, v) and can be calculated as

$$\omega = \nabla \times V = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}.$$

Spatial maps, at both horizontal plane and vertical transects, of power density, turbulence parameters, vorticity, and flood-ebb and time-average directional asymmetries were generated to highlight the spatial gradients at various temporal scales, such as instantaneous flood and ebb tides, tidally, spring-neap period.

6.3 Test and Analysis Matrix and Schedule

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Task 1								
Task 2								
Task 3								
Task 4								
Task 5								
Task 6								
Task 7								
Deliverable								

6.4 Safety

N/A

6.5 Contingency Plans

N/A

6.6 Data Management, Processing, and Analysis

6.6.1 Data Management

Model data, both directly simulated and derived, will be stored in the PNNL PIC system. All data will be in NetCDF or ASCII format. Outputs from the project will be submitted to the PRIMRE system, (https://openei.org/wiki/PRIMRE/) as required under TEAMER.

The final report will be submitted to the appropriate portion of PRIMRE for indexing and archive.

6.6.2 Data Processing

Model results of water level, velocity and turbulence parameters were automatically outputted in NetCDF format and no post-processing was required. Additional quantities derived from the model results such as vorticity and power density, were processed using either MATLAB or Python scripts and stored in NetCDF format. For model validation, model results were interpolated at the same water depth of ADCP data for accurate model-data comparison. Because the model uses sigma-stretch coordinate, variation of sea surface and total water depth were accounted for during data processing.

6.6.3 Data Analysis

Since model results are outputted at normalized vertical layers and water depth changes over a tidal cycle, model results were interpolated to the turbine hub-height. Data analysis of model results were conducted to identify maximum current and power density regime, high gradients, both horizontally and vertically, using spatial maps of technology-independent quantities.

7 PROJECT OUTCOMES

7.1 RESULTS

○ SUMMARY

The deployment and operation of floating tidal technology in the United States requires the assessment of environmental conditions and satisfaction of all environmental permitting requirements. Cook Inlet in Alaska was chosen as the location in which to evaluate the potential for deployment of the Orbital Marine Power Ltd. floating technology. This report describes the information gathered about energy resources and logistical, regulatory, and environmental conditions for siting and deploying the technology in Cook Inlet. State and federal regulations required for deploying are defined, as well as the additional requirement for a social license, particularly as it relates to native settlements and native corporations. To evaluate the potential for siting and deployment, bathymetry and tidal stream resources are assessed, and the presence of species and critical habitats is defined. This information is then used to evaluate the potential environmental effects of floating tidal technologies in coastal waters of Cook Inlet and to define some of the optimal locations for installation of these technologies. This initial assessment of logistical, regulatory, and environmental conditions for the deployment of a floating tidal technology is a first step toward technology siting and the achievement of environmental compliance.

The tidal currents in much of Cook Inlet are substantial with several locations that are appropriate for tidal energy development at the scale of the Orbital turbines. Limitations to development were noted that included the need to carefully monitor and plan around the endangered beluga whale population segment that is resident in Cook Inlet and surrounding waters, as well as concerns for endangered whales that are occasional visitors to the area, sea otters, and Stellar sea lions. Other marine mammals are protected in the area, and essential fish habitat for salmon, scallops, crab, and groundfish must be taken into consideration. Similarly, navigation corridors and shipping lanes must be accounted for in siting turbines.

There appears to be adequate baseline data for further examination of tidal energy sites in Cook Inlet, while there will be a need to plan for post-installation monitoring around potential collision risk of marine animals with turbines, underwater noise from the turbines affecting marine animals, potential effects of electromagnetic fields (EMF) from cables, and changes in benthic and pelagic habitat, as a result of the development.

○ Introduction

This work was performed under the Testing and Access to Marine Energy Research (TEAMER) program, sponsored by the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Waterpower Technologies Office, and carried out by Pacific Northwest National Laboratory.

This report summarizes information collected to inform the deployment and operation of floating tidal technologies in Cook Inlet, Alaska. In particular, environmental data needed to inform regulatory pathways were collected to facilitate the siting and deployment of marine energy devices in this area of the United States (U.S.) where few studies have been carried out. For the purposes of this report, the O2 floating tidal technology created by Orbital Marine Power Ltd. (Orbital) was used to represent full-scale floating tidal technologies.

Information collected and analyzed for this report was derived solely from publicly available databases as well as interactions with researchers and public officials associated with those data. These data allowed the authors to delineate some preferred locations for floating tidal development and to outline those areas where development might lead to conflicts or challenges associated with vulnerable marine populations and/or other users.

The report is organized into six sections addressing the following topics: (1) Orbital's tidal technology, (2) the U.S. regulatory context for deployment of floating tidal technology, (3) additional requirements Orbital must meet in working through regulatory processes, (4) examination of areas in Cook Inlet in relation to floating tidal stream turbines, (5) an assessment of the potential environmental effects of floating tidal technologies in coastal waters of Cook Inlet, and (7) an overall assessment of the adequacy of data available for initial development of floating tidal technologies in Cook Inlet.

○ Description of the Technology

The Orbital O2 device is a floating tidal turbine hull with two rotors suspended underneath, anchored to the seafloor with mooring lines (Figure 1). The device is 74 meters (m) long and floats semi-submerged, approximately 1.5 m above the waterline and 2.3 m below the water. The device is 50 m wide, including the span of the blades underwater. The total draft of the operational device is 23.2 m. The device is anchored to the seafloor with four anchors and mooring lines; each anchor has a footprint of approximately 15 m^2, at a preferred deployment depth of 50–100 m. The watch circle for each device is

30–40 m. Orbital is expected to deploy two to four devices in an array. Additional descriptions of the device can be found at https://www.orbitalmarine.com/.

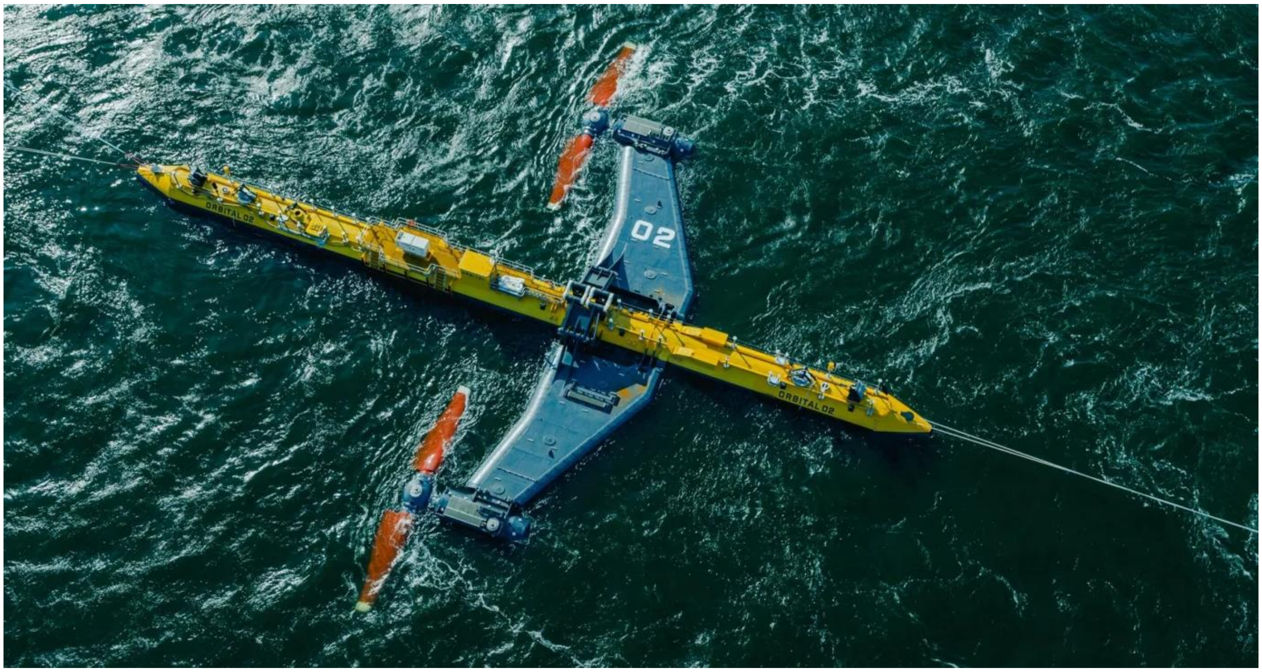

Figure 1. Orbital O2 floating tidal turbine, deployed at the European Marine Energy Center in Orkney, United Kingdom.

- Regulatory Context

Deployment and operation of the Orbital floating tidal turbine must meet federal, state, and, in some limited cases, local regulatory requirements. Descriptions of the regulatory processes (e.g., https://tethys.pnnl.gov/publications/handbook-marine-hydrokinetic-regulatory-processes) provide extensive detail to meet most marine energy regulatory needs. The services of a regulatory specialist will be beneficial as Orbital pursues deployment of its turbines in Cook Inlet in the state of Alaska. In general, however, the federal and state statutes and regulations that must be followed are summarized in Table 1, including the cognizant federal or state agencies and the primary receptors (marine animals or habitats) that occur in Cook Inlet for which the agencies are responsible.

Table 1. Federal and state statutes and regulations related to the deployment of floating tidal technology.

Jurisdiction	Regulation	Cognizant Agency	Receptor of Concern (where applicable)/Notes
Federal	Endangered Species Act, Magnuson-Stevens Conservation Act, Fish and Wildlife Coordination Act, Federal	NOAA-NMFS	Marine mammals, marine and most anadromous fish

Jurisdiction	Regulation	Cognizant Agency	Receptor of Concern (where applicable)/Notes
	Power Act, Marine Mammal Protection Act		
Federal	Endangered Species Act, Fish and Wildlife Coordination Act, Federal Power Act, Bald & Golden Eagle Protection Act, Migratory Bird Treaty Act	USFWS	Land-based and seabirds, certain species of anadromous fish, sea otters, migratory birds
Federal	Rivers and Harbors Act (Section 10), Clean Water Act (Section 404), Marine Protection and Sanctuaries Act (Section 103)	U.S. Army Corps of Engineers	Navigation
Federal	Federal Power Act, Public Utility Regulatory Policies Act, Energy Policy Act, Electric Consumers Protection Act, National Environmental Policy Act	FERC	National Environmental Policy Act process
Federal	PATON (Private Aid to Navigation)	U.S. Coast Guard	Navigation lighting and notice to mariners
State	Clean Water Act 18 AAC 70 Water quality standards	Alaska Department of Environmental Conservation	Restoration, protection, and conservation of water quality, water quantity, and aquatic habitat
State	Hydroelectric Project Authorization Title 16 Fish and Game. Critical Areas Title 5. Special Area Permit	Alaska Department of Fish and Game	Protecting fish and their habitats during construction and operation, and maintaining fish passage in all fish-bearing waterbodies.
State	Tideland Lease, Land use authorization, Right of Way	Alaska Department of Natural Resources: Division of Land, Mining, and Water	Benthic habitats. Shore-based infrastructure and crossing intertidal environments.
State	Clean Water Act Section 206	Alaska Department of Natural Resources: State Historical Preservation	Tribes with usual and accustomed fishing grounds in the area must be consulted to fulfill these requirements.
Native Corporations	Land Use Authorization Letter of Non-Objection	Native Corporations	Tribal enterprises must grant access for shore-based operations and provide a letter stating that the project does not interfere with their entry.

FERC = Federal Energy Regulatory Commission; NMFS = National Marine Fisheries Service; NOAA = National Oceanic and Atmospheric Administration; USFWS = U.S. Fish and Wildlife Service.

