Marine Mammal Behavioral Response to Tidal Turbine Sound

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PROJECT INFORMATION

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LONG-TERM GOALS

The primary goal of this project is to improve the understanding of how the sound emitted by tidal turbines may affect marine mammal behavior. This remains one of the areas of highest environmental uncertainty for marine energy, but also one that may be most possible to "retire" for initial demonstrations and arrays. A secondary goals is to evaluate the efficacy of marine mammal observations from a shore-based vantage point to detect change as a consequence of marine energy stressors. This has implications for studies of marine mammals in a range of environments, not just tidal energy sites.

OBJECTIVES

The objective of this project is to observe the presence, absence, and behavior of harbor seals (serving as an archetype for pinnipeds) and harbor porpoises (serving as an archetype for high-frequency cetaceans) in a region ensonfied by simulated turbine sound and assess any changes in presence, absence, and behavior as a consequence of this sound. The effects of the sound will be evaluated by a continuous variable, signal excess, that describes the difference between received of simulated turbine sound levels by marine mammals and ambient noise levels in the absence of a turbine. The latter will be estimated by a forward acoustic model that uses vessel proximity and current speed as inputs and verified by in-situ acoustic observations.

APPROACH

Study Location

The observation site is Admiralty Inlet, a relatively narrow, shallow channel connecting the main basin of Puget Sound to the Salish Sea. The channel is approximately 5 km in width at its narrowest point and, on average, approximately 60 m deep. The constriction in Admiralty Inlet produces tidal currents that can exceed 3 m/s. As a consequence, a tidal energy demonstration project, consisting of two turbines, was advanced over a multi-year period by a local utility district and international technology developer. Ultimately, cost considerations led to the termination of that project. However, the location remains attractive, in the longer-term, for tidal energy development and the demonstration project produced a significant quantity of baseline observations describing the natural and physical environment. The combination of existing data and future potential motivated its selection for this study.

Simulated Turbine Sound

Because turbines were not present at the site, their sound was simulated using a vessel-based playback from a J11 acoustic projector. The basis for this sound was observations of the Ocean Renewable Power Company's RivGen river current turbine, obtained by Dr. Polagye in 2014. A three second recording near the point of closest approach was filtered to contain sound between 30 Hz and 10 kHz. As shown in Figure 1, the sound is relative broadband, with a characteristic peak at 100 Hz associated with noise from the electrical generator. Because the RivGen turbine was relatively small (11 m in length, 1.5 m in diameter), the sound was amplified to a meansquare sound pressure level of 158 dB re 1µPa and played on a continuous loop. The amplitude and pressure spectral density of the sound was verified by suspending a hydrophone (OceanSonics icListen HF) 1 m from the J11 in quiescent water.

During the study, Dr. Joslin and laboratory staff moored a small vessel in Admiralty Inlet and deployed the J11 from its stern at a depth of approximately 10 m. A 2 kW Honda generator provided power to the amplifier, projector, and control computer while, all other vessel systems were shut down. A cartoon of this arrangement is shown in Figure 2. To minimize transmission of generator sound into the water, the generator was suspended above the deck with bungee cords.

