# Post-Installation Environmental Monitoring Summary

## 1 Introduction

This document provides a summary of all post-installation environmental monitoring planned for Snohomish County Public Utility District's tidal energy pilot demonstration project in northern Admiralty Inlet, Puget Sound, Washington. Since several technical aspects of post-installation environmental monitoring remain under development, the monitoring approach described here may change prior to turbine deployment. The objective is to provide a concise summary of proposed monitoring activities in order to provide context for individual monitoring plans. Section 2 describes the tidal turbines and their deployment locations. Section 3 provides a summary of plan objectives and the rationale for pursuing these objectives. Section 4 describes the monitoring infrastructure and instrumentation. Section 5 describes how these resources are proposed to address specific hypotheses.

## 2 Project Description

The proposed demonstration project consists of two turbines manufactured by OpenHydro, an Irish turbine developer. Each of these turbines has a 6 m diameter outer shroud, as shown in Figure 1. These will be deployed on a gravity tri-frame, with tubular cans contacting the seabed at the vertices. Turbine hub height will be 10 m above the seabed. The OpenHydro turbines are fixed-pitch, high-solidity rotors with an open center. The rotor cassette is the single moving part and is supported by water-lubricated bearings. A permanent magnet generator is contained in the shroud surrounding the blades. Anti-fouling coatings are applied to the interior surface of the shroud, hub, and rotor blades, but the gravity frame (steel, ballasted by concrete and aggregate) is left bare. The turbine shown in Figure 1 represents the 10 m version of 6th Generation technology. The turbines deployed in Puget Sound will be 6 m variants of this generation technology.

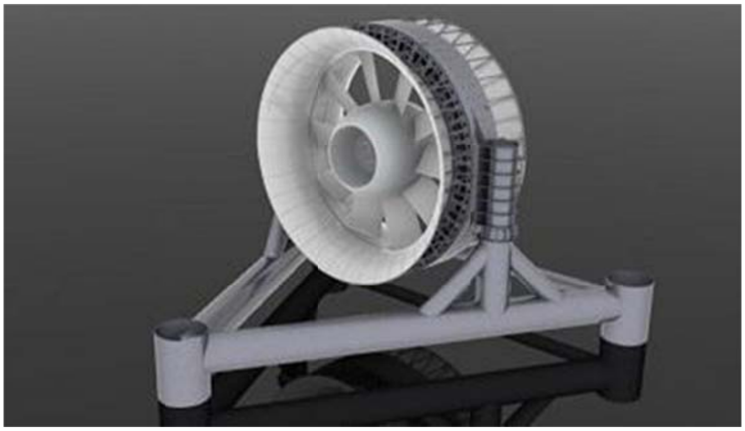


**Figure 1 – 10 m OpenHydro turbine. Blade geometry, shroud geometry, and tri-frame design reflect 6th Generation technology.**

The turbines will be deployed in northern Admiralty Inlet, Puget Sound, Washington. Admiralty Inlet is a constricted sill separating the deep Main Basin of Puget Sound from the Straits of Juan de Fuca and Straits of Georgia. At the narrowest point, between Admiralty Head and Point Wilson, the channel is approximately 5 km wide and 70 m deep. Excepting a small exchange through Deception Pass, the entire tidal prism of Puget Sound passes through this constriction, giving rise to tidal currents that routinely exceed 3 m/s (6 knots) at mid-water. The project site is approximately 1 km SE of Admiralty Head in 55 m of water (Figure 2). The project location was chosen on the basis of strong tidal currents (intensified by the proximity to the headland), negligible seabed slope (necessary to deploy the gravity foundation), separation from high vessel traffic areas (federal navigation lanes, ferry route), and ease of cable routing back to shore.

During deployment, the turbines will be lowered to the seabed by the three points on the triangular base shown in Figure 1. Hydraulic jacks are used to connect to the frame and are detached and recovered once the turbine is in position on the seabed. During recovery, a frame is positioned over the subsea base. The forward face of the shroud (facing the apex of the triangular base) is used to align the recovery frame. Hydraulics on the frame then engage with the subsea base and the entire turbine is recovered, much in the same manner as it is deployed. Each turbine will be connected to shore by a separate power cable. These cables will also provide power for monitoring instrumentation and fiber optic communication with the turbine and monitoring instrumentation.

The seabed is primarily cobbles (softball size and larger) intermixed with shell hash, gravel, and boulders (Greene, 2011). Cobbles and boulders are colonized by barnacles, sponges, and algae. Consolidated sediments underlay the cobble layer (Golder Associates, 2011; Landau Associates, 2011). The water column is generally well mixed, with weak stratification occurring only during neap tides. Turbidity is low (< 1 NTU), though there is considerable biological detritus at depth (Polagye and Thomson, 2010). Owing to the high level of commercial vessel traffic, mean broadband noise levels are relatively high at 117 dB re 1 µPa (Bassett et al., *in press*). Broadband received levels range from less than 100 dB during the quietest periods to more than 140 dB when vessels are in the immediate area. Strong currents also mobilize the gravel and shell hash on the seabed, periodically generating noise at higher frequencies (5-50 kHz, Bassett et al., *submitted*).

The biological environment is less-well understood, owing to the difficulty of conducting biological studies in high flow environments. The area is utilized by a number of marine mammal species (Southern Resident killer whales being the most notable due to their endangered and iconic status). Harbor porpoise are routinely present at the site with a strong diel pattern (much higher echolocation activity at night, Tollit et al., 2010; Cavagnaro et al., *in prep*). Harbor porpoise are much more common at this site than for other tidal energy sites where comparable data exists (Strangford Lough, Northern Ireland; Minas Passage, Nova Scotia). Several migratory fish species transit through the area, though spatial and temporal distributions are not well-understood.