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○ Additional Requirements for Orbital

Orbital will be required to fulfill all federal, state, and local regulatory requirements; in addition, gaining the approval of local tribes, indigenous peoples, and native corporations is necessary to make sure their way of life and harvests are not harmed by the proposed project. Tribal nations are considered to be sovereign; they must be consulted as one would consult another nation and are not considered to be merely another group of stakeholders. In general, U.S. federal agencies will carry out any formal consultations. However, gaining the trust and agreement of local tribes, as well as tribes that have usual and accustomed fishing grounds in or around the project, is necessary to ensure a successful outcome. There are two different approaches that must be made to encompass the tribes. The tribal communities represent the values and rights of those who live and work in and around Cook Inlet. In addition, the Cook Inlet Region, Inc. (CIRI) is one of 12 land-based Alaska Native regional corporations created under the Alaska Native Claims Settlement Act (ANCSA). CIRI's regional boundaries roughly follow the traditional Dena'ina territory of south-central Alaska. CIRI was incorporated on June 8, 1972, and is owned today by a diverse group of more than 9,000 shareholders who live in Alaska and throughout the world. CIRI has a portfolio and interest in energy and infrastructure with a focus on renewable energy. Tribes with communities and interests in the Cook Inlet area include those of Athabascan, Tlingit, Haida, Tsimshian, Inupiat, Yup'ik, Alutiiq/Sugpiaq, and Aleut/Unangax descent.

Gaining social license from stakeholders in each region is also key to establishing a successful project. These stakeholders will range across those that make their livelihood from the sea to those environmentally conscious groups who seek to conserve marine resources and the environment. As is true anywhere, groups and individuals may hide their true intentions in opposing or complicating a project. The key to working through these issues is to engage local expertise and meet early and often with stakeholders and tribes.

○ Delineating Areas in Cook Inlet for Floating Tidal Technologies

Cook Inlet is located in the central Gulf of Alaska stretching 180 miles inland reaching Anchorage in south-central Alaska (Figure 2). Areas within the waters of the Cook Inlet must be assessed for tidal current speeds and resources that could support energy harvest, as well as for areas where sensitive and/or protected living organisms, the habitats that support them, and ecosystem processes might be at risk of being damaged by the marine energy technology. Determining areas of Cook Inlet that might be suitable for floating tidal technologies requires an examination of the bathymetry and tidal currents to optimize locations for power production, as well as the location and extent of infrastructure that might limit or provide opportunities for location of tidal devices and power export cables. Each of these factors is discussed in the following sections.

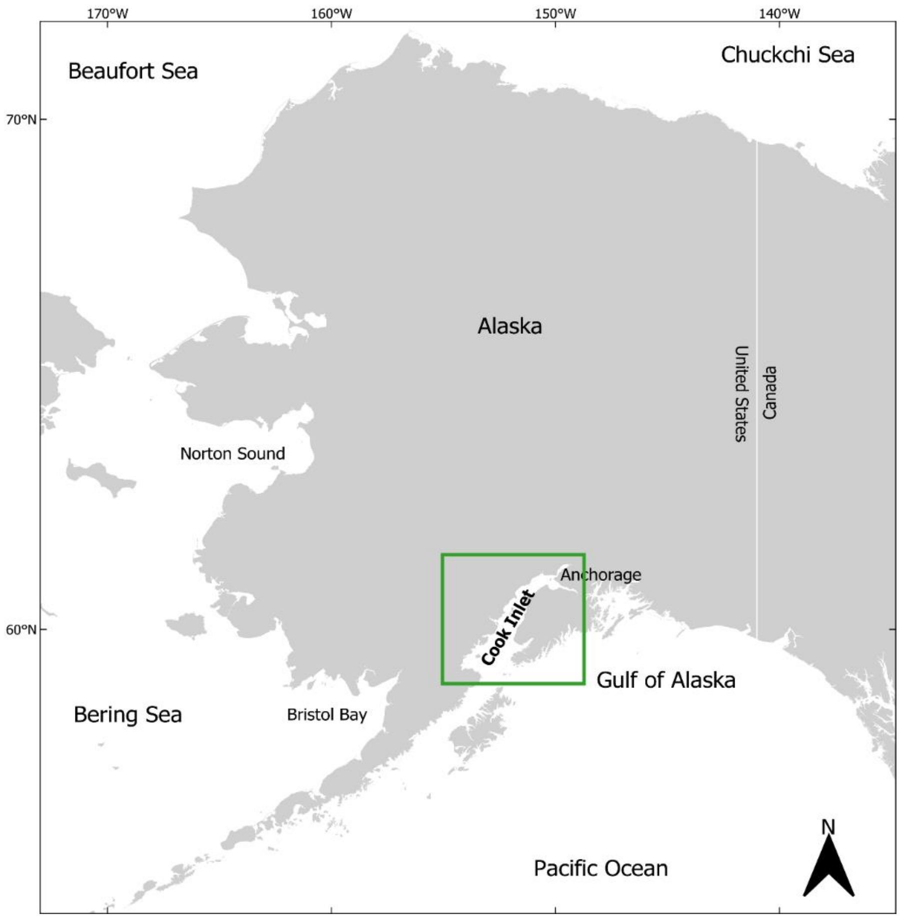


Figure 2. Map of Cook Inlet in Alaska.

- Bathymetry

The waters of Cook Inlet range in depth from 0 to 170 m, as shown by bathymetry measurements (Figure 3). Shallow waters (< 50 m) are mainly observed in the northern part of Cook Inlet, north of East and West Foreland. Deeper waters (> 50 m) are mainly observed in the central part of the inlet and the southern part of the inlet. Average and maximum depths are 29 m and 128.4 m, respectively, off Harriet Point, 32.4 m and 156.9 m between East and West Foreland, and 12.8 m and 56.1 m off Anchorage.

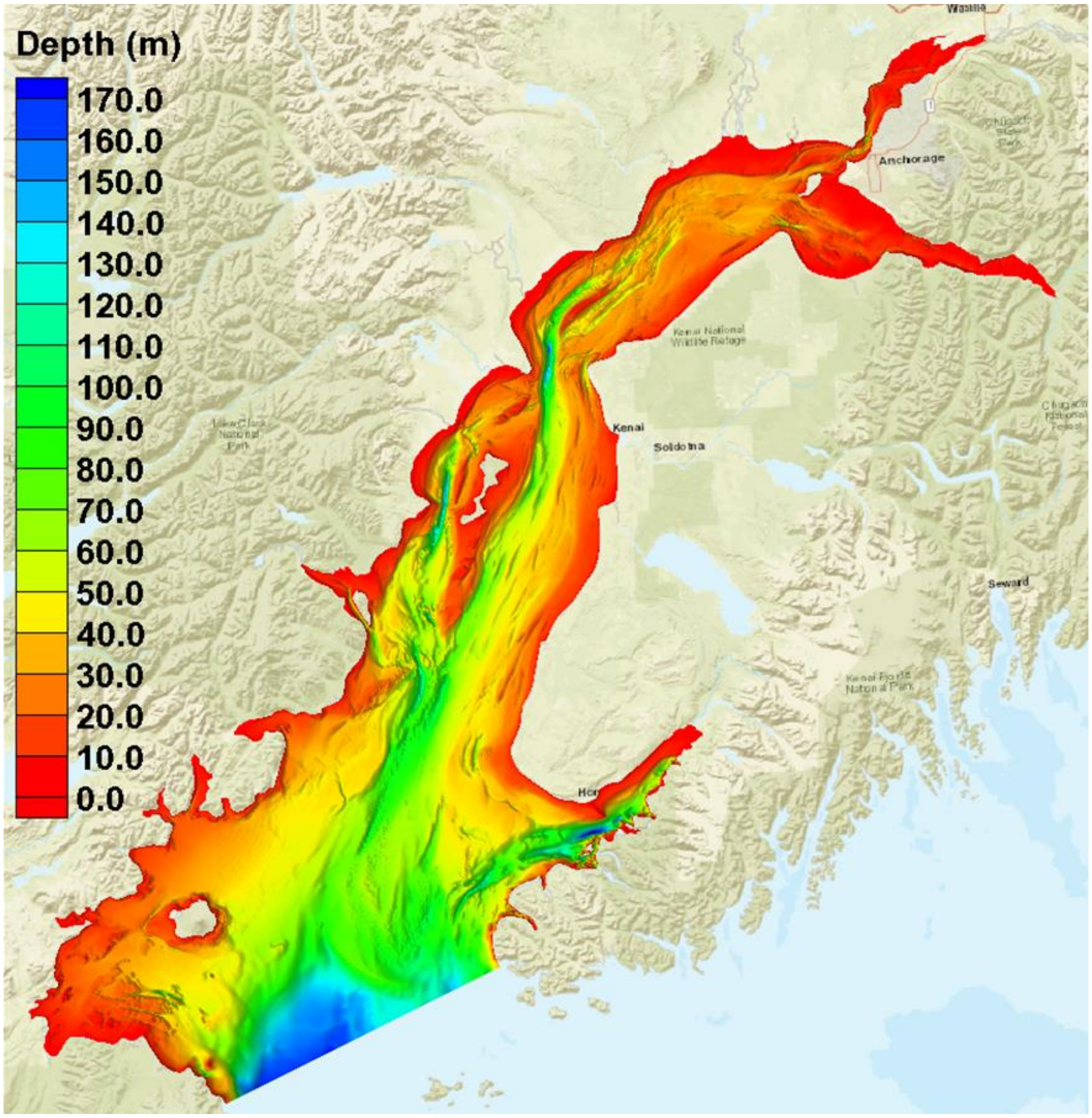


Figure 3. Bathymetry in Cook Inlet, Alaska, used for the tidal hydrodynamic model (Wang and Yang 2020).

■ Tidal Stream Energy Resources

Tidal stream energy resource characterization in Cook Inlet was assessed based on model outputs from a three-dimensional high-resolution tidal hydrodynamic model of the Cook Inlet, which was originally developed by Wang and Yang (2020). Several modifications were made in this new version of the Cook Inlet model, including refinement of the model grid in high tidal energy areas, adding river stream flow and wind forcing. An example of the refined model grid in the Foreland area is shown in Figure 4. Grid resolution was significantly refined in the areas that feature high tidal currents. The number of grid elements increased from 239,475 in the original model (Wang and Yang 2020) to 392,002 in the refined model. River discharge and sea surface wind were not considered by Wang and Yang (2020). For this study, both river discharge and wind forcing are considered and baroclinic motion is simulated. Figure 5 shows the stream flows for the major rivers discharged into Cook Inlet, including the Susitna River, Matanuska River, Knik River, and Kenai River. The largest river discharge is from Susitna River; it is greater than the river flows of the other three rivers combined. Wind data were obtained from the National Centers Environmental Prediction (NCEP) version 2 coupled forecast system model (CFSv2). Wind patterns in Cook Inlet are very dynamic, exhibiting strong spatial and temporal variabilities (Figure 6).