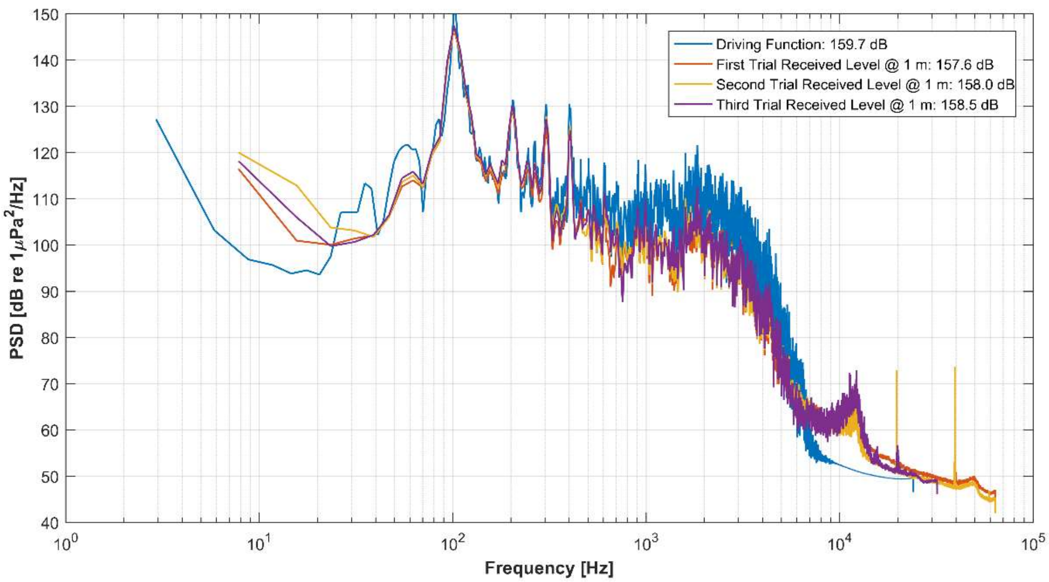

Figure 1: Simulated turbine sound used for the playback study. The blue spectrum represents the driving signal supplied to the amplitude and the other spectra represent the three deployments, as characterized in quiescent water in the harbor at Port Townsend, Washington.

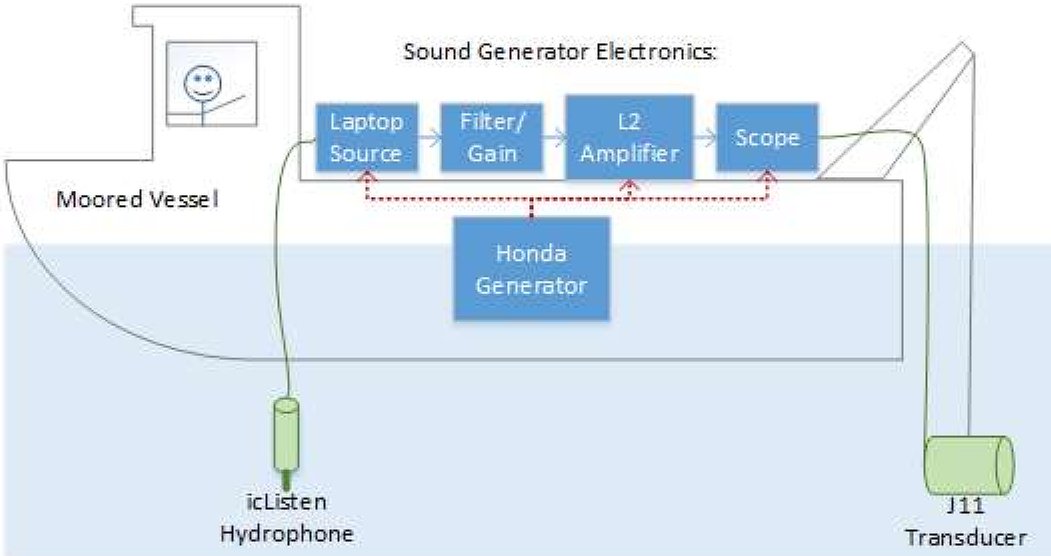

Figure 2: Cartoon of vessel configuration for playback operations

Given the high currents in Admiralty Inlet, a large mooring was required to anchor the 22 foot vessel used for the playback. This mooring, along with an autonomous instrumentation tripod shown in Figure 3 were deployed by a larger (50 foot) research vessel prior to each study and recovered after the 2 week study period.

For each day of the playback study, the small vessel would moor at the site for approximately 6 hours. Each playback session would start with a 10 minute warm up period during which the sound projection level was ramped up to 158 dB. During these periods, the projector was only operated when sighting conditions were sufficient for the shore observers to warn against the approach of endangered marine mammals. If endangered marine mammals, such as whales, approached, the playback was suspended until the animal had left the area.

The received levels from the playback were characterized by a series of drifting hydrophone measurements during the first survey. These results were interpreted to estimate a range-dependent transmission loss coefficient (N) where

$$TL = N \log_{10} D$$

TL is the transmission loss between the source and a receiver, in dB, and D is the slant distance between the source and a receiver in m. At distances greater than 200 m, the transmission loss coefficient was relatively constant, around 17 dB.