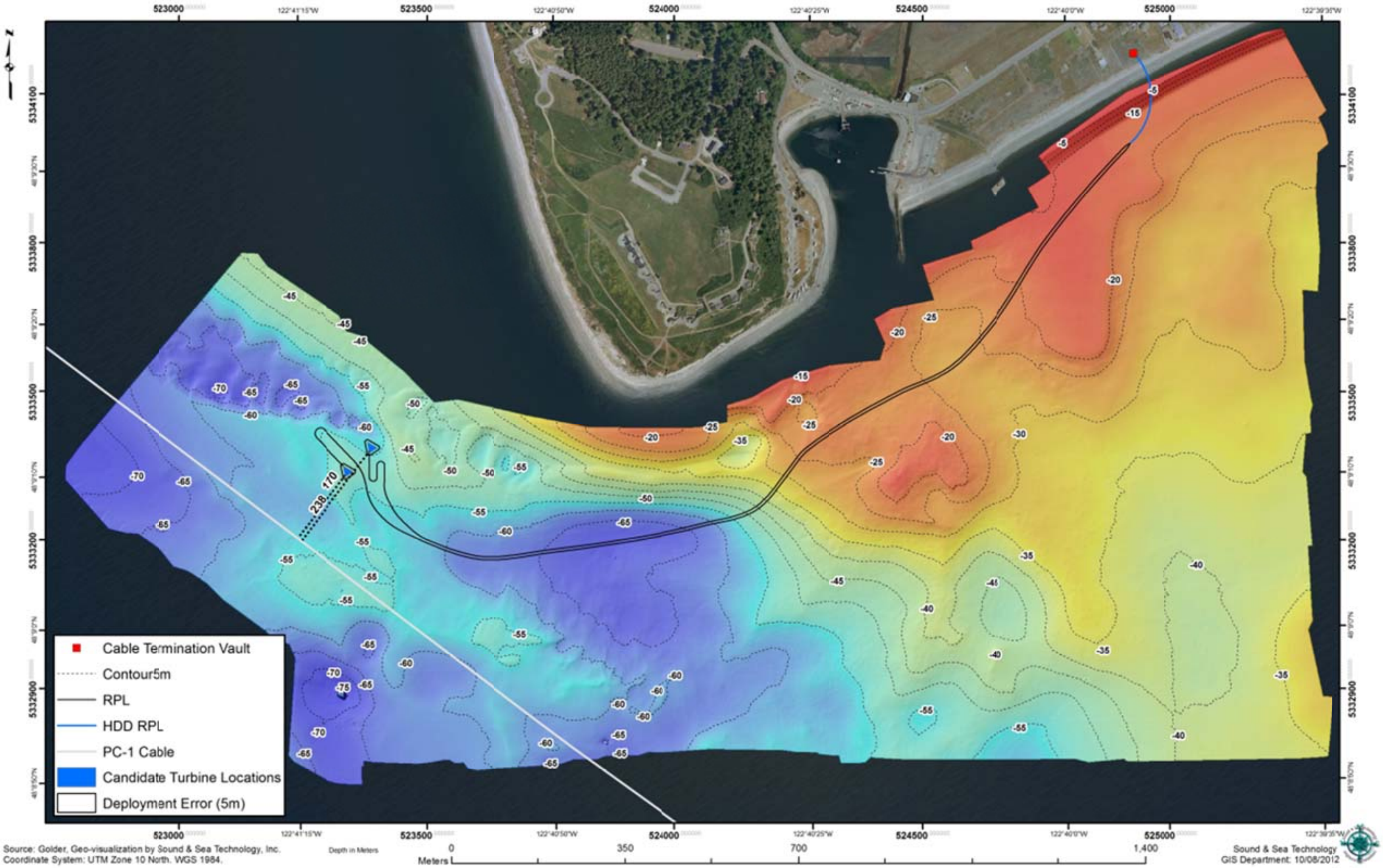


**Figure 2 – Turbine deployment location in northern Admiralty Inlet. Blue triangles denote turbines, each of which is connected back to shore via a separate power cable. Dashed red polygon to the east of Keystone Harbor is a marine protected area.**

# 3 Environmental Monitoring Objectives

Before discussing the tools that will be applied to environmental monitoring, it is first helpful to understand the desired objectives for environmental monitoring at the pilot-scale. The following hierarchical framework is adopted for discussion purposes:

- *Stressor*: a characteristic of tidal turbine operation (e.g., rotating blades, noise, EMF)
- *Change*: a detectable or measureable alteration to the environment caused by a stressor
- *Effect*: a change threshold denoting environmental significance
- *Impact*: a negative effect
- *Benefit*: a positive effect

At the scale of this project, environmental effects (either impacts or benefits) are unlikely (see Polagye et al. (2011) for a complete discussion). This pilot project does, however, provide a unique opportunity to collect data about environmental effects that could become changes for larger scale projects. Developing this information is crucially important for both resource agencies and industry. This pilot project is intended as a learning tool and, over the course of the project, the District will work with regulators and stakeholders through an Adaptive Management framework to maximize knowledge gain and transfer.

The focus study areas for this project are in the areas of static effects (e.g., presence of device foundation), dynamic effects (e.g., rotating blade), and acoustic effects. Studies are described in four monitoring plans, as summarized in Section 5. Some plans focus on stressors, while other focus on stressor-receptor interactions. This is not intentional, merely a product of how these plans evolved through collaborative discussion. Each of the plans also includes resource protection triggers based on monitoring data, which are not described in this summary. Over the course of project operation, other studies may need to be developed to address new questions or close gaps identified in these monitoring plans. The four plans and the areas addressed are:

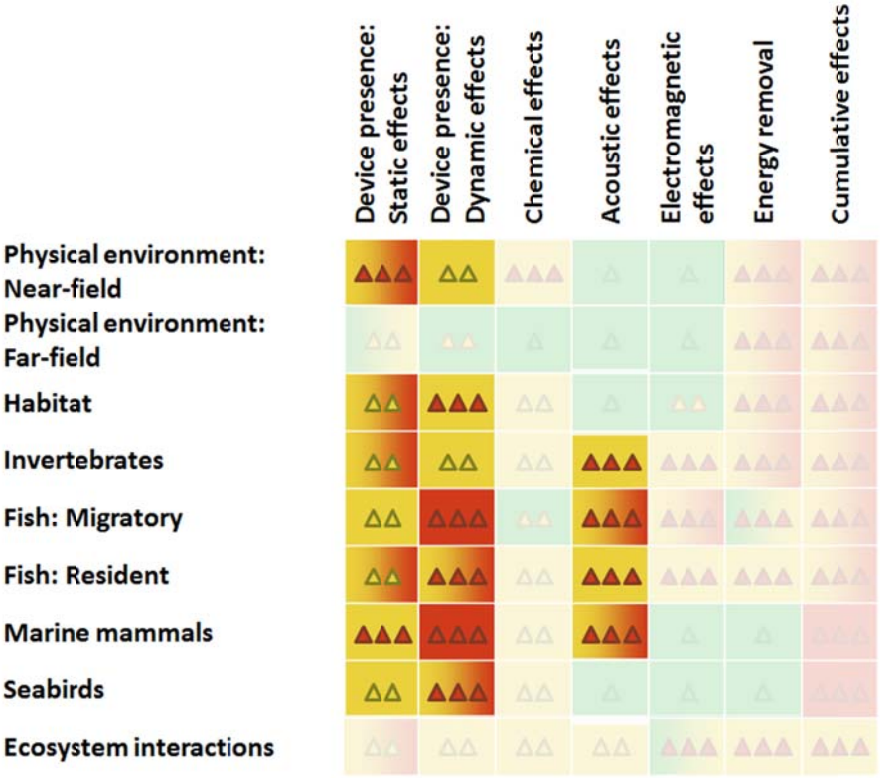
- *Benthic Habitat Monitoring*: static effects on near-field physical environmental, habitat, and fish
- *Near-turbine Monitoring*: dynamic effects on fish and marine mammals at ranges up to several meters from the turbine.
- *Acoustic Monitoring*: acoustic stressor produced by the turbine in operation.
- *Marine Mammal Monitoring*: avoidance, attraction, or change in behavioral state for marine mammals exposed to with static, dynamic, or acoustic stressors.

This study prioritization is driven by the outcomes of an environmental workshop (Polagye et al., 2011) that brought together over seventy experts from academia, regulatory agencies, and industry drawn from the US, Canada, and Europe. Workshop discussions focused on the potential significance of stressor-receptor interactions and the uncertainty around those interactions at both pilot and commercial scales of development. Workshop participants identified critical knowledge gaps that hindered their assessment of environmental risks and recommended monitoring priorities for pilot-scale deployments.

Figure 3 presents the stressor-reception interaction matrix developed by workshop participants for *commercial-scale* deployments (generalized over all sites and all turbine technologies). The color the severity of a potential interaction (i.e., red indicates a potentially significant interaction while green indicates a low significance interaction). Similarly, the number of triangles denotes the uncertainty around the significance of this interaction (e.g., three red triangles denote high uncertainty). Areas that are of potentially high significance but also have high uncertainty (yellow/red cells with three red triangles) should be focus areas for pilot project monitoring, in a general sense. However, the range of potential interactions in this category is too broad for any single pilot project to study all of them and prioritization is required.

The following considerations have helped to prioritize plans for pilot-scale monitoring at this project:

- Studies of cumulative effects of multiple stressors from a tidal energy project (defined by the workshop participants) and ecosystem interactions are not possible because of the pilot scale of the project. Consequently, no studies of cumulative effects of multiple stressors from a tidal energy project or ecosystem interactions are proposed. One workshop recommendation is to reduce this uncertainty through monitoring individual stressor-receptor interactions, which is a focus area for this project.
- Energy removal and far-field environmental effects (e.g., changes on the scale of an entire estuary) will be immeasurably small at the pilot scale and cannot be monitored for this project (Polagye et al., 2009). Resolving uncertainty in this area is a focus area for the US Department of Energy's National Laboratories and National Marine Renewable Energy Centers.
- Electromagnetic and chemical effects may be significant at the commercial scale, but at the pilot scale, the signal to noise ratio will be very small. Studies of these interactions are, at present, best performed in laboratories and are focus areas for the National Laboratories.