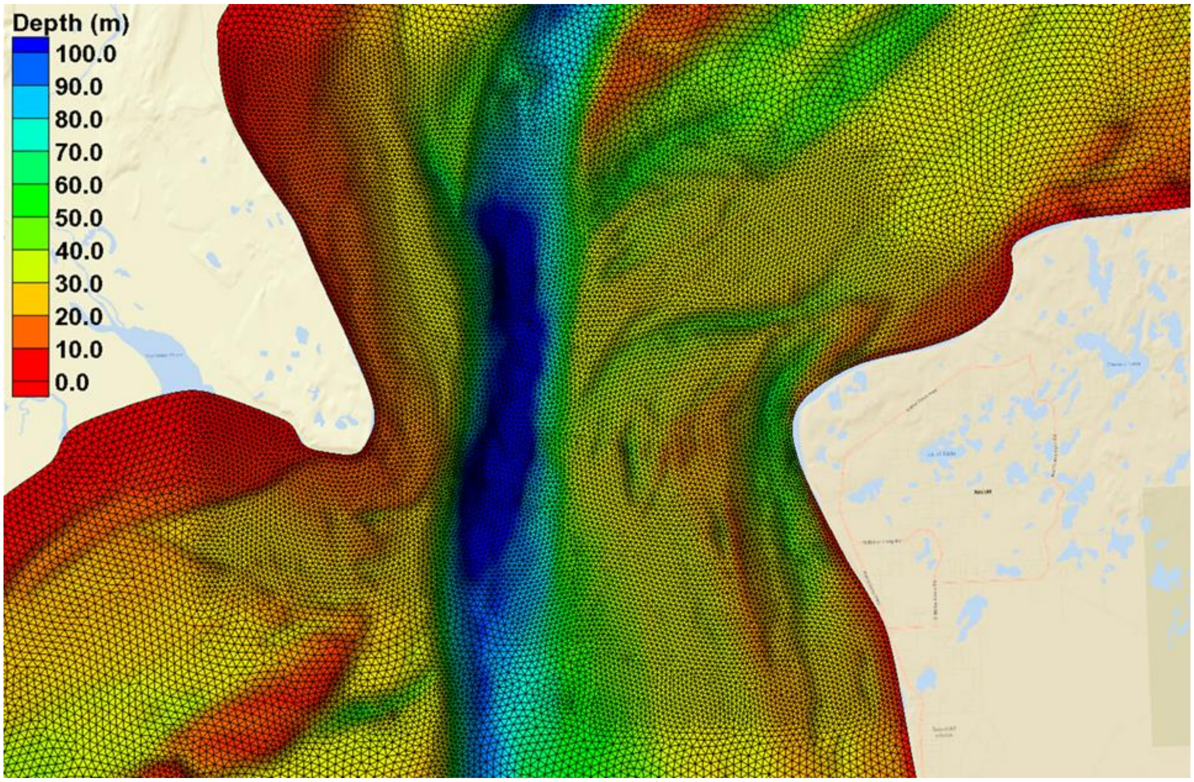


Figure 4. Refined model grid bathymetry in the area of Foreland in Cook Inlet, Alaska.

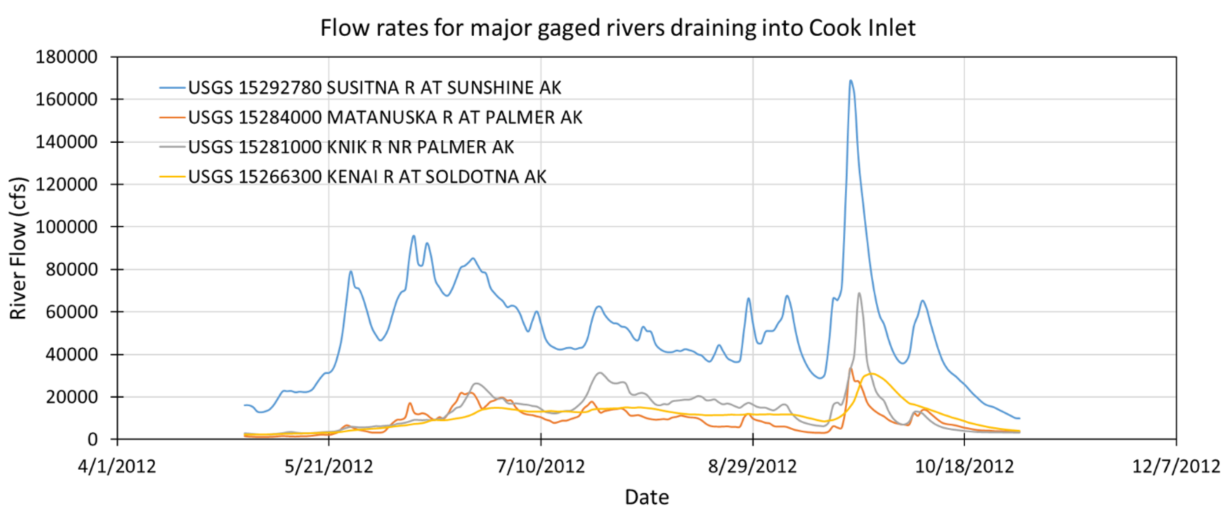


Figure 5. River flows from Susitna River, Matanuska River, Knik River, and Kenai River for the period of 5/1/2012–10/18/2012.

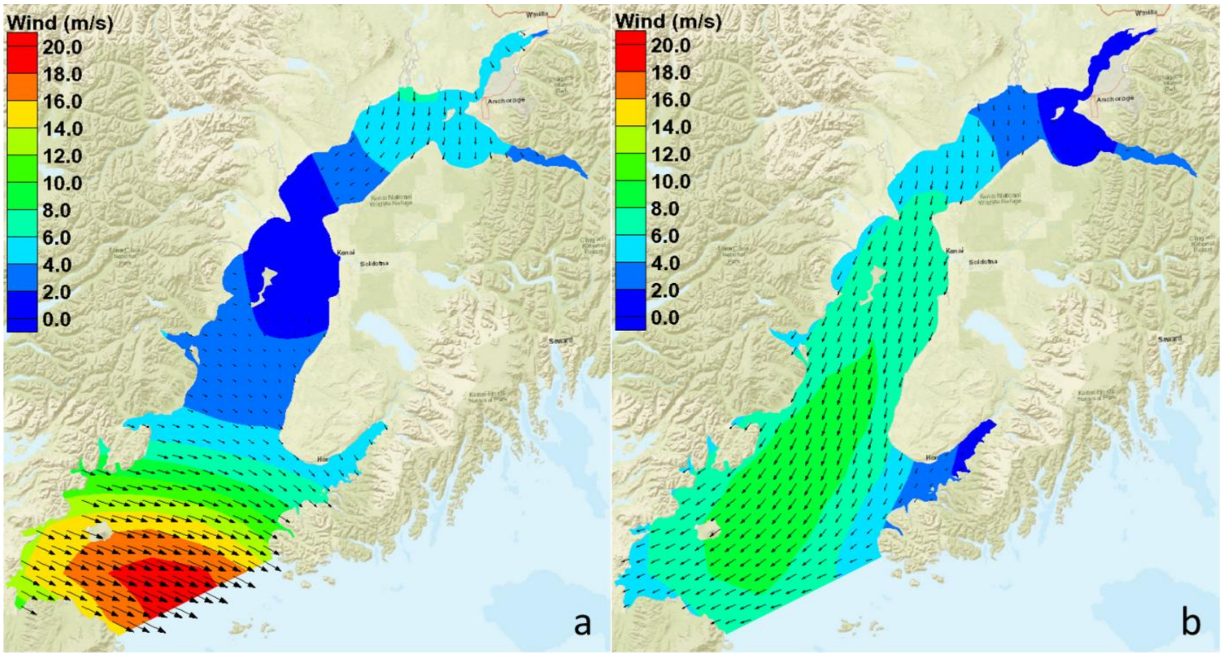


Figure 6. Instantaneous CFSV2 sea surface wind speed at (a) 00:00:00 GMT May 2, 2012 and (b) 00:00:00 GMT May 6, 2012.

Tidal stream energy resources can best be represented by the tidal power density, which is proportional to the cube of tidal currents. Strongest mean tidal power densities are observed in the Upper Cook Inlet, especially the Foreland area due to the effect of the flow being forced through the narrow channel (Figure 7). Locations off Anchorage, Harriet Point, and between East and West Foreland have great tidal energy resources that should be considered for harvesting. A zoomed-in image of the depth-averaged mean power density for the Foreland area is shown in Figure 8a; it shows strong power density across almost the entire cross-sectional area. The highest power density occurs in East Foreland, where the maximum depth-averaged mean power density is above 7 kW/m^2. Because floating tidal turbines are the focus of this study, power density distribution at a certain water depth below the surface is of interest. For example, Figure 8b shows the power density distribution and the suitable area for a 30 m diameter tidal turbine with a hub height of 18 m below sea surface and 3 m surface clearance. Clearly, even though East Foreland has the highest power density and strongest tidal currents, the area suitable for deployment is limited because of the shallow water depth. Recommended by International Electrotechnical Commission, the Annual Energy Production (AEP) is the ultimate parameter for tidal energy resource characterization and assessment. Simulated AEP distribution at 18 m depth in the Foreland area is shown in Figure 9. In the central channel, the AEP is greater than 6 GWh/yr and East Foreland has the highest AEP, greater than 7 GWh/yr. AEP is calculated based on the following parameters:

- water density – 1,025 kg/m^3;
- number of rotors = 1;
- rotor diameter = 30 m;
- rotor hub depth = 18 m below surface;
- minimum depth required = 40 m;
- cut-in speed = 0.5 m/s;

- rated speed = 2.046 m/s (resulting in 2 MW electrical power output at rated speed); and
- turbine efficiency = 0.45*0.86.

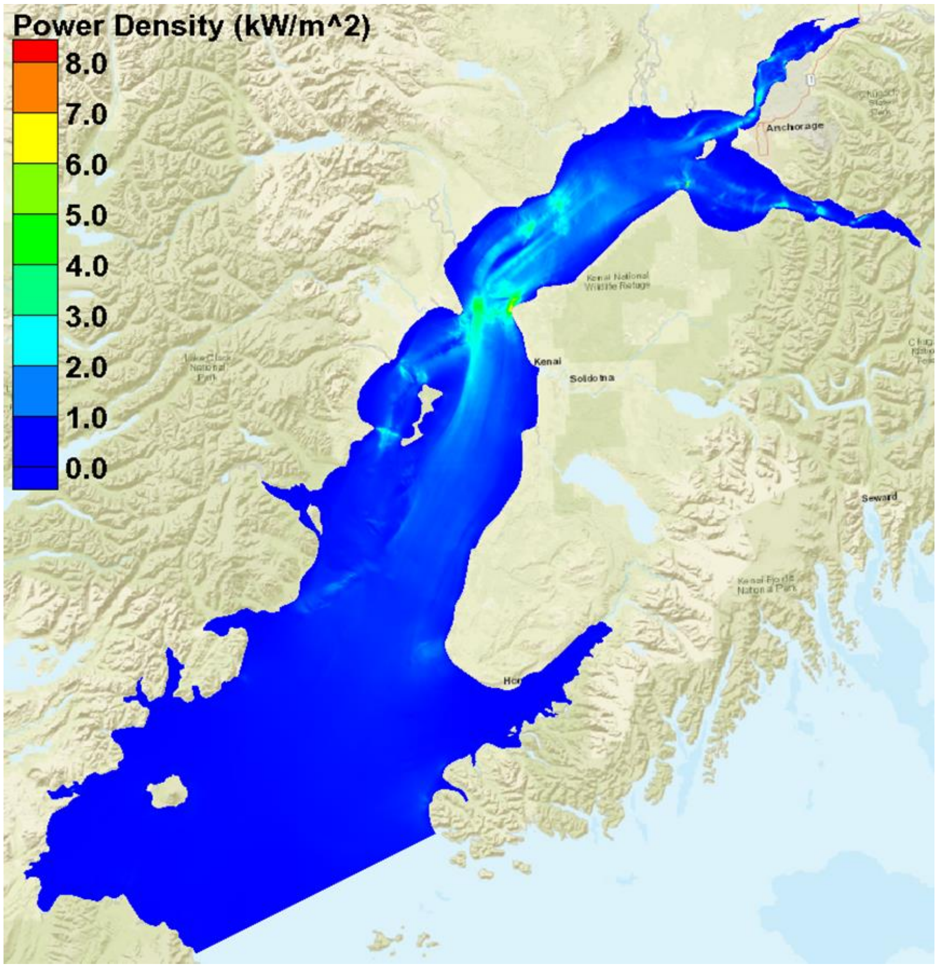


Figure 7. Simulated depth-averaged mean tidal power density in Cook Inlet.