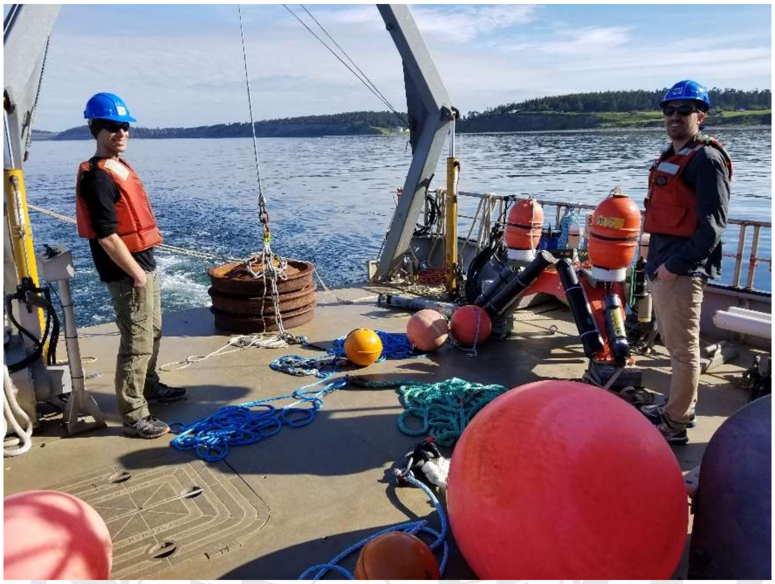

Figure 3: Mooring wheel stack and Sea Spider aboard the R/V Jack Robertson prior to deployment

Co-Temporal Environment

Automatic Identification Systems (AIS) broadcast the location, type, and speed of AIS-enabled vessels. These data were collected simultaneously to marine mammal observations by using an AIS receiver and computer. These data will be used to model ambient noise in the study area generated by passing ships, as discussed further on in this report.

In-situ data are collected using a Sea Spider platform equipped with several autonomous sensors. The platform is shown in **Error! Reference source not found.**. These include a Nortek Continental 470 kHz ADCP to measure currents, Loggerhead DSG recording hydrophones, and Chelonia C-PODs to characterize porpoise presence/absence below the water surface.

Marine Animal Observations

Marine mammal observations were conducted from a land-based vantage point overlooking the playback location. Admiralty Head (48.155N, -122.678W) was chosen based on its proximity to the playback site and because marine mammals observations had been successfully conducted at this location in 2011. Marine mammal observations were conducted by SMRU Consulting marine mammal biologists Drs. Frances Robertson and Jason Wood, supported by several undergraduate students.

<u>Data Collection</u>

Shore based observations were conducted following vantage-point methodologies. These encompass surveys where observers conduct repeated observations from one or more points that provide a good view of the study area (Oedekoven et al. 2013[1]). Vantage-point surveys have the advantage of being cost effective to run (compared to boat based surveys) and require fewer observers. There is also no risk of the observer's behaviour or presence influencing the focal animal species – this is crucial when trying to assess potential impacts of specific human activities such as tidal turbine device operation.

We employed a combination of systematic scan sampling and focal follow survey techniques using a photogrammetric approach. This method requires only a camera and binoculars, as opposed to more traditional methods involving a surveyors' theodolite. Reticle-compass binoculars were mounted on a custom-built frame above a Cannon D80 SLR camera (Figure 4). The camera was capable of both still image and video data capture allowing us to collect still images of pinnipeds and video tracks of harbor porpoise using the same equipment. Based on the known location of the camera and known locations of landmarks captured in the images, the locations of the animals in the images can be estimated.

Figure 4: Vantage point equipment setup. Cannon DSLR camera capable of both still image and video footage mounted with compass-reticule binoculars in a custom-built frame. The Tri-pod legs were marked to ensure that the system was set up in the correct position at the start of each day and the height measured to ensure that the camera was always at the same height. A specialized video panning tripod mount allowed for smooth panning across of the survey area.

Scan sampling was conducted in a systematic manner every ten minutes from north to south across the study area during daylight hours and when sighting conditions were considered good to moderate, i.e. with sea states less than Beaufort 3, no rain and landmarks on the far shore visible. Each scan lasted approximately two-minutes; environmental conditions (e.g. sea state,

[1] Oedekoven CS, ML Mackenzie, L Scott-Hayward, and E Rexstad (2013) statistical modelling of bird and cetacean distributions in offshore renewables development areas: Literature review. University of St. Andrews contract for Marine Scotland

cloud cover, glare, and an overall visibility score) were recorded at the start and end of each scan. When a pinniped was detected an image was collected and data on the species, group size, group composition (e.g. whether or not a calf or pup was present), activity state, behavior, heading and speed of movement were recorded using a digital recorder. Scans were paused to undertake focal follows when harbor porpoise (*Phocoena* phocoena) were detected.