| | Device presence: Static effects | Device presence: Dynamic effects | Chemical effects | Acoustic effects | Electromagnetic effects | Energy removal | Cumulative effects |
|---|---|---|---|---|---|---|---|
| Physical environment: Near-field | ▲▲▲ | △△ | ▲▲▲ | △ | △ | ▲▲▲ | ▲▲▲ |
| Physical environment: Far-field | △△ | △△ | △ | △ | △ | ▲▲▲ | ▲▲▲ |
| Habitat | △△ | ▲▲▲ | △△ | △ | △△ | ▲▲▲ | ▲▲▲ |
| Invertebrates | △△ | △△ | △△ | ▲▲▲ | ▲▲▲ | ▲▲▲ | ▲▲▲ |
| Fish: Migratory | △△ | ▲▲▲ | △△ | ▲▲▲ | ▲▲▲ | ▲▲▲ | ▲▲▲ |
| Fish: Resident | △△ | ▲▲▲ | △△ | ▲▲▲ | ▲▲▲ | ▲▲▲ | ▲▲▲ |
| Marine mammals | ▲▲▲ | ▲▲▲ | △△ | ▲▲▲ | △ | △ | ▲▲▲ |
| Seabirds | △△ | ▲▲▲ | △△ | △ | △ | △ | ▲▲▲ |
| Ecosystem interactions | △△ | △△ | △△ | △△ | ▲▲▲ | ▲▲▲ | ▲▲▲ |

**Figure 3 – Commercial-scale deployment generalized stressor/receptor significance (on a gradient green = low, red = high) and uncertainty (one green triangle = low uncertainty, two yellow triangles = moderate uncertainty, three red triangles = high uncertainty). From, Polagye et al. (2011), emphasizing focus study areas for this pilot project.**

## 4 Post-Installation Monitoring Tools

Each of the monitoring objectives summarized above requires specific tools. Post-installation monitoring will be conducted from shore, vessels, and instruments deployed on the turbine foundation, as described in the following sections. Of these, the approach for deploying and maintaining instrumentation on the turbine foundation is the area that remains under most active technical development.

### 4.1 Shore Monitoring

Three types of shore-based monitoring are proposed: human observers, passive acoustic monitoring, and vessel tracking.

The first are observers positioned on Admiralty Head, overlooking the project area as shown in Figure 4. These observers are intended to primarily monitor the position of marine mammals relative to the project area. Observers will use a combination of video and theodolite tracking, mirroring the approach taken by DeNardo et al. (2001) to monitor killer whale behavior in Norway. The theodolite tracks an individual with high spatial accuracy (e.g., < 2 m uncertainty at a range of 2 km), while the video is used to monitor the spacing and behavior of animals within a group. The objective is this monitoring is to identify attraction, avoidance, or change in behavioral state associated with exposure to turbine noise as marine mammals move through the ensonified area. Pre-installation estimates (Polagye et al., *in prep*) indicate that marine mammals will only detect turbine noise with high probability within a few hundred meters of the turbine due to expected variations in turbine noise output with tidal state and variations in ambient noise with vessel traffic (frequencies less than 1 kHz) and tidal state (frequencies greater than 1 kHz).

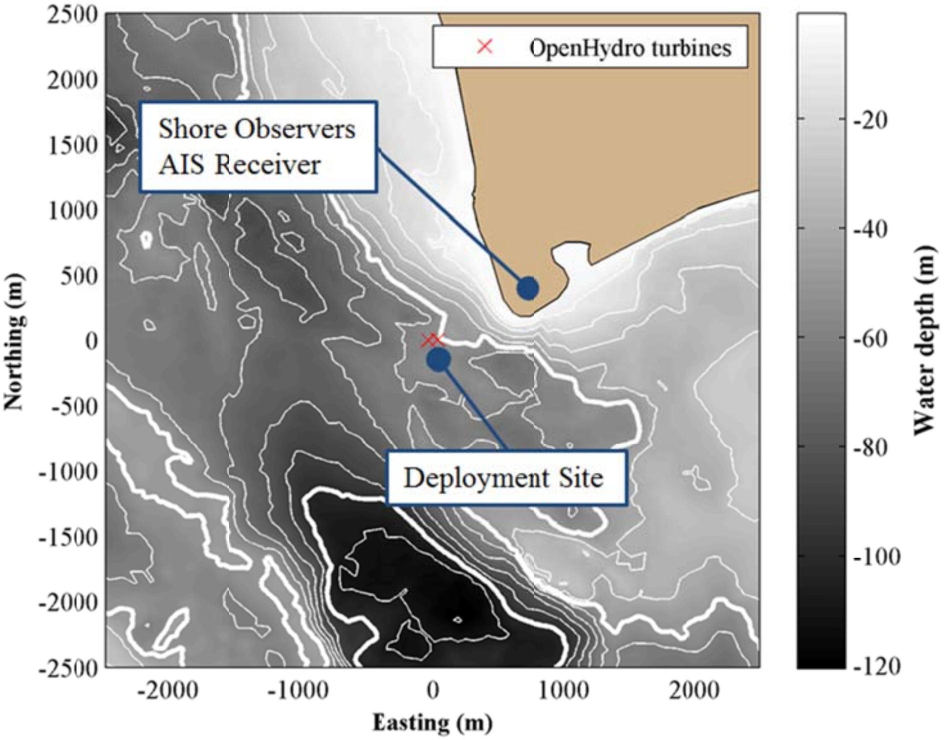


**Figure 4 – Project area with location of shore observer station noted on Admiralty Head.**

The second is a broadband hydrophone deployed at the Port Townsend Marine Science Center. This hydrophone is intended to increase detections of Southern Resident killer whale vocalizations as they transit through the inlet. In combination with existing observer networks and detections of vocalizations by hydrophones on the turbine foundation, notification of a Southern Resident killer whale transit would result in a rapid-response intensification of observations from several monitoring systems (shoreline observers, turbine instrumentation) intended to detect attraction, avoidance, or change in behavioral state associated with turbine noise or prey aggregation around the device.

The third is an Automatic Identification System (AIS) receiver deployed on Admiralty Head to monitor vessel traffic in the project area. This information provides helpful context for noise and marine mammal monitoring (e.g., Bassett et al., *in press*). Specifically, marine mammal observations must be stratified by, among other factors, proximity of shipping since marine mammals are expected to demonstrate avoidance to high-intensity (e.g., > 140 dB re 1µPa) ambient noise. Additionally, characterization of turbine noise described in the acoustic monitoring plan will be most effective when vessels are not underway in close proximity to the project. The effective range for the AIS receiver is approximately 20 km, which will detect vessel traffic beyond a distance where it would significant elevate ambient noise levels.

### 4.2 Vessel Monitoring

Vessel-based monitoring excels at collecting data over broad spatial scales. For example, vessel-based monitoring has been used to characterize ambient noise variability in the project area. Noise data are collected either by hydrophones cabled back to a survey vessel or autonomous near-surface drifters. Both techniques are suitable for collecting ambient noise data without contamination from pseudo-sound (turbulent eddies shed by the hydrophones, Bassett et al., *submitted*). Similar techniques will be used for characterizing the noise produced by turbines. Pre-installation monitoring also utilized a vertical line array of hydrophones to study diving patterns of killer whales by localizing their vocalizations (Tollit et al., 2010). This type of line array provides information about the depth and range of a noise source and may be used for post-installation monitoring of Southern Resident killer whales. When combined with information from shoreline observers, the bearing (as well as depth and range) to a Southern Resident could be estimated, as well.

While pre-installation studies have used vessel-based Doppler profilers to characterize the tidal resource intensity (Palodichuk et al., *in press*), these tools are not well-suited to studying turbine wakes due to beam spreading. At turbine depth, the four beams of a profiler bracket a circle 50 m in diameter, which is much greater than the width of the turbine wake (approximately 6 m). Measurements of wake and inflow conditions will be provided by instrumentation on the turbine foundation.

Pre-installation studies included the successful deployment of ROVs from surface vessels for benthic habitat monitoring (Greene, 2011). In order to be effective, ROV surveys must be timed around diurnal inequalities with protracted weak currents (e.g., < 1 m/s). This can provide several hours of operating time. ROVs will be used to survey the turbine foundation and cable route to characterize colonization and verify the assumption that the project will not increase scour or sedimentation.