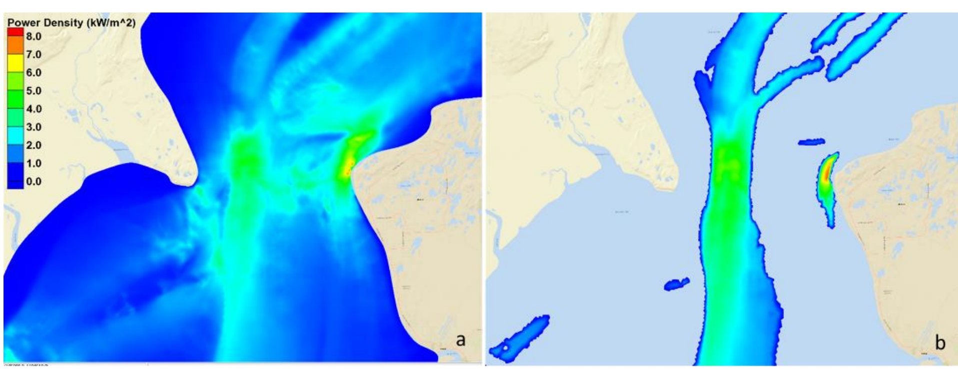


Figure 8. Depth-averaged mean tidal power density in (a) the Foreland area and (b) the mean power density at 18 m depth below the sea surface.

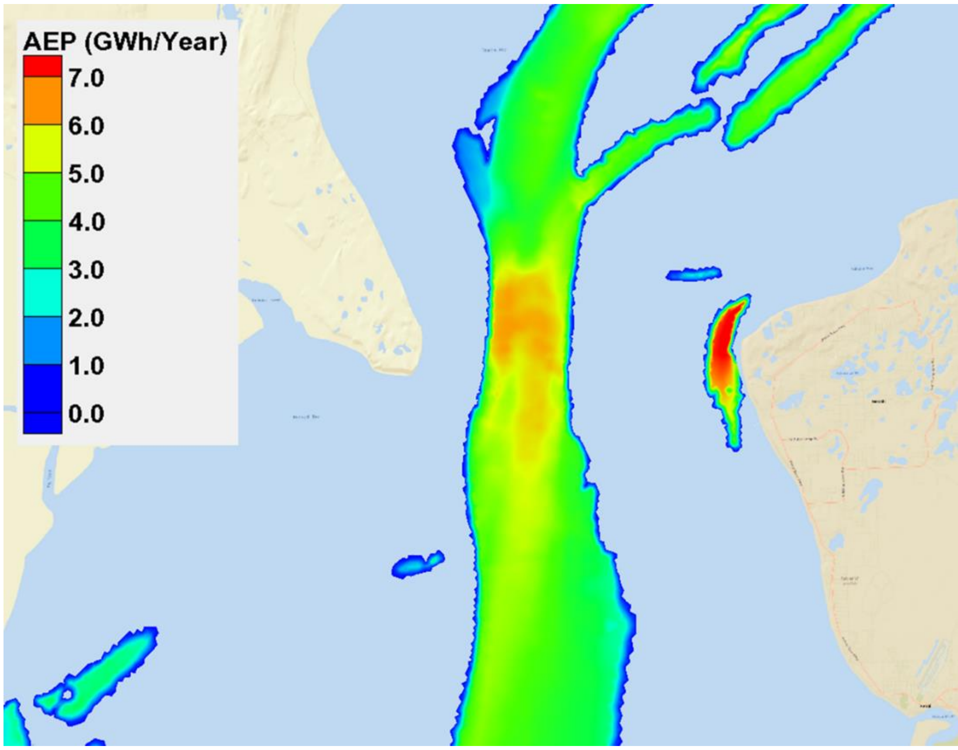


Figure 9. Simulated AEP distribution at 18 m water depth below sea surface in Foreland, Alaska.

■ Protected and Sensitive Marine Animals and Habitats in Cook Inlet

The most stringent and challenging regulatory processes for marine energy in the U.S. are associated with the protection of species and habitats. These processes are driven by the presence of endangered or threatened species, species protected under other statutes, and habitats that support a wide range of species. The species and habitats that will drive placement of a tidal project in Cook Inlet are described here, and discussed under each of the specific protection mechanisms of importance.

- *Species and Critical Habitats in Cook Inlet*

The following marine species are U.S. federally listed as threatened or endangered and/or listed by the state of Alaska. Each of these species is known to be present in Cook Inlet year-round or seasonally (Table 2). In some cases, segments of populations are protected under special programs. The major concerns are for listed marine mammals, particularly cetaceans (whales), while the state-listed population segment of the Northern sea otter population and a federally-listed segment of the Stellar sea lion population are also present in Cook Inlet. The population segment of beluga whales is likely to present the greatest concern for tidal energy development in Cook Inlet.

Table 2. Federal or State Status (threatened, endangered) of the marine species that can potentially occur in Cook Inlet.

	Threatened		Endangered		
Species	**State of Alaska**	**Federal**	**State of Alaska**	**Federal**	**Notes**
Beluga Whale (*Delphinapterus leucas*)				X	Distinct population segment in Cook Inlet (73 FR 62919); designated critical habitat in Cook Inlet (76 FR 20179)
Blue Whale (*Balaenoptera musculus*)			X	X	(35 FR 18319)
Fin Whale (*Balaenoptera physalus*)				X	(83 FR 4032)
Gray Whale (*Eschrichtius robustus*)				X	Western north Pacific distinct population segment (83 FR 4032)
Humpback Whale (*Megaptera novaeangliae*)			X	X	(81 FR 62259)
Killer Whale (*Orcinus orca*)				X	
North Pacific Right Whale (*Eubalaena japonica*)				X	(73 FR 12024); designated critical habitat in the Gulf of Alaska (73 FR 19000)
Northern Sea Otter (*Enhydra lutris kenyoni*)		X			Southwest Alaska distinct population segment (74 FR 51988)
Sei Whale (*Balaenoptera borealis*)				X	(35 FR 12222)
Sperm Whale (*Physeter macrocephalus*)				X	(35 FR 18319)
Steller Sea Lion (*Eumetopias jubatus*)				X	Western distinct population segment (64 FR 14052); designated critical habitat (79 FR 46392)

- *Endangered Species in Cook Inlet*

Species of concern in Cook Inlet that are listed as endangered under the Endangered Species Act of 1973 (ESA) are described and their distributions are presented here.

- Beluga Whale

Figure 10. Beluga whale (NOAA Fisheries).

Beluga whales (*Delphinapterus leucas;* Figure 10) inhabit arctic and subarctic waters where they can move between saltwater and freshwater. They are usually found in shallow coastal waters during the summer months. During other seasons, they inhabit deep water areas. Belugas also seasonally inhabit estuaries and large river deltas. They return to their birth areas along the coast each summer to hunt, breed, and calve. Belugas grow up to 5 m long, weigh more than a ton on average, and live up to 90 years. They are social animals that hunt, migrate, and interact in groups. All beluga whale populations are protected under the Marine Mammal Protection Act (MMPA). The beluga whale distinct population segment (DPS) in Cook Inlet is one of five populations of Beluga in Alaska and it is listed as endangered under the ESA. The Cook Inlet stock is also designated as depleted under the MMPA. The critical habitat of beluga whale in Cook Inlet is shown in Figure 11.

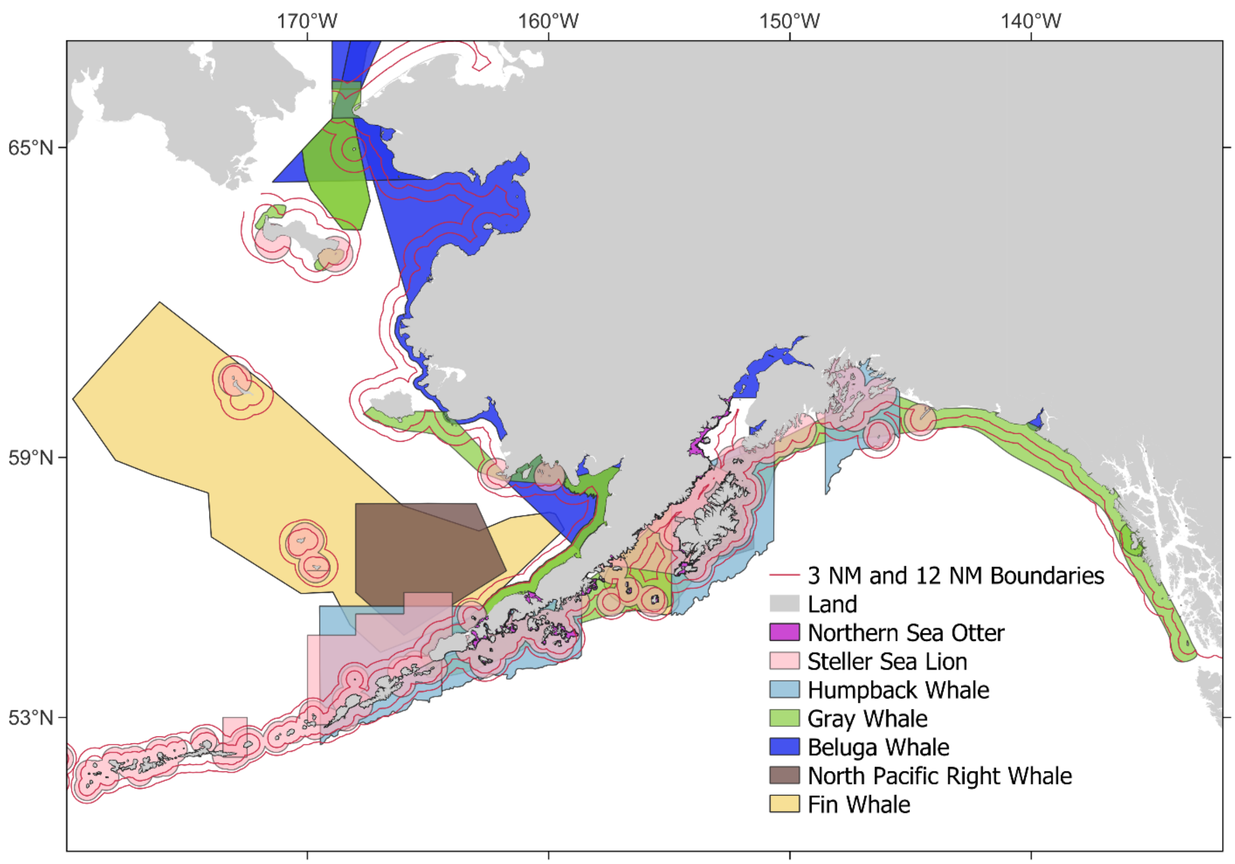


Figure 11. Critical habitat of ESA-listed marine mammals in southwest Alaska (Note: Data for blue whales, sei whales, and sperm whales were not available).

- Blue Whale

Blue whales (*Balaenoptera musculus*) are the largest whale and animal ever known to exist. They are long and sleek and have a mottled blue-gray coloration (Figure 12). They weigh up to 150 T, measure up to 33 m long (females being larger than males), and are estimated to live up to 90 years. Blue whales inhabit all the oceans except the Arctic. They migrate in summer toward their feeding grounds and in winter toward

Figure 12. Blue whale (NOAA Fisheries).

their breeding grounds. Along the eastern Pacific coast, they are observed off Mexico and Central America in winter, and off the West Coast and in the Gulf of Alaska in summer. Calving areas tend to be located in the warmer waters in the Gulf of California. Blue whales, designated as endangered under the ESA, are protected throughout their range under the MMPA and are designated as being depleted under the MMPA throughout their range. Although blue whales are not likely to occur in Cook Inlet, their presence cannot be entirely ruled out.