Focal follow methods are more feasible for cetaceans than for pinnipeds. Therefore, we only conducted focal follows for harbor porpoise. Focal follows were performed using the same vantage point equipment used for scan sampling (Figure 4); on detection of a group of harbor porpoise the Cannon D80 SLR was switched to video mode and the group was followed for a minimum of two minutes where possible. Data on porpoise group composition, size, activity state, behavior, heading and speed of movement were recorded directly onto the video file through an external microphone connected to the Cannon D80 SLR. Each surfacing was also noted to both aid in the detection of harbor porpoise during localization processing and to collect data on surfacing times and rates.

Harbor seal (*Phoca vitulina*) and harbor porpoise populations in Puget Sound are known to be present in Admiralty Inlet year-round (Jeffries et al. 2000, Calambokidis and Baird 1994, Smultea et al. 2015[2]), but there is evidence for seasonal patterns in animal occurrence throughout the year. Therefore, the study was designed to incorporate a seasonal component. Three control-playback trials were conducted during the spring, summer and autumn. Each trial was conducted over a period of two weeks that allowed for a control period and a playback period, each of approximately the same duration.

Data Processing and Analysis

Prior to image and focal follow data processing, sighting and effort data were filtered discard data during poor sighting conditions. Standard environmental and sighting condition data were collected during each scan of the survey area, including sea state, the percentage of glare within the study area, cloud cover and an overall “sightability” score on a scale of 1 – 4 (from best to worst sightability). The sightability score is a subjective measure that combines the sea state, percent cloud cover, and percent glare. Sightability (particularly of landmarks) was also hampered by the presence of forest fire smoke during surveys conducted in early August, thus the sightability score also considered the impacts of forest fire smoke on the overall visibility of the survey area and crucial landmarks. The sightability score allows for a systematic method of reviewing data quality. Scans conducted where the average sightability score was ≤ 2 were

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[2]Jefferies, SJ, P Gearin, HR Huber, DL Saul, and DA Pruett (2000) Atlas of Seal and Sea Lion Haulout Sites in Washington, February 2000.

Calambokidis, J and R Baird (1994) Status of marine mammals in the Strait of Georgia, Puget Sound and the Juan de Fuca Strait and potential human impacts. Symposium on the Marine Environment. January 13 and 14, 1994.

Smultea, M. et al., 2015. Puget Sound marine mammal aerial surveys, 2013-2015. In *Marine Mammal Working Group - Puget Sound Ecosystem Monitroing Program (PSEMP)*. Olympia, WA.

retained for analysis. This ensured that data were collected when sea states were ≤ 2 and glare obscured no more than an average of 30 percent of the study area. In addition to sighting conditions, scans were filtered to exclude those where small or medium private motorboats had been recorded within the study area, as they contribute to received levels but could not be accounted for in the same manner as larger vessels equipped with location transponders.

All images and video footage collected from the land based observation station during good sighting conditions were analysed in a specially designed PAMGuard Landmark module. Data on the observation station (location and height above sea level), location of landmarks and tide data were uploaded to the PAMGuard module prior to image processing. Each image/video frame must include a minimum of two visible landmarks for an animal's position at the sea surface to be estimated. Prior to processing images of pinnipeds and focal follow video files of harbor porpoise, a location accuracy assessment was undertaken to quantify the location errors associated with the methods used.

Location accuracy was assessed using a combination of images of the playback vessel collected during each trial and DAISY drifts that were deployed on 24 May to characterize received levels from the projector. Eight DAISY drifts and 218 locations of the playback vessel were available for comparison between known GPS location and the estimated location resulting from the landmark photogrammetry method. The playback vessel location shifted with the state of the tide but on average was ~658m (range: 556m – 765m) from the land based observation station. The DAISY drifts were an average of 587m from the observation station (range: 353m – 907m). The location accuracy analysis also allowed for an assessment of landmark selection to determine which, if any, combinations of landmarks should be avoided.