### 4.3 Turbine Monitoring

Instrumentation deployed on the turbine foundation is best suited to long-term monitoring efforts with higher data and power requirements than pre-installation, autonomous monitoring to characterize a site (e.g., Sea Spider instrumentation packages, Polagye and Thomson, *in press*). Monitoring systems deployed on the turbine foundation represent the most ambitious aspect of project monitoring and, potentially, the source of highest-value monitoring data. Turbine monitoring systems are grouped into two categories – instruments that will be deployed for the duration of the demonstration project (fixed) and instruments that will be periodically recovered for maintenance (recoverable). Unless otherwise specified, instruments are connected to shore via the turbine power/data cables and can be controlled and reconfigured (e.g., changes to duty cycle, sampling rate) from shore.

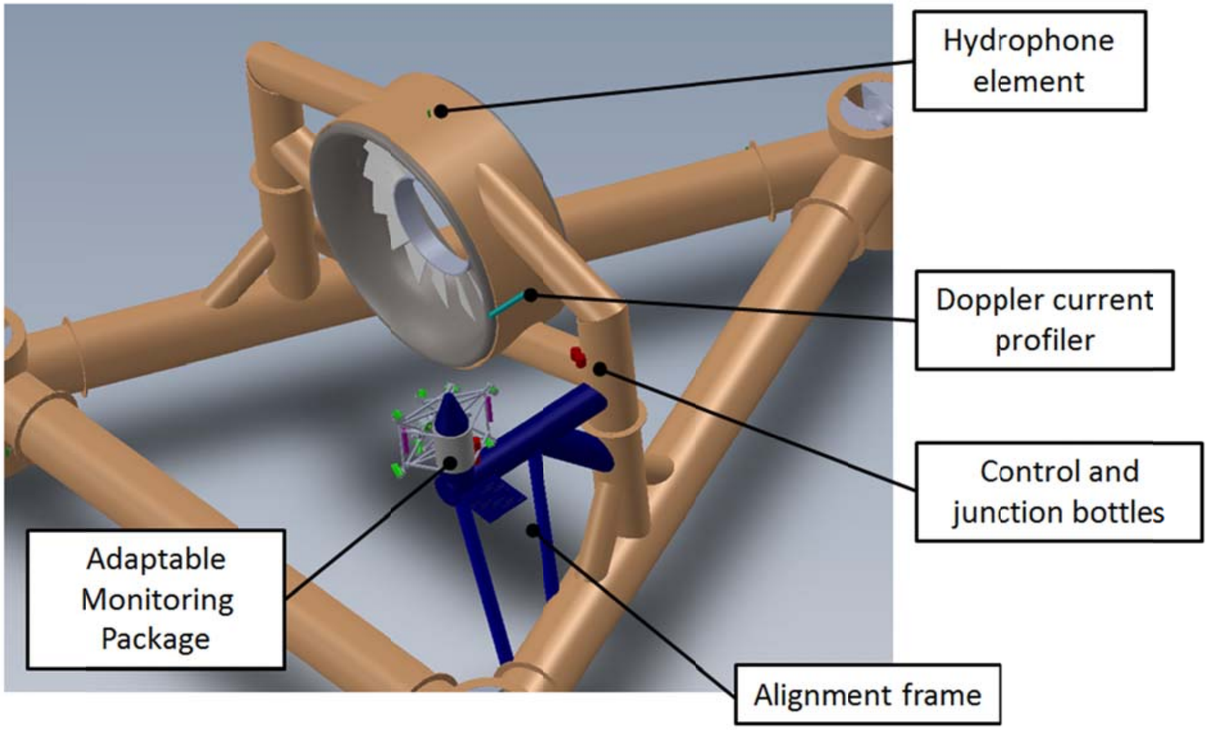


**Figure 5 – Conceptual instrumentation layout (fixed and recoverable). Instrumentation shown on a 4th Generation turbine (this has a higher rotor solidity than the 6th Generation turbine). The general dimensions of the subsea based and support structure are approximately constant between technology generations for the same rotor size.**

Fixed instrumentation on each turbine will include:

- Outward looking Doppler profilers to characterize turbine inflow conditions and the wake and upward looking Doppler profilers (one turbine) to characterize the vertical structure of the inflow velocity and device wake. These will be mounted at hub height on the outer surface of the turbine shroud. This information will be used to characterize turbine efficiency and provide context for environmental monitoring.
- Broadband hydrophones to monitor turbine noise and marine mammal vocalizations. Depending on technology feasibility, either a localizing array will be deployed or a single hydrophone. A localizing array would be able to determine the distance and bearing to vocalizing marine mammals in the project area. Average localization errors are unlikely to exceed 10 m at a distance of 300 m. If it is not feasible to deploy a localizing array on the turbine foundation, a vertical line array from a surface vessel could provide similar information in a "rapid response" mode. The information from the hydrophone(s) will be used to monitor for long-term changes in the turbine noise signature (as could accompany wear on the bearings or biofouling of the blades) and to detect vocalizing marine mammals at distances on the order of several kilometers. This information would be used to initiate rapid-response observations for Southern Resident killer whales.

- Turbine performance sensors monitored by OpenHydro's Supervisory Control and Data Acquisition (SCADA) system. Monitoring includes generator voltage/current, rotor rotational rate, structural vibrations, and generator temperature. While not directly related to environmental monitoring, pre-installation acoustic estimates (Polagye et al., *in prep*) suggest that observations of turbine noise and marine mammal responsiveness to turbine noise should be stratified by power generation state.

The fixed instrumentation system is being designed with limited expansion capability in order to allow other instrumentation to be incorporated ahead of project deployment. This could, for example, include an instrumentation package being developed by the National Renewable Energy Laboratory that would augment turbine performance monitoring.

Recoverable instrumentation on each turbine is centered around an Adaptable Monitoring Package and includes:

- A stereo imaging system to monitor the turbine rotor and characterize species-specific interactions with the turbine at close range. Because artificial illumination is required, the functional range for optical measurements is likely to be limited by the presence of biological "snow" to somewhere between 3 and 7 m. Field tests of this system are planned for summer 2012 to reduce this uncertainty. Additionally, because of the potential for behavioral disturbance caused by artificial lighting and high data bandwidths (100 MB/s at 10 Hz frame rate), this system will not be generally configured to operate continuously. Higher duty cycles could be enabled when Southern Resident killer whales might venture into the field of view for the camera systems. Bioaccumulation on the camera optical ports will require maintenance interventions every 3-6 months (less intervention in winter months, more intervention in summer months).
- An acoustic imaging system (BlueView P900-2250) with a similar field of view to the stereo imaging system, initially used to verify the limits for artificial illumination (frequency, duration) that do not cause a significant biological response.
- Water quality (one turbine) as part of a long-term study of dissolved oxygen levels in Puget Sound by the Washington Department of Ecology. Oxygen sensors drift over time and require recalibration every 3-6 months. This pilot project will not affected dissolved oxygen concentrations, but this partnership is intended to demonstrate the long-term potential for integrating tidal energy projects with Ocean Observing Systems (OOS).
- Click detectors (stand-alone) to monitor cetacean echolocation activity (principally harbor porpoise). These instruments (C-PODs) will not be connected to turbine power and data systems. Instruments will be deployed in redundant pairs. On board battery and storage capacity is sufficient for 3+ months of deployment. The detection radius for echolocation activity is approximately 200 m. Data from C-PODs will be compared to the 3+ year pre-installation baseline data for harbor porpoise activity to evaluate whether turbine operation reduces echolocation activity or alters factors underlying echolocation activity (day/night, current speed, season, etc.). Click train data from C-PODs also can be used to identify "landmark" activity, periods in which marine mammals are echolocating directly at the C-POD (or the structure it is attached to). This information will be compared to the rate of pre-installation "landmark" encounters for Sea Spider instrumentation packages to evaluate whether harbor porpoise are taking direct notice of the turbine during operating and/or idle periods.