- Fin Whale

Figure 13. Fin whale (NOAA Fisheries).

Fin whales (*Balaenoptera physalus*) are the second largest whale and are found in all oceans worldwide. They have pointed heads and streamlined bodies that are darker on the dorsal side and white on the underside; many of them have streaks of white trailing up their sides (Figure 13). Fin whales are designated as endangered under the ESA and are protected throughout their range under the MMPA, under which they are designated as being depleted. Fin whales feed in Alaska waters during the spring and summer and migrate toward warmer water breeding and calving areas in fall and winter. In Alaska, fin whales are found in the western Chukchi Sea, the Bering Sea, throughout the Gulf of Alaska, and in lower Cook Inlet (see Figure 11 for the location of their critical habitat).

- Gray Whale

Figure 14. Gray whale (NOAA Fisheries).

Gray whales (*Eschrichtius robustus*) have a mottled gray body with broad pectoral flippers and dorsal humps (Figure 14) and are found only in the North Pacific Ocean. They weigh up to 27 T, measure 13 to 15 m, and move into shallow coastal waters to feed. Gray whales migrate south in the fall to breed off the coast of Baja California. In summer, most of the Eastern North Pacific stock migrates to the northern Bering and Chukchi Seas and along the U.S. West Coast to feed. Western North Pacific stocks typically migrate along the coast of eastern Asia, but satellite tagging has shown individuals from eastern populations migrating across the Gulf of Alaska and along the west coast of North America as far south as Mexico. The western North Pacific DPS is listed as endangered under the ESA and depleted under the MMPA. Both western and eastern North Pacific stocks are MMPA protected throughout their range. The critical habitat for gray whale is shown in Figure 11.

- Humpback Whale

Figure 15. Humpback whale (NOAA Fisheries).

Humpback whales (*Megaptera novaeangliae*) live in all oceans of the world, migrating up to 8,000 km. They may weigh up to 30 T, measure up to 18 m in length, and have a lifespan of 80 to 90 years. Their bodies are primarily black with differing amounts of white on their pectoral fins, bellies, and under their tails (Figure 15). Humpback whales feed on plankton, crustaceans, and small fish off the

U.S. West Coast. In the North Pacific, there are four populations of humpback whales. The Mexico DPS breeds along the Pacific coast of Mexico and feeds between California and the Aleutian Islands (Alaska). The Central American DPS breeds along the coast of Central America and feeds off the west coast of the United States and British Columbia (Canada). The Hawaii DPS breeds off Hawaii and feeds in southeast Alaska and British Columbia. Finally, the western North Pacific DPS breeds off the coast of west Asia and feeds in the west Bering Sea and off the coast of Russia and the Aleutian Islands. The Mexico DPS, the Central America DPS, and the western North Pacific DPS are listed as endangered under the ESA. Humpback whales are also protected under the MMPA throughout their range. The western North Pacific stock, central North Pacific stock, and California/Oregon/Washington stock are designated as depleted. Humpback whales may be seen at any time of the year in Alaska, but most individuals spend the winter in temperate or tropical waters. In the spring, they migrate back to Alaska to feed. In southwest Alaska, humpback whales are mainly located around Kodiak, the Barren Islands at the mouth of Cook Inlet, and around the Aleutian Islands (see Figure 11 for the location of their critical habitat).

- Killer Whale

Figure 16. Killer whale (NOAA Fisheries).

Killer whale (*Orcinus orca*), often referred to as orca, is the largest member of the dolphin family, weighing up to 4 T and measuring up to 10 m in length. Killer whales live 30 to 90 years, are considered to be the ocean's top predators, and can be found in every ocean worldwide, living in higher concentrations near the poles. Killer whales are largely black on the top with white undersides and white patches near the eyes, and they have a large dorsal fin (Figure 16. Resident, transient, and offshore killer whales are recognized in the northeastern Pacific Ocean. In the U.S., resident killer whales are distributed from Alaska to California, and include four distinct populations of resident killer whales: Southern, Northern, Southern Alaska, and Western Alaska (70 FR 69903). Killer whales in Alaskan waters are typically found along the continental shelf stretching from southeastern Alaska to the Aleutian Islands, migrating north through the Bearing Strait toward the Chukchi and Beaufort Seas during spring and back in the fall. Killer whales are MMPA protected throughout their range. The Southern Resident DPS is classified as endangered under the ESA and the transient population as depleted under the MMPA.

- North Pacific Right Whale

Figure 17. North Pacific right whale (NOAA Fisheries).

North Pacific right whales (*Eubalaena japonica*) are among the rarest of all large whales. They are one of three right whale species (Atlantic Right whales exist in the north Atlantic Ocean and Southern Right whales in southern hemisphere waters). Northern Pacific Right whales weigh up to 80 T, measure 13 to 15 m long, and live for more than 70 years. They have large, round, black bodies with no dorsal fin and patches of raised rough skin scattered around their heads (Figure 17). Their migration patterns are not well known, but they are believed to feed during summer in high latitudes and migrate toward temperate regions during winter. No calving grounds are known to exist in the eastern North

Pacific, but other species of right whales are known to have their young in shallow coastal waters. In Alaska, the population off the west coast is only represented by a few individuals. They are protected throughout their range under the MMPA and are also designated as depleted under the MMPA. Most North Pacific Right whales are found in the central North Pacific and the Bering Sea. In 2006, critical habitat was designated for the species, which includes a large area in the Bering Sea and a relatively small area in the Gulf of Alaska just south of Kodiak Island (Figure 11).

- Sei Whale

Sei whales (*Balaenoptera borealis*) are sleek whales with streamlined bodies (Figure 18). They weigh up to 45 T, measure from 12 to 18 m long, and live for 50 to 70 years. Sei whales inhabit subtropical and temperate ocean waters with a preference for mid-latitude temperatures. Their migration patterns are not well known but they are typically observed in deep ocean waters. Sei whales in the Pacific Ocean are observed from California to the Gulf of Alaska in the summer, and in winter, from central California to the equator. Sei whales are categorized as endangered under the ESA and depleted under the MMPA throughout their range. They are protected throughout their range under the MMPA.

Figure 18. Sei whale (NOAA Fisheries).

- Sperm Whale

Sperm whales (*Physeter macrocephalus*) are found in the deep ocean, around the world. They are the largest of all toothed whales; females weigh 14 T and measure up to 12 m and males weigh 40 T and measure up to 16 m, and have a lifespan of 60 years. Sperm whales are gray with some white patches on their undersides. They have large heads that make up about a third of their body, a small lower jaw set with large teeth, small flippers, and a small dorsal fin (Figure 19). Their migration patterns are not well understood and vary by life history and sex. Female sperm whales and calves tend to remain in tropical waters throughout the year, whereas adult males inhabiting mid-latitudes generally move toward the poles in summer. They are protected throughout their range under the MMPA, and are designated as endangered under the ESA and as depleted under the MMPA throughout their range.

Figure 19. Sperm whale (NOAA Fisheries).

- Stellar Sea Lion

Stellar sea lion (*Eumetopias jubatus*) is the largest member of the "eared" seals family (Figure 20). Adult males measure up to 3.3 m in length and can weigh up to 1,100 kg. Adult females are around 2.6 m and weigh up to 360 kg. In Alaska, Steller sea lions are protected throughout their range under the MMPA. The western DPS is listed as endangered under the ESA and is designated as depleted under the MMPA. The population of the western DPS has decreased by approximately 77 to 81 percent from the 1970s to the early 2000s. They live along the coasts of the Aleutian Islands and Bering Sea (see Figure 11 for their critical habitat). During the nonbreeding season, they venture into the deeper continental slope and pelagic waters.

Figure 20. Stellar sea lion (NOAA Fisheries).

- *Threatened Species*

The description and distribution patterns of the species listed as threatened under the ESA are presented below.

- Northern Sea Otter

Northern sea otters (*Enhydra lutris kenyoni*) are large members of the weasel family with dense brown-black fur and webbed hind feet (Figure 21). They measure up to 1.5 m long; males weigh up to 45 kg and females weigh up to 32 kg. Northern sea otters forage in shallow coastal waters, consuming 25 percent of their body weight per day. Sea otters are nonmigratory and typically maintain a home range of a few dozen square kilometers or less for their entire life. Northern sea otters inhabit the coastal waters of Washington State, British Columbia, the Aleutian Islands, and Southern Alaska. There are three stocks of Northern sea otter: the southeast stock found in southeast Alaska, the south-central stock found from the edge of the southeastern stock to the eastern edge of Cook Inlet, and the southwest stock found west of the western edge of Cook inlet. The Southwest Alaskan stock is listed as threatened under the ESA and as depleted under the MMPA. All three stocks are protected throughout their range under the MMPA. The critical habitat for the Northern sea otter is shown in Figure 11.

Figure 21. Northern sea otter (National Geographic).

- *Protected Marine Mammals*

Descriptions and distribution patterns of the species protected throughout their range under the MMPA are described below. See the previous section for the descriptions of beluga whale, blue whale, fin whale, and gray whale.

- Harbor Porpoise

Harbor porpoises (*Phocoena phocoena*) weigh between 61 and 77 kg, measure approximately 1.6 m in length, and have an average lifespan of 24 years (Figure 22). On the west coast of North America, harbor porpoises inhabit waters from California to Northern Alaska and Canada with at least 10 distinct stocks within this range. Three stocks are identified in Alaskan waters: Southeast Alaska, Gulf of Alaska, and Bering Sea. Those found in Cook Inlet are recognized as being part of the Gulf of Alaska stock. They are often found in harbors, bays, and estuaries in water less than 200 m deep. They feed on demersal and benthic species, including herring, capelin, and cephalopods. Harbor porpoises are not categorized as being at risk, but are protected throughout their range, as all marine mammals are, under the MMPA.

Figure 22. Harbor porpoise (NOAA Fisheries).

- Harbor Seal

Harbor seals (*Phoca vitulina*) are one of the most common marine mammals along the U.S. West and East Coasts. They are part of the true seal family and have short flippers (Figure 23). They weigh up to 129 kg, measure up to 1.82 m in length, and have a lifespan of 25 to 30 years. Harbor seals have small home ranges, mate at sea, and give birth during the spring and summer. They are both deep and shallow divers and feed on fish, shellfish, and crustaceans. While harbor seals haul out to rest and breed, they are generally not capable of extensive movement on land. There are 16 stocks of harbor seals in the U.S., 12 in Alaska. The Alaskan stocks include the Cook Inlet/Shelikof Strait stock, which has been stable or increased in numbers over the past 8 years. Cook Inlet supports a high abundance of seals all year round, with lower and middle Cook Inlet being a highly popular location for harbor seals. Harbor seals are not categorized as being at risk but are protected throughout their range under the MMPA.

Figure 23. Harbor seal (NOAA Fisheries).

- *Other Key Species*

Other species have been noted as depleted and are of interest to conservation organizations and government regulators but are not yet afforded special protection.

- Sunflower Sea Star

The sunflower sea star (*Pycnopodia helianthoides*) is a large sea star, iconic of the northeast Pacific Ocean (Figure 24). It is among the largest sea stars in the world—it has a maximum arm span of 1 m, and can have 16 to 24 limbs. It was declared a critically endangered species by the International Union for Conservation of Nature - IUCN (Gravem et al. 2020). Its distribution ranges from California to Alaska, although it is no longer observed in Oregon and California; it is present in Puget Sound and Alaska in low numbers. It occurs in many different


Figure 24. Sunflower sea star (Oregon Public Broadcasting)

types of marine habitats including mud, sand, shell, gravel, rocky bottoms, kelp forest, and lower intertidal, at depths from 0 to 435 m.