Images of pinnipeds recorded during scans that met the requirements for usable data were processed in the PAMGuard Landmark module using the same methods employed to triangulate the positions of the playback vessel and DAISY drifts. In brief, the image number associated with a useable sighting was selected within the PAMGuard module, a minimum of two visible, known landmarks were selected and the animals' location at the surface water was estimated based on the location of these landmarks and the observation station height above sea level (Figure 5). The estimated range and location of the animal was added to the sightings database and the distance from the animal to the playback location (determined by the presence of the marker buoy during control periods, or the playback vessel during playback periods) was calculated. To date, only the pinniped data have been processed.

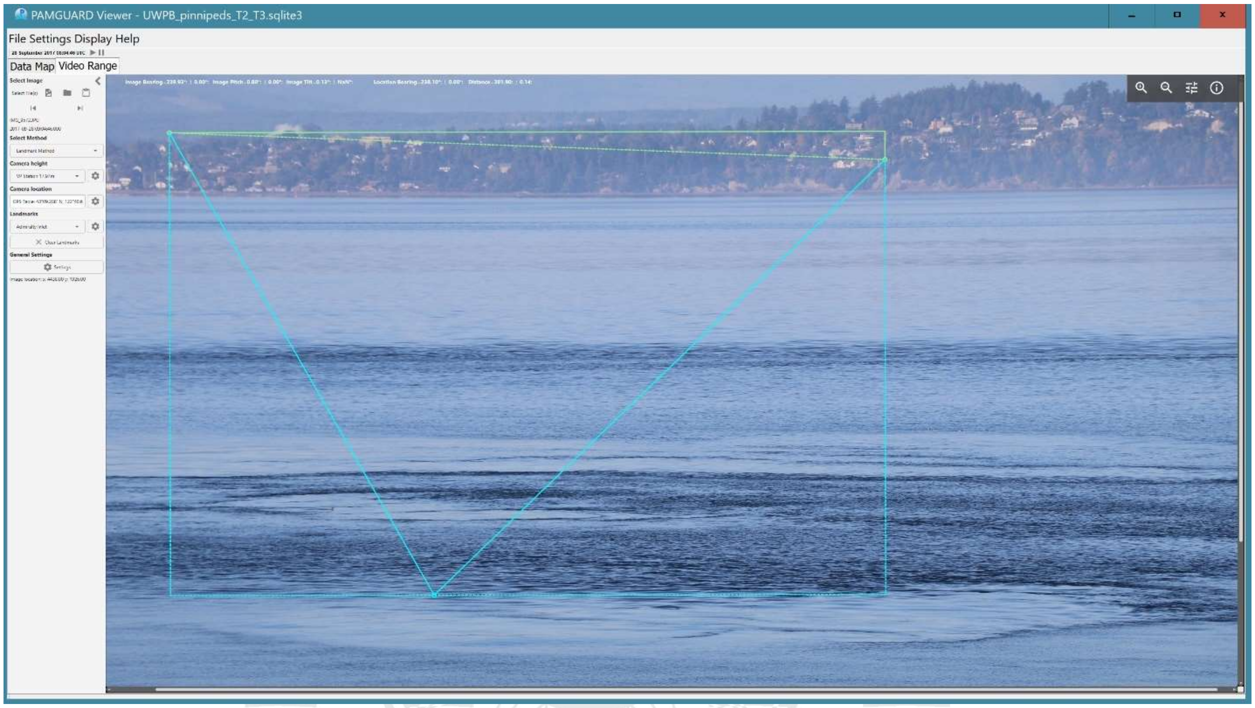

Figure 5: Screen capture from the PAMGuard Landmark module showing the selection of two known and visible landmarks (in green) and the selection and localization of a harbor seal (in blue).

A similar approach to process harbor porpoise focal follows will be undertaken in the last stage of the project. Video files for tracks collected during suitable sighting conditions will be selected within the PAMGuard Landmark module. Video footage will be played until a porpoise or group of porpoise are visible at the sea surface (aided by the observers' acoustic cue for a surfacing event). Frames will be selected where the animal or group is at the highest point of its surfacing, and a location will be triangulated using the same methods as applied for the vessel and pinniped images.

Signal Excess Model

A frequency-dependent forward acoustic model for ambient noise and turbine playback sound will be used to correlate "signal excess" with animal behavior. In brief, signal excess corresponds to the degree to which playback sound exceeds background noise levels as:

$$SE(x,t,f) = RL(x,f) - NL(x,t,f)$$

where the signal excess (*SE*), in dB, at location x (two-dimensional position), time t and frequency *f* is equal to the received level (*RL*) at location *x* and frequency *f* minus the noise level (*NL*) at the same position, time, and frequency. If the noise level is lower than the hearing threshold of harbor seals or harbor porpoise, then the hearing threshold will be substituted for the noise level in signal excess calculation.