- Fish tag receivers (stand-alone) to monitor for the presence of tagged fish in the project area. These instruments (Vemco receivers) will not be connected to turbine power and data systems. Instruments will be deployed in redundant pairs. On board battery and storage capacity is sufficient for 6+ months of deployment. The detection radius for tags is approximately 250 m. Information from the Vemco receivers will be combined with observations from the stereo camera systems to evaluate whether the species observed by the cameras are consistent with tagged species in the project area. The District does not intend to conduct dedicated tagging studies, because the extent of Admiralty Inlet in comparison to the detection radius for the receivers means that tag detection is, at best, opportunistic. Pre-installation acoustic estimates (Polagye et al., *in prep*) suggest that fish are unlikely to detect turbine noise at ranges beyond a few hundred meters.

The Adaptable Monitoring Package (Figure 6) is being designed with limited expansion capability in order to allow new instruments to be incorporated into monitoring plans after deployments of the turbines. Similarly, if fixed instrumentation were to become inoperative, a replacement could be incorporated into the recoverable package.

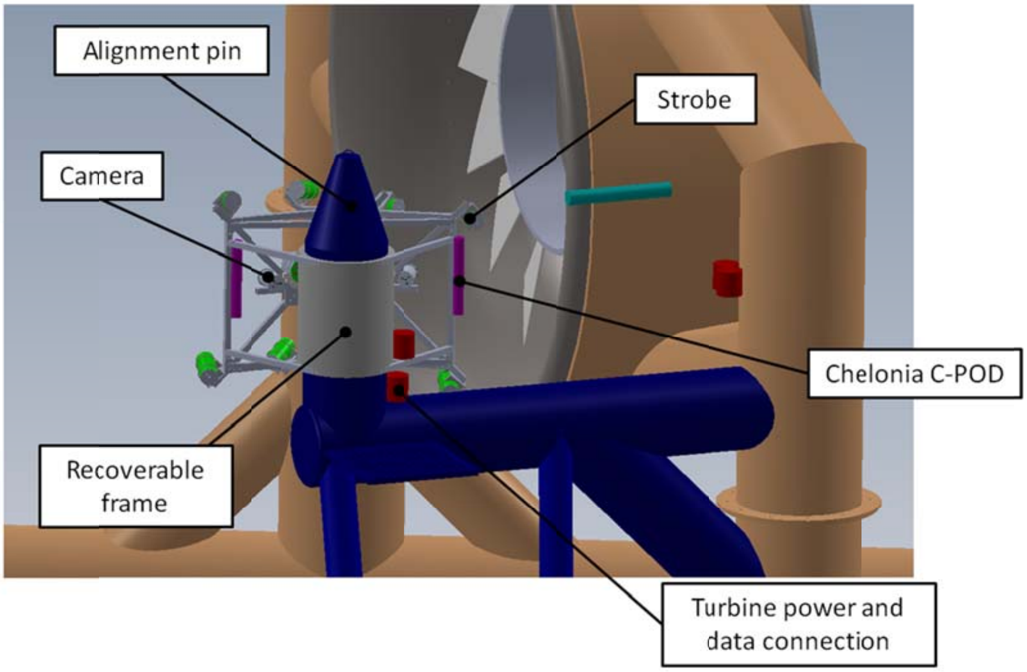


**Figure 6 – Adaptable Monitoring Package detail**

Because of the water depth and current velocities, the recovery and redeployment of instrumentation is one of the defining technical challenges of this project. Specifically, the challenge is that some instrumentation will require more frequent maintenance than the turbine itself, must be deployed in close proximity to the turbine rotor, and must be cabled to shore. An instrumentation package is, therefore, needed that can be recovered to the surface, serviced, redeployed, and reconnected to turbine power and data systems without the use of divers (safety consideration) or work-class ROV (limited availability in Puget Sound). The stereo imaging system bandwidth (100 MB/s at 10 Hz) necessitates a fiber optic connection to shore. A wet-mate power (2 conductors) and fiber (4 fiber optic channels) connector is manufactured by Teledyne ODI and is used in ocean observing systems. The connectors are expensive (~$100k per connector and cable assembly) and have a limited number of connect/disconnect cycles

(~100). All recoverable instrumentation will be connected to the grey frame shown in Figure 6 with data and power connections aggregated to a single wet-mate connection. During redeployment, this frame will mate with the blue alignment pin on the turbine foundation and reconnect to turbine power/data systems. The most likely redeployment scenario involves a “powered frame” on an umbilical to a surface vessel. The powered frame (positively buoyant) would be connected to the instrumentation frame (negatively buoyant) for a neutrally buoyant combined package. ROV technology would be adapted to provide camera, lights, and thrusters on the powered frame. The powered frame would position the instrument frame on the alignment pin and then release it, allowing gravity to engage the instrument frame and buoyancy to bring the powered frame back to the surface. During maintenance, the instrument frame would be recovered using redundant acoustic releases. No anchoring would be required for this operation.

Because recovery of the OpenHydro turbines requires unobstructed access to the rotor face on the apex side of the foundation tri-frame (upper right portion of Figure 5), the recoverable instrumentation package can only be deployed to one side of the turbine rotor. In order to monitor upstream and downstream conditions on both ebb and flood, the two turbine foundations will be deployed in a mirrored configuration (i.e., one foundation will be rotated 180 degrees relative to the other, as shown in Figure 7). Several options were considered that would allow instrumentation to be deployed at hub height on both sides of the turbine rotor, but all presented an unacceptable increase in technical risk and cost (e.g., potential that the turbines could not be recovered using the approach proven in the Bay of Fundy; monitoring system structural requirements driving overall turbine design requirements).

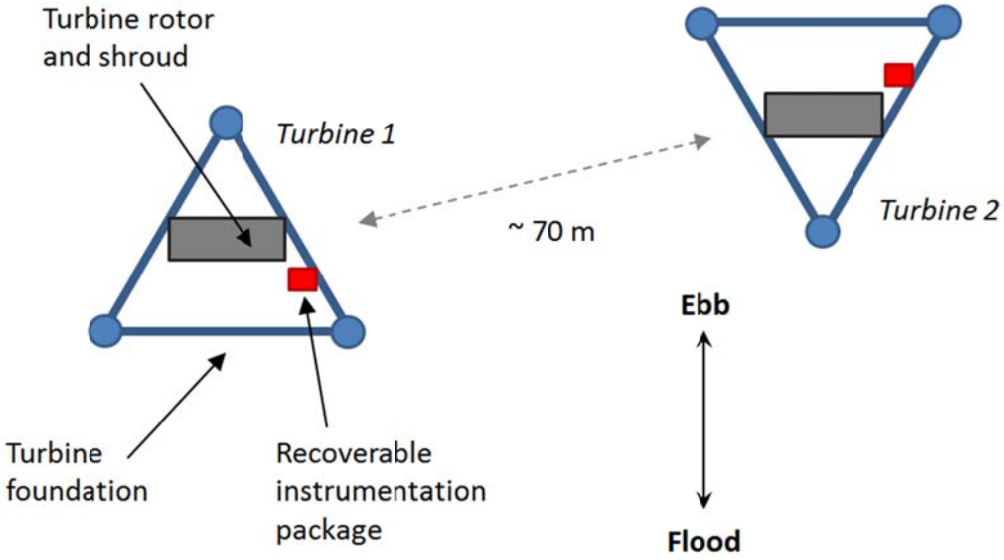


**Figure 7 – Turbine and monitoring system arrangement**

## 5 Post-Installation Monitoring Plans

All post installation monitoring plans are described in terms of specific hypotheses, the tools and analytical approaches that will be applied, and a discussion of why these are appropriate hypotheses to test.

### 5.1 Benthic Habitat Monitoring Plan

***Hypothesis 1*****:** *The turbine will be colonized and provide artificial habitat that supports different benthic communities than are currently present in the Project area.*

Pre-installation surveys (Greene, 2011) have characterized the benthic habitat in the Project area as cobbles and boulders, colonized by barnacles, sponges, and algae. The turbine foundation will have considerably greater vertical relief (e.g., turbine shrouds will extend to 13 m above the seabed) and may support different benthic communities. Anecdotal reports from tidal energy projects in Europe indicate that turbine foundations are often colonized within a year of deployment. Information about how this project affects the local benthic community structure would provide information about how a larger array might affect the community and guidance for engineering refinements to foundations that promote desirable benthic communities (potential benefit) and minimize undesirable benthic communities (potential impact).