■ Essential Fish Habitat in Cook Inlet

Essential fish habitat (EFH) is defined by the Magnuson-Stevens Fishery Conservation and Management Act as "waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." EFHs have been identified in southwestern Alaska for the following groups:

- salmon – juveniles and adults,
- scallop – all life stages,
- king and Tanner crabs – all life stages, and
- groundfish – all life stages.

Habitat Areas of Particular Concern (HAPCs) are smaller habitat areas within EFH and are priority areas for conservation and management efforts. HAPCs within southwestern Alaska include the following:

- the Alaska Seamount Habitat Protection Areas,
- the Bowers Ridge Habitat Conservation Zone, and
- the Gulf of Alaska Coral Habitat Protection Areas.

EFH and HAPCs are mapped in Figure 25 and the implications of these areas are discussed in the following sections.

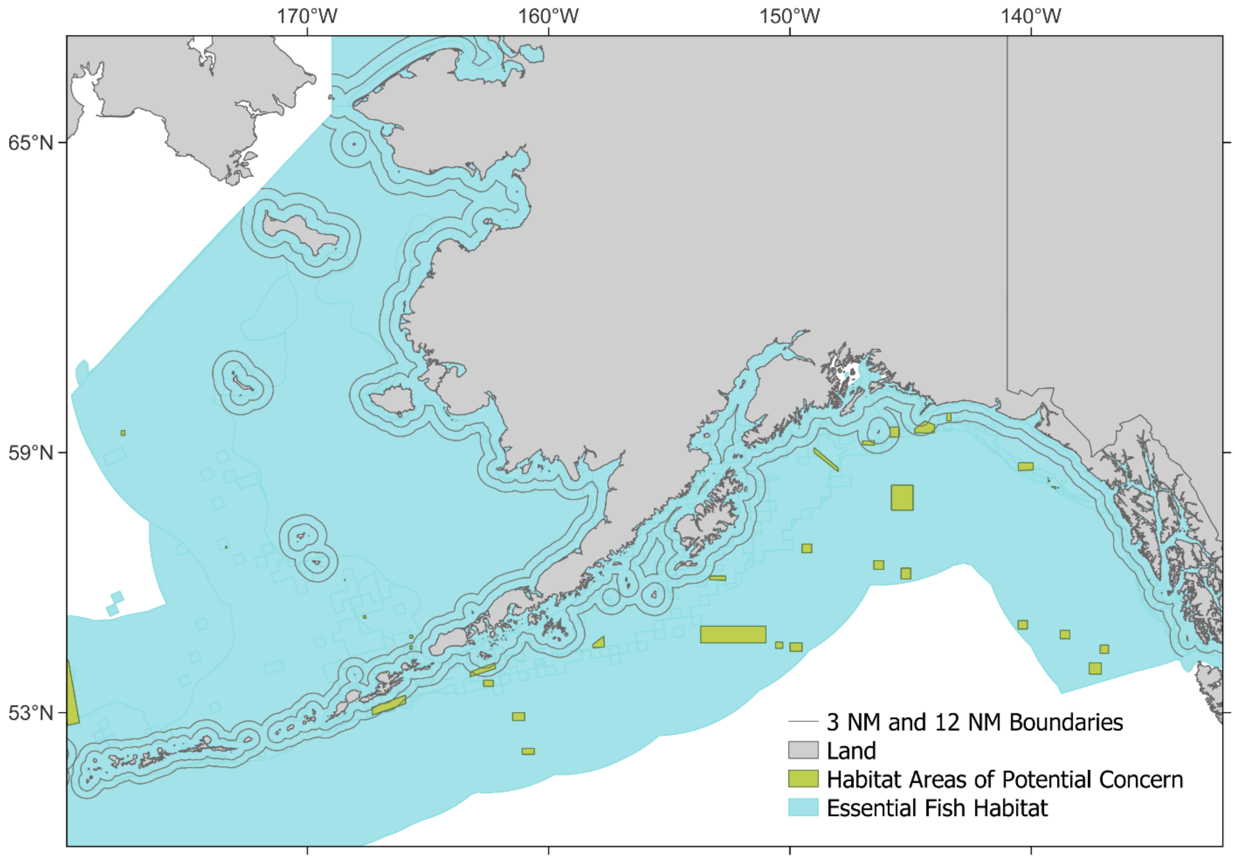


Figure 25. Essential fish habitat and habitat areas of particular concern in southwest Alaska, U.S.

EFH for salmon, scallop, and king and Tanner crabs in southwest Alaska are described below and depicted in Figure 26.

- *Salmon*

Five species of Pacific salmon are present in southwest Alaska: Chinook (*Oncorhynchus tshawytscha*), Coho *(Oncorhynchus kisutch)*, Pink *(Oncorhynchus gorbuscha)*, Sockeye (*Oncorhynchus nerka*), and Chum *(Oncorhynchus keta)*. Kelp harvesting areas are important for ocean rearing of juveniles, and for juvenile and adult migration. All species feed throughout the entire water column.

- *Scallop*

EFH areas that are used for kelp harvesting are habitats supporting several scallop species (weathervane scallops [*Patinopecten caurinus*], pink or reddish scallops [*Chlamys rubida*], spiny scallops [*Chlamys hastata*], and rock scallops [*Crassadoma gigantea*]) throughout their life stages. Eggs and larvae of scallops are planktonic and the larval dispersal duration takes place over a month. The settlement of larvae occurs at the bottom of the water column. Juveniles and adults are generally not mobile.

- *King and Tanner Crabs*

Species of interest in the Bering Sea/Aleutian Islands area include red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), golden (or brown) king crab (*Lithodes aequispinus*), and Tanner crab (*Chionoecetes bairdi* and *C. opilio*).

King and Tanner crabs inhabit shallow inshore areas (less than 50 m depth) during reproduction and mating. The larval stage is planktonic, and larvae are generally distributed in the upper 30 m of the water column. The settlement of larvae occurs on the bottom of the water column and in shallow areas. Important locations for king crab spawning and juvenile rearing in southwest Alaska include the area north and adjacent to the Alaska Peninsula (Unimak Island to Port Moller), the eastern portion of Bristol Bay, and nearshore areas of the Pribilof and Saint Matthew Islands.

Recent drops in populations of several species of commercially harvested crabs may bring additional scrutiny and protection in the future.

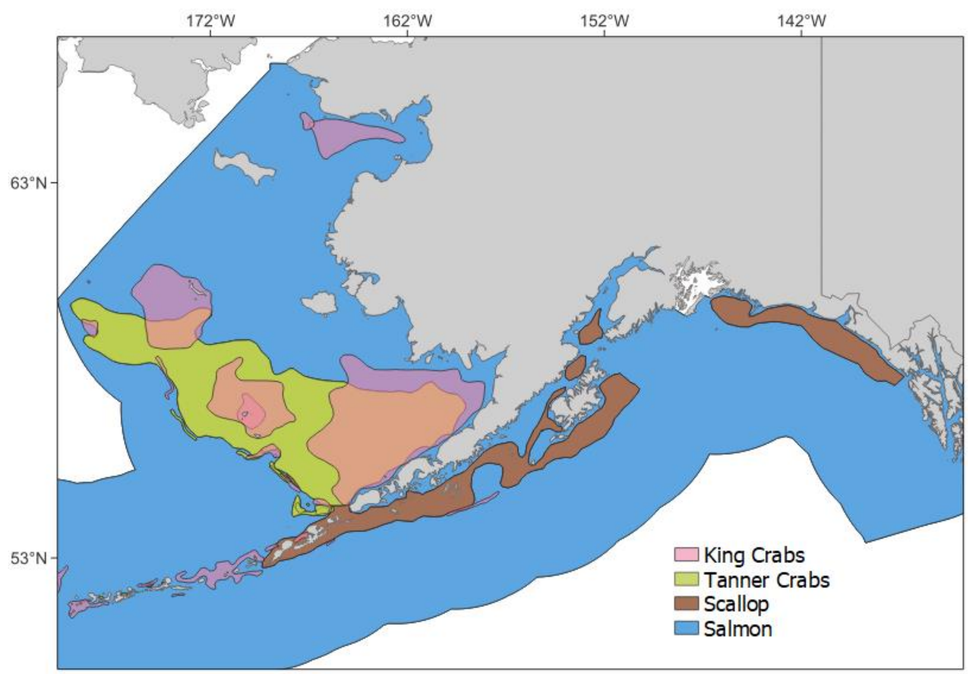
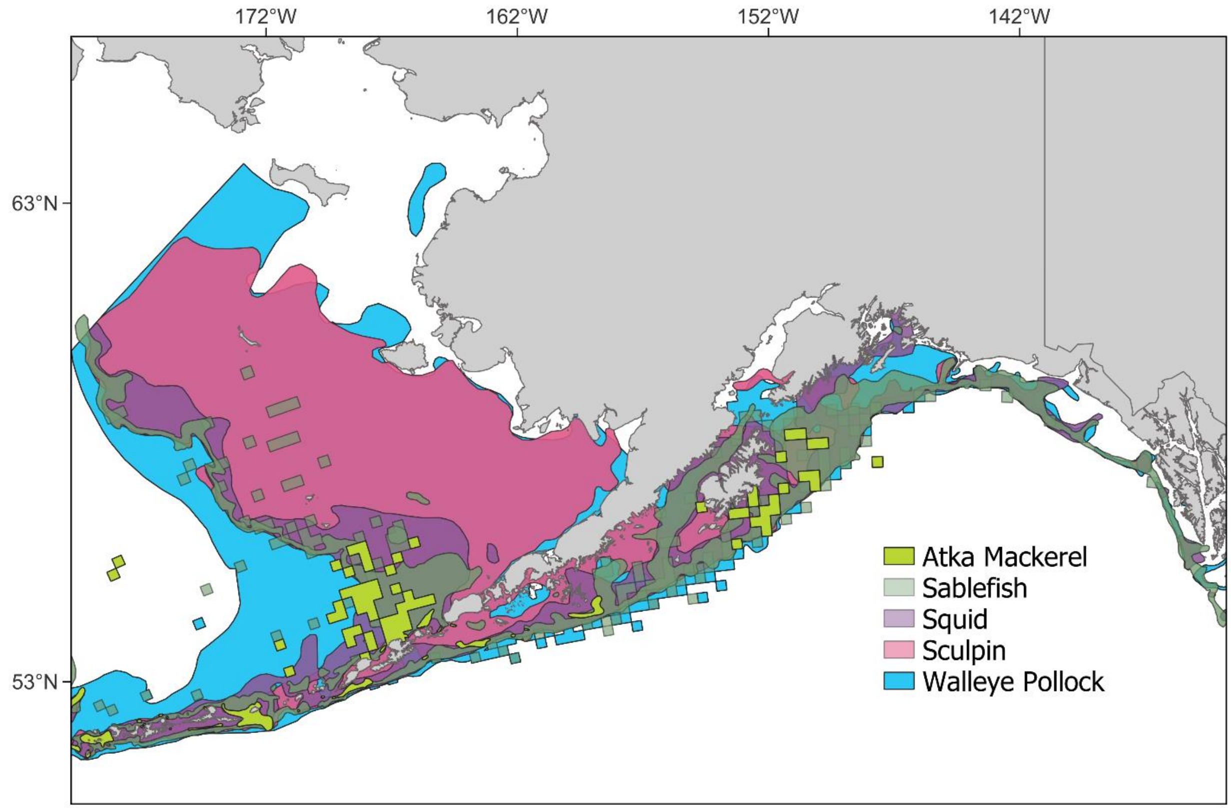


Figure 26. Essential fish habitat for king and tanner crabs, scallop, and salmon in southwest Alaska, U.S.