Received level of playback turbine sound is calculated from the source level (158 dB) (*SL*) and transmission loss (*TL*) estimated from the DAISY drifts during Trial 1 where

$$RL = SL - TL.$$

Ambient noise levels are calculated by a combination of sediment noise level and ship noise levels, which prior studies have shown to dominate the soundscape at this site. Sediment noise is typically generated above 1 kHz and is correlated with near-bed water velocity[3]. Using the ADCP data collected on the Sea Spider and relations from Bassett et al. we can estimate the one-third octave noise levels associated with sediment transport.

Ship noise levels are estimated using source levels from Veirs et al. (2016)[4], adjusted for vessel speed based on Wagstaff (1973)[5], and *TL* loss estimates from Basset et al. (2012)[6]. Vessel noise inclusion is based on vessel class and position obtained from AIS data.

Because mammalian cochlea act as band pass filters, signal excess is calculated in one-third octave frequency bands. Further, to avoid complicating and weakening our statistical analyses, signal excess will only be calculated at two sets of frequencies. Figure 6 shows the hearing thresholds of harbor porpoise and harbor seals. Based on the frequency overlap between the turbine playback sound (Figure 1) and the hearing of these two species, signal excess is calculated for harbor seals in the one-third octave bands centered at 100 and 1000 Hz. Since harbor porpoise are unlikely to hear the tone 100 Hz, signal excess is calculated in the one-third octave bands centered at 1 and 4 kHz. The signal excess model will be validated against the acoustic measurements made by the Loggerhead DSG.

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[3] Bassett, C., Thomson, J. and Polagye, B., 2013. Sediment-generated noise and bed stress in a tidal channel. *Journal of Geophysical Research: Oceans*, 118(4), pp.2249-2265.

[4] Veirs, S., Veirs, V. and Wood, J.D., 2016. Ship noise extends to frequencies used for echolocation by endangered killer whales. *PeerJ*, 4, p.e1657.

[5] Wagstaff, R.A., 1973. RANDI: Research ambient noise directionality model (No. NUC-TP-349). NAVAL UNDERSEA CENTER SAN DIEGO CA.

[6] Bassett, C., Polagye, B., Holt, M. and Thomson, J., 2012. A vessel noise budget for Admiralty Inlet, Puget Sound, Washington (USA). *The Journal of the Acoustical Society of America*, 132(6), pp.3706-3719.