Surveys to characterize colonization of the turbines (e.g., coverage, colonization rates, and species involved) will consist of focal observations of specific regions of one turbine by an ROV deployed from a surface vessel. Surveys will be timed around diurnal inequalities that provide extended periods (i.e., multi-hour) when currents are weak enough to operate an ROV. Surveys will be conducted every three months for the first year of project operation and twice per year thereafter.

***Hypothesis 2***: *The contact points between the turbines and the seabed will not result in deposition of fine sediments or scour.*

Pre-installation surveys indicate that the seabed in the project area is predominantly scoured of fine-grained sediments due to the strong tidal currents in the project area. Because turbidity is relatively low in Admiralty Inlet (Polagye and Thomson, 2010) and the currents reverse direction approximately every six hours no net accumulation of fine-grained sediments are expected in the turbine wake or around turbine structures. Accumulation of fine-grained sediments where none presently exist would alter benthic communities and could be environmentally significant (i.e., rise to the level of a change) for a large-scale installation.

During the ROV surveys to characterize colonization of the turbine structures, the ROV will survey the locations the turbine foundation contact the seabed to evaluate scour or deposition.

**Hypothesis 3**: *The power cable and horizontal directional drill exit point will be colonized and are likely to return to pre-installation conditions over time.*

As for the subsea base, the power and data cables to shore are likely to be colonized by marine life. Unlike the subsea base, these will not have significant vertical relief, so the creation of different benthic habitat is unlikely and the primary interest is in determining the rate at which these cables are colonized and whether, over time, any significant cable movement occurs. Similarly, the rate at which the horizontal directional drill exit point is colonized and returned to a pre-installation state is of interest.

During the ROV surveys to characterize colonization of the turbine structures, the ROV will also survey several focal points along the cable route and the horizontal directional drill exit point.

### 5.2 Acoustic Monitoring Plan

The acoustic monitoring plan is intended to verify the suitability of assumptions made in a pre-installation acoustic estimate (Polagye et al., *in prep*) and inform the spatial and temporal extent for marine mammal monitoring activities.

***Hypothesis 1***: *Turbine sound will vary with power generation state*

Turbine sound is likely to vary with power generation state (i.e., more sound will be produced when the turbines are closer to their rated capacity than around cut-in speed). However, no studies to date have rigorously assessed this relation. Pre-installation estimates indicate that if turbine sound does vary with power generation state (as shown in Figure 8), the extent of marine mammal responsiveness to turbine sound will also be a strong function of power generation state. Understanding time-varying nature of turbine sound is central to evaluating the acoustic effects for large arrays and informing engineering design decisions that could enable quieter turbines.

Turbine sound will be characterized using drifting hydrophones deployed at a range of distances from the turbines at different tidal velocities (e.g., 1.5, 2.0, and 2.5 m/s). Surveys will be conducted during early morning hours, when vessel traffic in Admiralty Inlet is at a minimum (Bassett et al, *in press*). The survey sequence will involve drifting hydrophone measurements with both turbines operating, engaging the brake on one turbine to measure the sound from a single device, engaging the brakes on both turbines to measure ambient noise in the absence of turbine operation, and then releasing the brakes in sequence to return to the initial operating state. In doing so, any acoustic transients associated with engaging or disengaging the brakes will also be characterized.

Pre-installation estimates (Polagye et al., *in prep*) indicate that characterizing turbine sound will be more successful during currents exceeding 2 m/s and should be concerned within several hundred meters of the turbine. Figure 9 shows the percentage of one-third octave bands likely to be detected at different inflow conditions (and, comparably, power generation states).

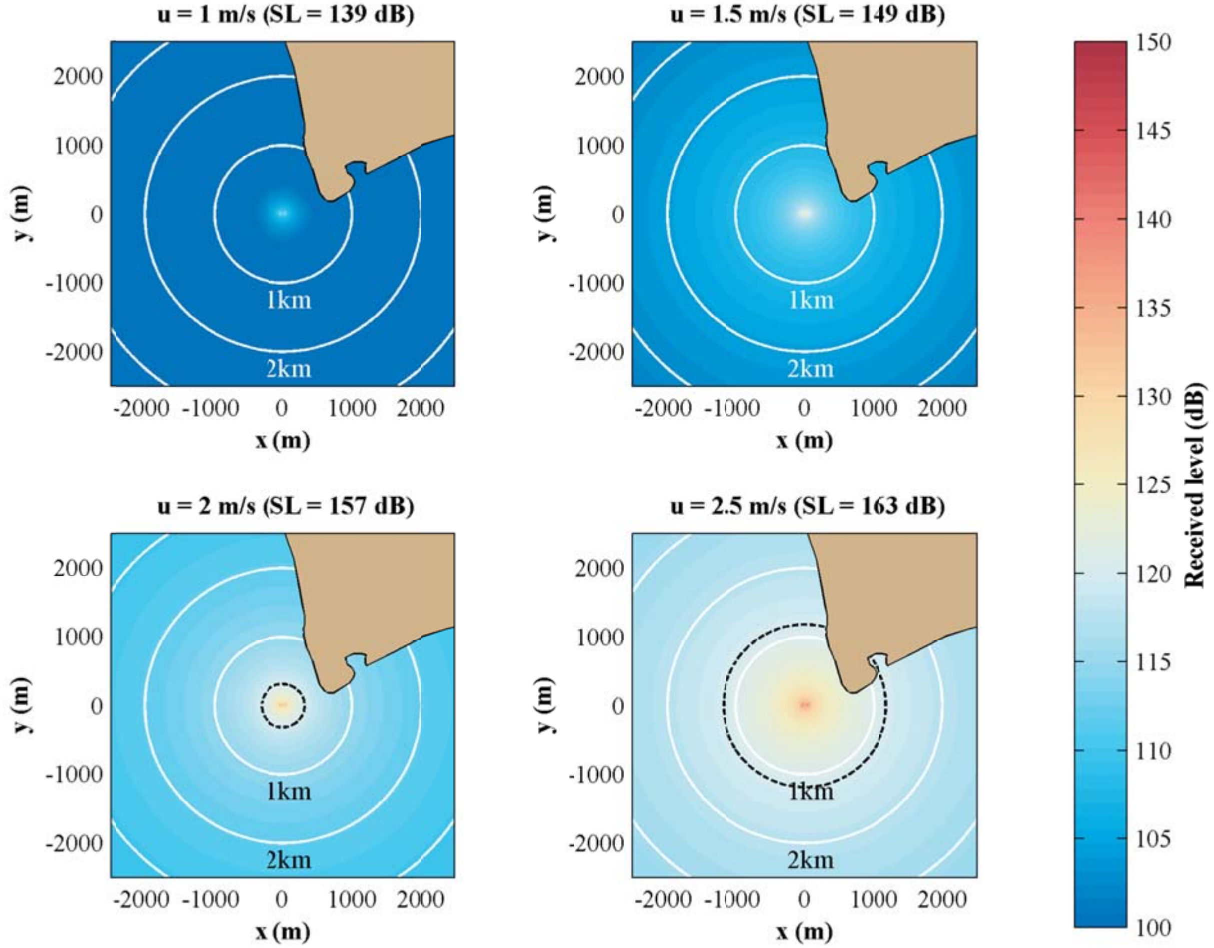


**Figure 8 – Broadband (25 - 25 000 Hz) received levels at four inflow velocities (30 m depth relative to surface). Dashed black contour denotes the 120 dB isobel (regulatory harassment threshold at this site). (Polagye et al., *in prep*)**

***Hypothesis 2***: *Turbine sound may demonstrate a long-term variation due to wear on bearings or biofouling of the rotor and shroud.*

If, over the time, the bearings on the turbine experience wear or the rotor and shroud are fouled (in spite of anti-fouling coatings), the acoustic signature of the turbine may vary. Information about long-term trends in sound produced is needed to evaluate acoustic effects over the operating life for a commercial project (nominally 25 years). While this pilot project will be substantially shorter in duration at five years, this time frame does correspond to expected maintenance intervals and information about trends in the acoustic signature of a device will be instructive.