- *Groundfish in the Gulf of Alaska*

Groundfish species in southwest Alaska include walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), flatfish, rockfish, atka mackerel (*Pleurogrammus monopterygius*), skates, sculpins, sharks, and octopus. Forage fish species, grenadiers, and squids are also included in this group. All life stages of groundfish inhabit the water column of pelagic waters throughout the Gulf of Alaska (Figure 27). Juvenile and adult stages are generally located in the lower portion of the water column along the entire shelf.


172°W
162°W
152°W
142°W
63°N
53°N
Atka Mackerel
Sablefish
Squid
Sculpin
Walleye Pollock

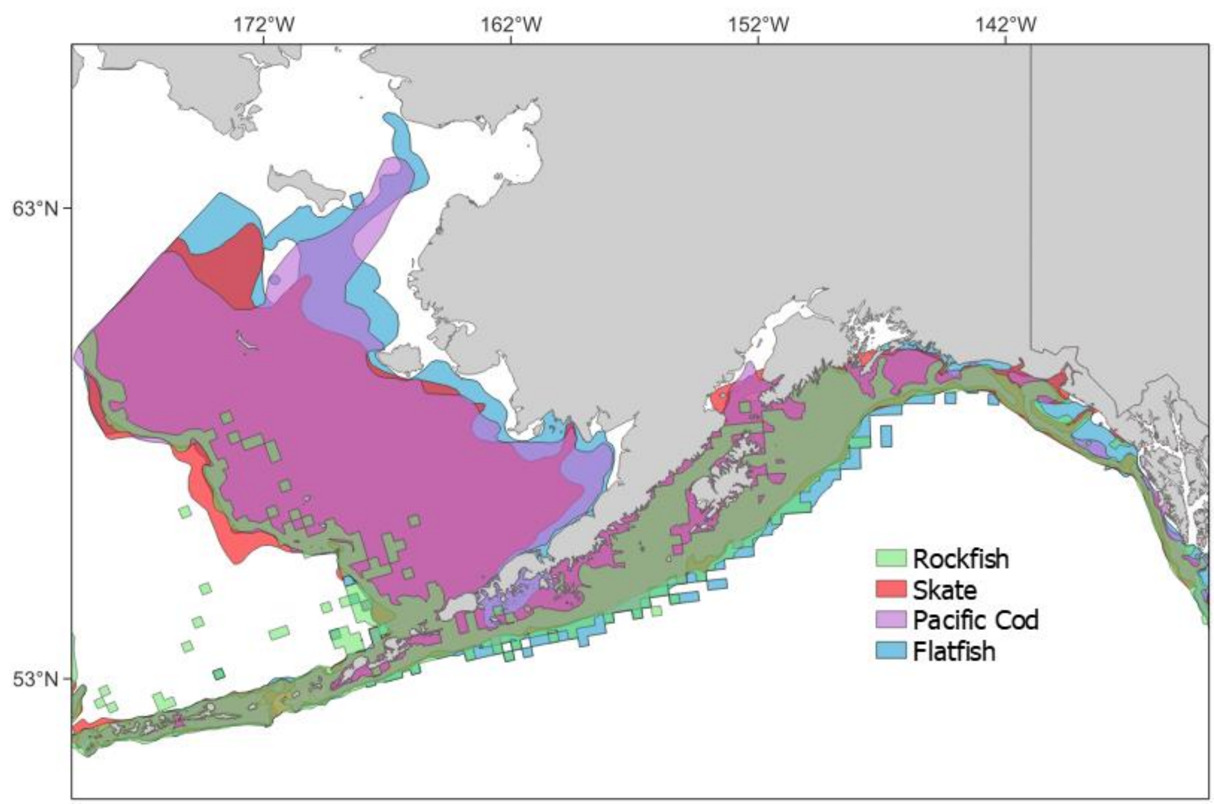

172°W
162°W
152°W
142°W
63°N
53°N
Rockfish
Skate
Pacific Cod
Flatfish

Figure 27. Essential fish habitat for groundfish species in southwest Alaska.

○ Seabirds Around Cook Inlet

Figure 28. Horner puffin (Audubon).

Cook Inlet supports a wide variety of birds, many of which rely on the water and/or shoreline for food sources, safety, and/or reproduction. Cook Inlet provides important habitat for many at-risk water birds that may spend all year round or certain seasons in the Inlet. Many of these birds are divers and routinely spend time below the surface of the water foraging for food. A few species such as red-faced cormorants and Aleutian terns live and breed almost exclusively along Alaskan coasts.

■ Auks, Murres, Puffins

Figure 30. Rhinoceros auklet (Audubon).

Auks, murres, and puffins spend great portions of their lives on large expanses of water, including open ocean and coastal bays and inlets (Figures 28-30). They all forage beneath the surface of the water for food. Auks, murres, and puffins specialize in a piscivorous diet eating mostly small fish between 2–6 inches long, along with small marine crustaceans, squid, octopus, and zooplankton. Of the auks, murres, and puffins found in Cook Inlet, some forage down to 20 m (i.e., ancient murrelet), 30 m (i.e., rhinoceros auklet, parakeet auklet, marbled murrelet, Kittlitz's murrelet, horned puffin, and tufted puffin), 45 m (i.e., common murre, pigeon guillemot), and the thick billed murre regularly forages down to 100 m and has been found as deep as 200 m. Of these, most species have a conservation status categorized by the IUCN Red List as "least concern" however, the marbled murrelet and Kittlitz's murrelet statuses are 'endangered' and 'near threatened' respectively.

Figure 29. Thick billed murre (Audubon).

■ Cormorants

Cormorants are medium to large sea birds weighing 0.35 to 5 kg and having a life span of up to 25 years in the wild (Figure 31). Cormorants are fish eaters and dive to catch their prey, which mainly consists of small fish and crustaceans, including herrings, greenlings, sculpin, sand lance, shrimp, and crabs. The double-crested cormorant, red-faced cormorant, and pelagic cormorant are all found in Cook Inlet. Cormorants dive to depths of up to 45 m, with double-crested cormorants typically only diving as deep as 7.5 m, red-faced cormorants diving as deep as 30 m, and pelagic cormorants typically up to 35 m deep. All three species of cormorants found in Cook Inlet have a conservation status of "least concern" categorized by the IUCN Red List. Red-faced cormorants are found almost exclusively along the southern Alaskan coast and throughout the Aleutian Islands.

Figure 31. Pelagic cormorant (Audubon).

■ Ducks and Geese

Figure 32. Long-tailed duck (Audubon).

Figure 32. Bufflehead (Audubon).

Figure 34. Steller's eider (Audubon).

Many ducks and geese are found in Cook Inlet (Figures 32-34). Ducks are omnivores that typically feed on a variety of aquatic plants, seeds, grasses, small fish, invertebrates, and amphibians. Geese are omnivores as well, but their diets are mainly made up of plants—mostly grasses, nuts, seeds, and berries and only occasionally an insect or small fish. Ducks and geese are not deep divers; most of the species in Cook Inlet do not pass 10 m in diving depth (i.e., black scoter, white winged scoter, surf scoter, bufflehead, common goldeneye, barrows goldeneye, red-breasted merganser, greater scaup, and Steller's eider). Some dabblers are very poor divers and almost exclusively forage along the surface or just below the surface when in the water (i.e., American wigeon, mallard, brant). Only a few deep diver ducks exist in Cook Inlet, including the common eider that dives up to 20 m, the harlequin duck that dives up to 50 m, and the deepest diving duck—the long-tailed duck—that dives up to 60 m. Of the ducks and geese in Cook Inlet, most have a conservation status designated by the IUCN Red List of "least concern." The black scoter and common eider both have a status of "near threatened," and the long-tailed duck and Steller's eider both have a status of "vulnerable."

■ Grebes

Figure 33. Horned grebe (Audubon).

Grebes are water birds different from ducks because, instead of having webbed feet (Figure 35), they have lobed toes used to propel themselves under water to forage. Grebes are typically freshwater birds but can be found in saltwater bays and inlets during the winter. The horned grebe and red-necked grebe are both found in Cook Inlet in winter months. Grebes' diets are mostly made up of small fish, aquatic insects, crustaceans, and often their own feathers to slow digestion, and their diets may vary depending on the season. Grebes typically keep their dives 7–9 m deep or shallower. The horned grebe and red-necked grebe have the respective conservation statuses designated by the IUCN Red List of "vulnerable" and "least concern."

■ Gulls and Terns

Figure 34. Black-legged kittiwake (Audubon).

A variety of gulls and terns are found in Cook Inlet (Figure 36 -37). Gulls are omnivores and usually opportunists that have the potential to eat highly variable diets, including fish, invertebrates, mollusks, eggs, birds, seaweed, seeds, berries, and carrion. The glaucous-winged gull, short-billed gull, black-legged kittiwake, Bonaparte's gull, and herring gull are all found in Cook Inlet. Most gulls find their food on or just below the surface of the water when foraging in aquatic habitats. However, the black-legged kittiwake—the only diving gull—may dive up to 1 m below the surface to forage. All gulls in Cook Inlet are

Figure 35. Aleutian tern (Audubon).

categorized as being of "least concern" conservation status by the IUCN Red List aside from the black-legged kittiwake, which has a status of "vulnerable." Terns are almost entirely carnivorous eating mostly small fish, crustaceans, and mollusks. The Arctic and Aleutian terns are the two types of terns found in Cook Inlet. Arctic terns often plunge dive to catch prey down to half a meter below the surface. Aleutian tern mostly feeds along the surface of the water, occasionally plunge diving into the water. Designated by the IUCN Red List, the arctic tern has a conservation status of "least concern" and the Aleutian tern has a status of "vulnerable.". The Aleutian tern has a very limited breeding range of only the southern and eastern edges of Alaska and the Aleutian Islands, and they spend their time along those coasts or on the open ocean during the winter.

- Loons

Figure 36. Red-throated loon (Audubon).

Loons are water birds the size of large ducks (Figure 38). Like ducks, they have webbed feet, but unlike ducks they are more heavyset, have solid bones, and their legs are farther back on their body, making their bellies sit submerged in the water as they swim. Their farther back legs, webbed feet, and solid bones make them less buoyant and allow them to be excellent divers. Loons dive to catch prey, most of which consists of fish, and to avoid threats. Loons can dive up to 60 m deep and stay underwater for up to 5 minutes. Three kinds of loons are found in Cook Inlet: the Pacific loon, common loon, and red-throated loon. All of them have a conservation status of "least concern" designated by the IUCN Red List.

- Petrels

Figure 37. Fork-tailed storm petrel (Audubon).

Petrels are a distinct kind of seabird found in Cook Inlet; they are categorized as tube nosed seabirds along with albatross and shearwaters, all of which have unique tubular nostrils and hooked beaks (Figure 39). Petrels are mostly carnivorous scavengers that feed on varied fish, crustaceans, squid, worms, and carrion. In Cook Inlet, fork-tailed storm petrels and northern fulmars can be found. Both species dive; the fork-tailed storm petrel stays less than a meter from the surface when diving and the northern fulmar dives down to 3 m. Both the fork-tailed storm petrel and northern fulmar have conservation statuses of "least concern" according to the IUCN Red List.

- Jaegers/Skuas

Figure 38. Parasitic jaeger/Arctic skua (Audubon).

Jaegers (North America) or skuas are carnivorous, gull-like seabirds (Figure 40). They are known to be aggressive predators preying on eggs, young birds, and even other adult birds. They attain much of their food by chasing and attacking other birds forcing them to drop their prey. They may also eat rodents, insects, and berries, and may forage their food by skimming the surface of the water. Jaegers do not typically dive underwater to catch food. The pomarine jaeger/skua and the parasitic jaeger/Arctic skua may both be found in Cook Inlet during migration, or nonbreeding individuals may be found year-round. Designated by the IUCN Red List, the pomarine jaeger/skua and the parasitic jaeger/Arctic skua both have a conservation status of "least concern."