During the acoustic characterization study, received levels for the drifting hydrophones will be correlated with received levels recorded by the fixed hydrophones on the turbine foundation. Because these fixed hydrophones will also detect “pseudo-sound” associated with turbulence, flow shields will be required. Turbine noise recordings will be archived on a low duty cycle (e.g., < 10%) and used to assess trends on an annual basis (stratified by power generation state and proximity of shipping).

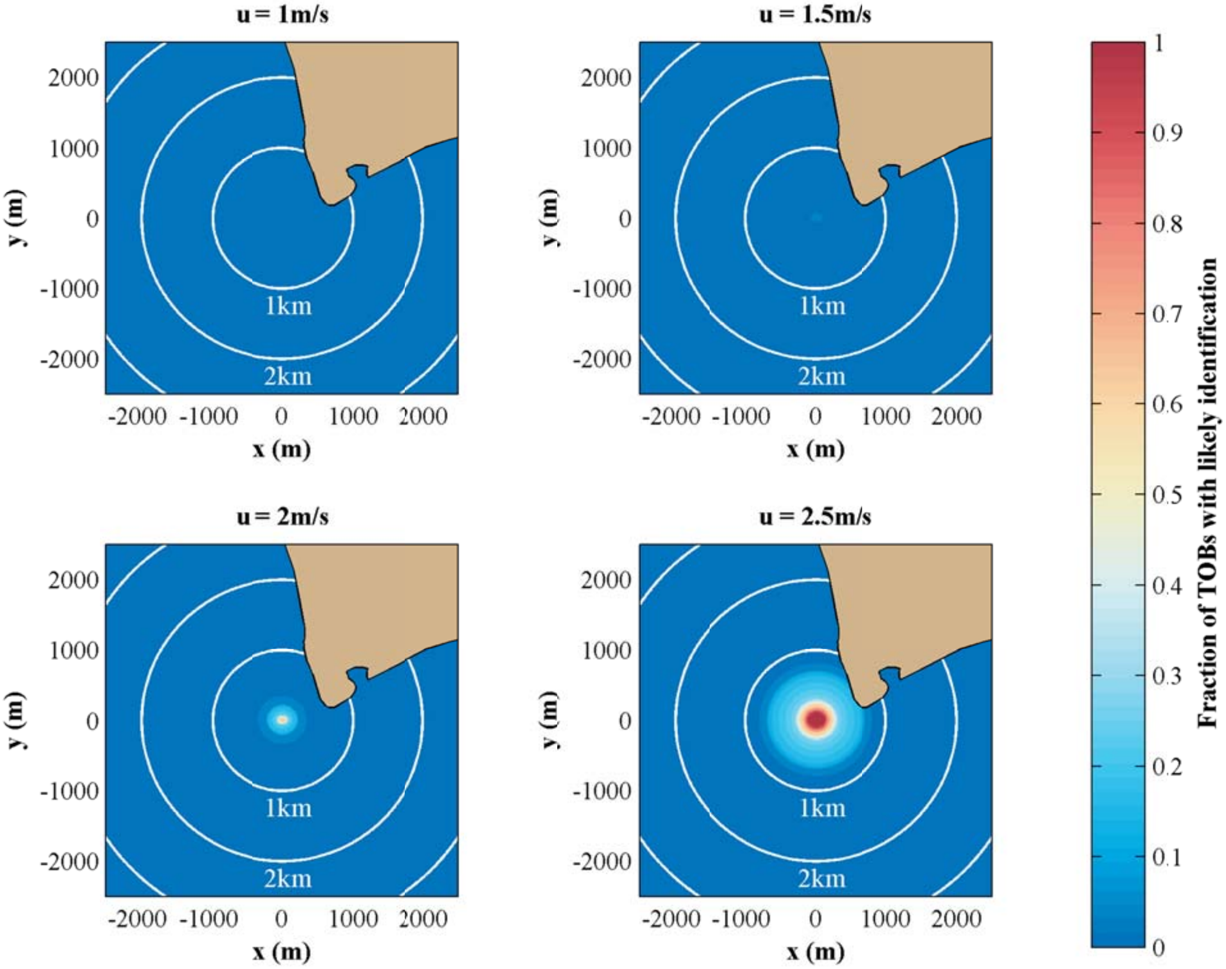


**Figure 9 – Fraction of one-third octave bands likely to be identified at four inflow velocities by a drifting hydrophone receiver (at least 75% probability, 25 – 25 000 Hz, 5 m depth relative to surface). (Polagye et al., *in prep*)**

### 5.3 Near-turbine Monitoring Plan

Note: the hypotheses and specific approaches described here are presently under active development, pending the outcome of stereo-camera instrumentation trials during the summer of 2012.

***Hypothesis 1****: Strobe illumination may result in a species-specific startle response, avoidance response, or attraction.*

Artificial illumination is necessary for optical image capture at the depth of the project. Additionally, in order to “freeze” motion and produce a crisp image of objects moving at velocities on the order of several meters per second an exposure time of 2-50 µs is recommended (Gallager et al., 2004). This cannot be achieved with a mechanical shutter, but is within the capabilities of machine vision strobes in dark environments (i.e., strobe acts as a virtual shutter). However, the use of strobe illumination may affect behavior of marine animals in a manner that depends upon a number of factors including strobe rate and duration of illumination, organism or fish species and life stage, and hydrodynamic conditions. Fish behavior in response to strobe lights may be complex; based on studies at dams on the Columbia River (Johnson et al. 2003, Johnson et al. 2005, Simmons et al. 2006), there was a wide range of attraction and avoidance behaviors that varied with time of day and species. Marine fish behavior in response to lighting appears to be similarly complex, with great variation among different species and life stages, from avoidance to attraction, or no reaction to lights (Marchesan et al. 2005, Stoner et al. 2008, Ryer et al. 2009).

The objective of this study is to establish species- and season-specific thresholds for fish responsiveness to the strobes (duration and strobe frequency) that will inform appropriate use of the camera system for studies of presence/absence (Hypothesis 2), interaction with the moving rotor (Hypothesis 3), artificial reef effects (Hypothesis 4), and avoidance behavior (Hypothesis 5). In other words, this study will develop operating guidelines for the strobes that minimize behavioral changes associated with its operation. It is unlikely that these thresholds will be absolute and close consultation with the MARC will be required to develop these guidelines. Studies will be structured to evaluate the effect of strobe frequency (up to 10 Hz), duration of lighting (up to 60 seconds), and time between successive lightning periods. Information from the acoustic camera will serve to detect strong startle responses, avoidance responses, and the “cool down” time required for behavior to return to normal once strobe illumination ceases.

***Hypothesis 2***: *The turbine may attract aquatic species due to the area of refuge offered by the low-velocity wake.*

Observations of the OpenHydro turbine at EMEC have shown that fish (specifically, Pollock) aggregate in the turbine wake during low-velocity conditions because this offers an energetically preferable area of refuge. As water velocity increases, fish leave the area, either for energetic reasons or because of the acoustic stressor. Understanding the attraction of aquatic species (predators and prey) to turbines is needed to evaluate environmental impacts for large-scale development.

The primary monitoring tool will be the stereo cameras deployed on the turbine foundation, though some supplemental information may be provided by Vemco receiver detections from outside the cameras’ field of view. The need to periodically maintain these cameras (biofouling, repositioning) is the principal driver for the recoverable instrumentation package on the turbine foundation. Observations will be duty-cycled in order to limit the behavioral changes associated with artificial lighting and to provide a manageable data stream for analysis (at maximum frame rates, each stereo camera pair generates ~100 MB of data per second). Adaptive Management will be employed, post-installation, to determine an optimal duty cycle and duration of measurements.

***Hypothesis 3*****:** *Marine animals are unlikely to pass through the rotor or open center during turbine operation.*

Video observations of the OpenHydro turbine at EMEC have not shown aquatic species (fish, marine mammals, or diving seabirds) to pass through the rotor or open center during turbine operation. Passage through the turbine during operation poses a risk of blade strike. Active acoustic observations of the Ocean Renewable Power Company turbine in Eastport, Maine indicate that smaller fish may swim through the turbine during all operating states. The differences between these observations may be associated with the species involved or type of device. Certainly, concern over potential injury or mortality associated with blade strike represents a critical uncertainty associated with potential environmental impacts of tidal energy development.