■ Bald Eagles

Bald eagles are large birds of prey found across Canada, the U.S., and Northern Mexico (Figure 41). They are heavily populated along the Canadian West Coast and Alaska, including the Aleutian Islands and Cook Inlet, and they reside in these areas all year round. Bald eagles like to live near waterbodies (both saltwater and freshwater) so they can hunt their favorite food—fish. However, they are also found to eat birds, small mammals, reptiles, and carrion. When hunting in waterbodies, bald eagles do not dive more than a few centimeters into the water. Instead, they skim the water with their talons to grab prey at the surface. Bald eagles have a conservation status of "least concern" according to the IUCN Red List.

Figure 39. Bald eagle (Audubon).

○ Assessment of Environmental Effects from Marine Energy Devices on Marine Animals and Seabirds in Cook Inlet

The greatest perceived threats to marine animals and birds that will influence the regulatory processes may include the following:

- risk of collision with tidal turbine blades
- effects of underwater noise from the device
- effects of electromagnetic fields (EMF) from the power export cable
- entanglement in mooring lines and inter-array cables
- haulout on a floating device and/or roosting seabirds on the device
- displacement of animals from critical habitats by anchors, mooring lines, or the device.

Each of these risks may require some investigation; while there are increasing bodies of knowledge for most of these stressors on marine animals and habitats (Copping and Hemery 2020), specific details of these interactions have not been studied for most of the species in Cook Inlet. In Cook Inlet, the most difficult hurdle to overcome from a permitting perspective is likely to be the presence and movement of the highly endangered segment of the beluga whale population that resides in the inlet. A monitoring program around the turbines will likely be needed to observe potential interactions. Results derived from previous studies of underwater noise, EMF, and changes in habitats can likely be applied to Cook Inlet, although regulators may call for some additional studies or monitoring. For example, it will be necessary to record the underwater operational noise from the O2 turbines to ensure that it falls under the U.S. guidelines for marine mammals and fish. Haulout concerns for marine mammals and roosting of seabirds can probably be addressed by mitigating areas and angles where the animals might have access. While the presence of one or a small number of tidal turbines in Cook Inlet is unlikely to significantly displace animals, marine mammal observer surveys might be needed to ensure that the belugas are not affected.

Evaluating the potential for underwater noise from the generator and other moving parts of the tidal device to disturb marine mammal navigation and communication requires an understanding of the hearing ranges of key species, particularly marine mammals and some species of fish. Information about the hearing range of marine mammals can help to determine whether there is likely to be an overlap with the frequency of the marine energy device. The hearing range of marine mammals underwater is detailed in Table 3.

Table 3. Marine mammal underwater functional hearing ranges (Southall et al. 2019).

Functional Hearing Group	Relevant Species	Functional Hearing Range
Low-frequency cetaceans	Blue, fin, gray, humpback, right, and sei whales	10 Hz to 30 kHz
High-frequency cetaceans	Beluga, killer, and sperm whales	100 Hz to 150 kHz
Very high-frequency cetaceans	Harbor porpoise	150 Hz to 180 kHz
Phocid pinnipeds	Harbor seal	100 Hz to 100 kHz
Otariid pinnipeds	Stellar sea lion and Northern sea otter	100 Hz to 50 kHz

- ## Suitability Assessment for the Development of Marine Energy Projects in Cook Inlet

The suitability of Cook Inlet for developing a tidal energy project was assessed through a spatial analysis that included the relevant environmental, logistical, and regulatory parameters considered for such project. The parameters included in the spatial analysis consisted of

- environmental parameters – bathymetry and average yearly current velocities
- logistical parameters – navigation routes, distance to ports, underwater cables
- regulatory parameters – species critical habitat and EFH.

Table 4 describes each data layer included in the heatmap analysis and the constraints for their inclusion in or exclusion from the analysis. For example, navigation routes (> 10 vessel tracks) need to be avoided and are excluded as areas for potential tidal development in the analysis. The heatmap allows for identifying suitable areas for a tidal energy project across these various parameters.

Table 4. Parameters included in the heatmap analysis and associated constraints, in order to identify suitable areas for developing a tidal energy project in Cook Inlet, Alaska.

Category	Parameter	Constraint
Environmental	Average annual current velocities	> 1 m/s
	Bathymetry	50 – 80 m
Logistical	Navigation routes > 10 vessel tracks	Entire area excluded

Category	Parameter		Constraint
	Distance to ports		0 – 40 km
	Underwater cables		Entire area excluded (500 m buffer on each side of cable)
Regulatory	Critical habitat	Beluga Whale	Entire area excluded
		Northern Sea Otter	
		Stellar Sea Lion	
	Essential fish habitat	Pacific Cod	Entire area excluded
		Salmon	
		Scallop	
		Sculpin	
		Skates	
		Walleye Pollock	
		Rockfish	
		Sablefish	

The heatmap was produced using QGIS 3.26.3. A grid of points of approximately 0.5 miles x 0.5 miles in resolution was produced for the area of Cook Inlet. Parameters that signify suitable areas for development of a tidal energy project were noted in each grid to produce a unique point layer for each parameter. The point layers were merged and a heatmap was produced within the symbology settings of QGIS. The heatmap shows that areas with greater clustering of points appear as more suitable and areas with less clustering of points appear as less suitable, as is shown by the color gradations in Figure 40.

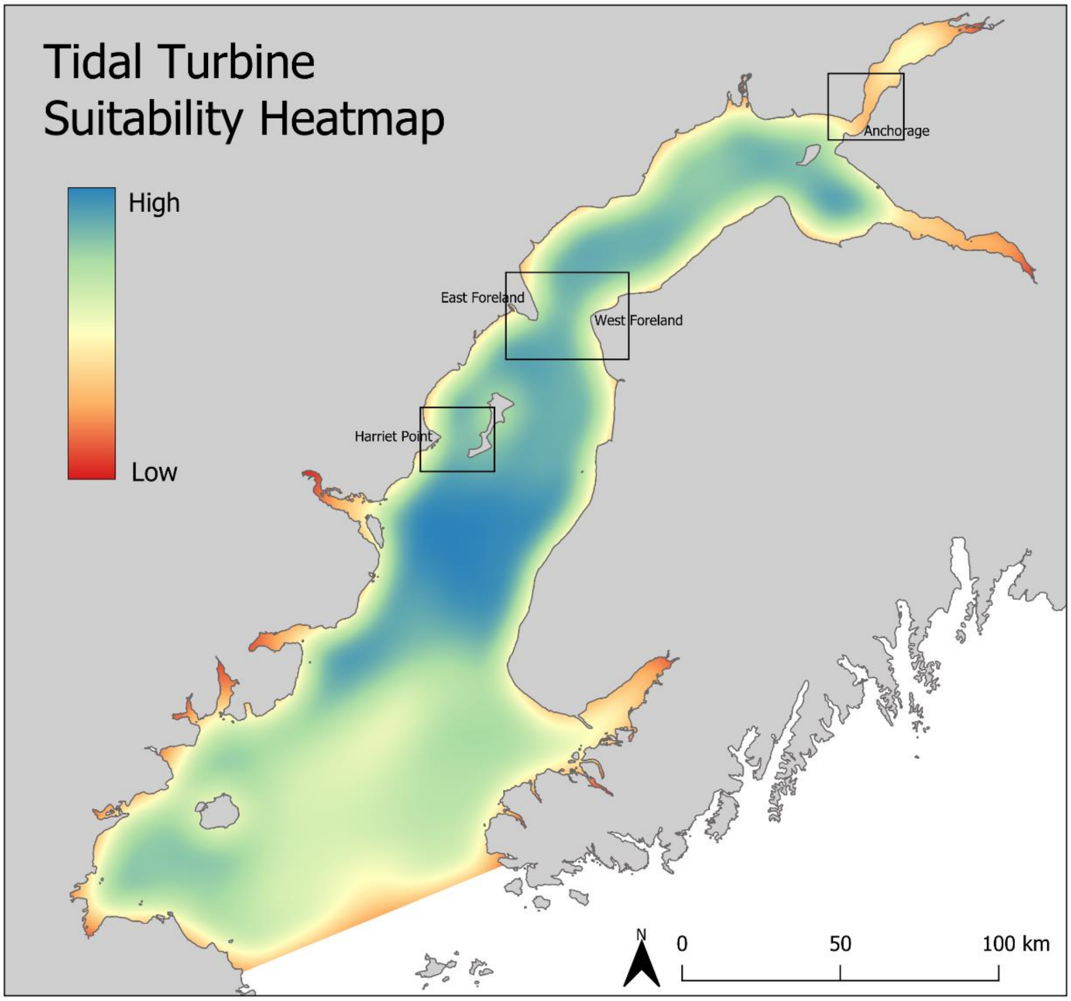


Figure 40. Heatmap of the suitability for developing a tidal energy project in Cook Inlet, Alaska. Red = low suitability and blue = high suitability.

Based on the heatmap obtained from the spatial analysis, the northern part of the inlet has higher suitability for developing a tidal energy project. In the locations of interest, the waters between the East and West Foreland sites have the highest suitability for developing a tidal energy project, followed by waters off Harriet Point. The low suitability observed off the Anchorage coast can be explained by high vessel traffic, shallow bathymetry, and the presence of critical habitat for beluga whales.

- ### Adequacy of Environmental Data for Initial Development of Floating Tidal Turbines

The information gathered for this assessment was derived from publicly available databases and was examined based on the suitability for the deployment and operation of floating tidal technologies in

Cook Inlet, Alaska. While these data resemble the information likely to be required for regulatory assessment, this analysis does not describe or replace any regulatory requirements.

After extensive searches of online datasets and information sources, it is the opinion of the authors that there are unlikely to be significant additional sources of information about the presence of marine animals or habitats of interest in Cook Inlet that will support the development of floating tidal energy. It is further the opinion of the authors that these data are sufficient for assessing the baseline conditions of the areas of interest, and that additional baseline data collection over a short period of time (months to years) is not likely to further inform a baseline assessment of the areas.

These data and information form a snapshot and (in some cases) inform trends in marine animals' distribution and the presence of critical habitats. Combined with physical data and ancillary information, this information can be used for an initial assessment of where floating tidal technologies might succeed in Cook Inlet, while ensuing minimal effects on precious marine resources.

7.2 Lesson Learned and Test Plan Deviation

The major lesson learned by the project team was the realization that there are relatively few data sources that address living resources in the Cook Inlet area. Most publicly available datasets cover areas that are far larger than Cook Inlet and/or lack specificity to the area. Future projects in remote areas such as Cook Inlet would benefit from coordinating local academics and non-governmental organizations who may hold data of interest, particularly as they address marine mammals, fish, and seabirds, but that are not added to public databases. It is not clear to what extent these data exist or whether they will add to the overall picture of environmental analysis in Cook Inlet, but they could be examined and the data holders encouraged to contribute to public databases.

The only deviation from the Test Plan was the addition of the Spatial Analysis that combined the presence of marine animals and habitats of concern, with tidal current data, as well as logistical data such as navigation lanes and ports. This addition was made as the data were readily available and it seemed to provide value-added to the project.

8 Conclusions and Recommendations

This analysis supports the suitability of Cook Inlet for floating tidal energy development at the scale that one or more Orbital O2 devices would present. There are adequate tidal sites around the Forelands as well as off Anchorage and Harriet Point. Constraints due to the presence of endangered marine mammals, as well as fish of fisheries and conservation importance, and protection of seabirds, will require careful siting, collection of post-installation monitoring data, and perhaps mitigation, to ensure that tidal development does not harm marine resources or impact the ability of the Cook Inlet communities and Native Corporations to make a living.

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10 APPENDIX

Detailed data and descriptions that need to be included for context, but that are not appropriate for the body of the report, should be included as appendices.