The primary monitoring tool to address the hypothesis that aquatic species are unlikely to pass through the rotor (based on the experience testing a similar turbine at EMEC) will also be stereo cameras. As for the second hypothesis, the most appropriate duty cycle and duration of observation will be determined through Adaptive Management with resource agencies. During observations, the cameras will be oriented towards the turbine rotor to maximize the portion of the rotor in the field of view.

***Hypothesis 4***: *The turbine may attract marine animals due to an artificial reef effect.*

It is likely that the turbine support structure will act as an artificial reef and attract fish that associate with complex habitat. This may have positive or negative effects, depending on the attracted species.

The objective of this study is to characterize how marine animals are using the turbine support structure over all stages of the tide. This will be correlated with information about the colonization of the subsea base and turbine support structure collected by the Benthic Habitat Monitoring and Mitigation Plan.

Since reef effects are a lower priority than strike/collision, this study will be conducted after the presence/absence, artificial illumination, and rotor interaction studies planned for the first year of operation.

The primary monitoring tools to address the hypothesis will be the stereo cameras, complemented by imagery from the acoustic cameras. The objective will be characterize, to the lowest taxonomic level possible, marine animal use of the turbine support structure over various time scales and tidal current conditions.

***Hypothesis 5***: *Fish may avoid the turbine due to its pressure field or sound (particle velocity or acoustic pressure).*

In addition to direct interaction and attraction/aggregation, fish may avoid the turbines. This could occur at relatively close range (within a few rotor diameters) as they detect hydrodynamic pressure changes upstream of the turbine on their lateral line system. Detection of acoustic particle velocity may be possible for some fish species at similar distances by the same biological mechanism. At greater distances, up to several hundred meters, fish may exhibit avoidance behavior in response to acoustic pressure (i.e., turbine sound), though fish behavioral responses to sound are not well understood (Hawkins and Popper, 2012). Avoidance at close range, if preventing strike or collision, could be beneficial. However, avoidance at greater range would be undesirable, since a large array could create a barrier to migratory species.

Since avoidance of the pilot-scale turbines is a lower priority than strike/collision, this study will be conducted after the seasonal presence/absence, artificial illumination, and rotor interaction studies planned for the first year of operation.

The primary monitoring tools to address the hypothesis will be the stereo cameras, complemented by imagery from the acoustic cameras for avoidance associated with upstream pressure changes or acoustic particle velocity. Avoidance at greater range would likely require lower frequency active sonars. Because these systems may produce sound at frequencies audible to marine mammals, study plans for longer range avoidance will need to be developed in consultation with appropriate resource agencies.

### 5.4 Marine Mammal Monitoring Plan

***Hypothesis 1***: *Pinnipeds may respond to the acoustic stressors from turbine operations or prey aggregations through attraction or avoidance.*

Marine mammal behavioral responsiveness to noise is a well-known, but not well-understood in terms of relating a particular noise to a particular response (e.g., as discussed in Southall et al., 2007). The acoustic stressor from project operation is, however, likely to be the first cue associated with the project that is detected by marine mammals. The zone of noise detection establishes an upper bound on the zone of responsiveness. As described in Polagye et al. (*in prep*), given assumptions regarding the time variation of turbine noise and pre-installation measurements of ambient noise, the zone of probable detection extends no further than a few hundred meters around the turbines for mid-frequency cetaceans, high-frequency cetacean, and pinnipeds. The zone of detection for low-frequency cetaceans is likely to be somewhat greater, but cannot be estimated with certainty due to a lack of audiogram information for this class of marine mammal.

Pinniped responsiveness to turbine noise will firstly be evaluated by 2-3 experienced shoreline marine mammal observers positioned on Admiralty Head, utilizing a scan sampling procedure. Observations will focus on identifying attraction or avoidance within the zone of detection for turbine noise. Initially, the zone of detection will be as established by the pre-installation estimate (Polagye et al., *in prep*), but will be updated once information is available from post-installation noise characterization (§ 5.2). Observations will be stratified by month, time of day, and presence of prey species in the vicinity of the turbines (as informed by the Near-turbine Monitoring and Mitigation Plan). The duration and frequency of shoreline observations will be developed through collaborative discussions with resource agencies and may be modified, post-installation, through Adaptive Management.

***Hypothesis 2***: *Harbor porpoise may respond to the acoustic stressors or prey aggregations through attraction or avoidance. Their high rate of occurrence in the Project area provides an opportunity to conduct studies with greater statistical power than for other marine mammals.*

Pre-installation monitoring indicates a high level of porpoise activity at this location (Tollit et al., 2010; Cavagnaro et al., *in prep*). Consequently, observations of harbor porpoise may have greater statistical power to detect behavioral change. First, shoreline observers will monitor the point of closest approach (POCA) and directionality (i.e., approach towards the turbine outside of zone of audibility and movement while inside zone of audibility) in comparison to the estimated signal excess of turbine sound at various distances. Second, click train data from C-PODs also can be used to identify “landmark” activity, periods in which marine mammals are echolocating directly at the C-POD (or the structure it is attached to). This information will be compared to the rate of pre-installation “landmark” encounters for Sea Spider instrumentation packages to evaluate whether harbor porpoise are taking direct notice of the turbine during operating and/or idle periods. Third, comparisons will be made to pre-installation information (3+

years), in order to determine if statistically significant differences in echolocation activity, or the factors underlying echolocation activity (as determined by a Generalized Linear Model) have changed significantly as a consequence of turbine operation. Finally, shoreline observations associated with the first hypothesis will be used to evaluate the detection probability for C-PODs (e.g., after Kyhn et al., 2012). C-PODs will be deployed for the duration of the pilot project and recovered every 3-6 months as part of the maintenance cycle for the Adaptable Monitoring Package.

***Hypothesis 3***: *Killer whales may respond to the acoustic stressors or prey aggregations in the vicinity of the turbine through attraction, avoidance, or change in activity state. Their endangered and iconic status warrants special consideration.*

Killer whales are an endangered and iconic species in Puget Sound. In recognition of this, the Marine Mammal Monitoring and Mitigation Plan allocates a higher intensity of effort to observing their behavioral response to the turbines than other marine mammals. Information about how killer whales interact with tidal turbines must be established before larger-scale or longer-term projects could be considered in Admiralty Inlet. While pre-installation studies indicate that interaction with a tidal turbine is unlikely to result in significant injury or mortality (Carlson et al., 2012), behavioral changes are also of concern.

Unlike pinniped and harbor porpoise monitoring, monitoring of killer whales will continue throughout the project lifetime and utilize shore-line observers, localizing hydrophones, and the near-turbine monitoring system. These tools will be utilized in a rapid-response mode when killer whales are transiting through Admiralty Inlet. Based on pre-installation monitoring (Wood et al., 2010), ~40 transits occur each year. Rapid responses would likely be possible for at least 50% of these and would be informed by existing sighting networks and detections of Southern Resident killer whale vocalizations by the shore-based hydrophone in Port Townsend or the hydrophones on the turbine foundations. First, shoreline observers would provide high-accuracy information about group and individual positions and behavioral states while within the zone of turbine sound detection. Second, localizing hydrophones (either on the turbine foundations or deployed from a vessel as a line array) would be used to track killer whales as they pass through the zone of detection. Passive acoustic data would also be post-processed if a transit is reported after the fact (i.e., passive acoustic data will be archived). Further, the stereo-camera systems could be operated at higher duty cycle to investigate whether killer whales are interacting directly with the turbine (as limited by the need to not artificially influence behavior). Additionally, information from the near-turbine monitoring plan will identify potential prey aggregations that might serve to attract killer whales to the turbines. Unlike harbor porpoise or pinnipeds, the number of killer whale transits will not be large enough to employ a grid-based GAM/GEE analytical approach, as power to detect change will be too low. In order to test the hypotheses of attraction/avoidance or behavioral change, the following metrics will be used for shoreline observations: directionality of transit, surfacing interval, behavior state, surface active behavior (SAB), click rate, and call rate. The data collected will be analyzed to identify behavioral responses and modifications to the monitoring approach will be developed collaboratively with resource agencies through Adaptive Management.

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