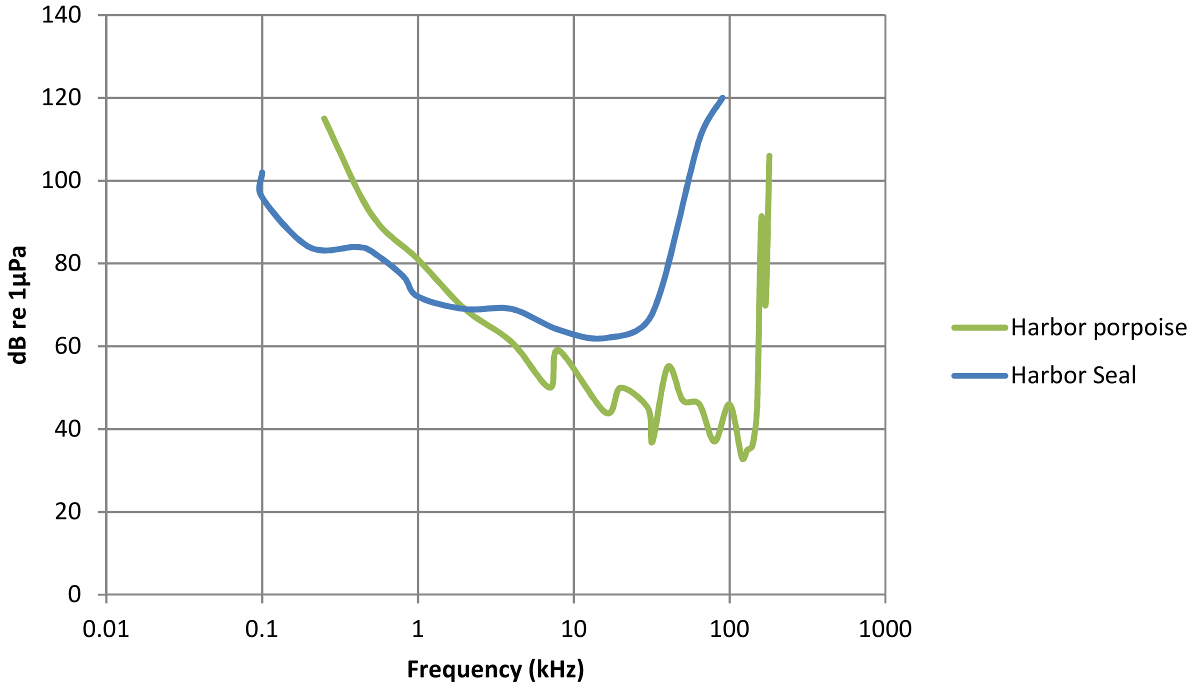

Figure 6: Audiograms of harbor porpoise[7,8] and harbor seals[9]. The harbor porpoise audiogram is a combined mean from the two references.

WORK COMPLETED

Preliminary Marine Mammal Observations

Preliminary marine mammal observations were conducted in late October 2016 to test the vantage-point equipment and determine any modifications to the methods that might be required prior to the start of the playback trials. These preliminary observations also allowed for an initial assessment of location accuracy using the photogrammetry approach. Based on these preliminary assessments, refinements to the observation procedure were made and the vantage-point observation station on Admiralty Head was surveyed to provide an exact location and height above sea level for the station, as well as landmark specific data for the PAMGuard Landmark module. This included the installation of a discreet marker pin to allow the observation team to locate the exact vantage point location each time they returned to the site.

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[7] Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.W., and de Haan, D., 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. *The Journal of the Acoustical Society of America*, 112(1), pp 334-344.

[8] Andersen, S., 1970. "Auditory sensitivity of the harbour porpoise, *Phocoena phocoena*," in *Investigations on Cetacea*, edited by G. Pilleri (Institute for Brain Research, Bern, Vol. 2, pp. 255-259.

[9] Götz, T. and Janik, V.M., 2010. Aversiveness of sounds in phocid seals: pycho-physiological factor, learning processes and motivation. *The Journal of Experimental Biology*, 213, pp. 1536-1548.

Marine Mammal Observations and Playback Trials

The three control-playback trials planned for the spring, summer and autumn were conducted during the 19 – 31 May, 26 July – 9 August, and 18 September – 1 October 2017, respectively. Marine mammal observations were conducted over 11 days in May, 14 days in July and August and 13 days in September and October. During the spring surveys, weather conditions impeded data collection on two days, the 23 and 30 May. In July and August weather conditions and poor visibility resulting from forest fire smoke impeded data collection on the 6 of August. In September poor weather conditions hampered data collection on 29 September. Table 1 summarizes the days on which useable data were collected during each trial and the useable scan effort available for each trial. 760 useable scans, averaging 2.29 minutes in duration and totaling 31.33 hours of effort were collected over the three playback trial periods.

Table 1: Summary of the number of days on which useable scan data were collected during each control-playback trial. The total amount of effort in hours, and for each control and playback period during the spring, summer and autumn trials is also included.

	Spring Trial [hours]	Summer Trial [hours]	Autumn Trial [hours]
Useable Scan effort			
Total	10.10	10.10	11.13
Control	5.18	5.14	6.28
Playback	4.52	4.57	4.45

Data processing

Processing of sighting data and focal follow data collected during all three trials is underway. All pinniped sightings that met the acceptable criteria have been processed and focal follow data is expected to be processed before the end of the 2017.

RESULTS

Location Accuracy Assessment

Location accuracy of the vantage point photogrammetry approach was reassessed across the course of the three playback trials using known locations of the playback vessel and available DAISY drifts. The location error at 100 m estimated from the DAISY drifts was 5.3 m and for the playback vessel was 6.3 m. The overall average location error was 40.3 m, but was consistently less than 100 m (Figure 7). The estimated location error as a function of spatial position is shown in Figure 8. In addition, the assessment determined which combinations of landmarks should be avoided in processing sighting images and focal follow video frames. This location accuracy assessment will be updated with additional video data collected of a research vessel with GPS within the study area.

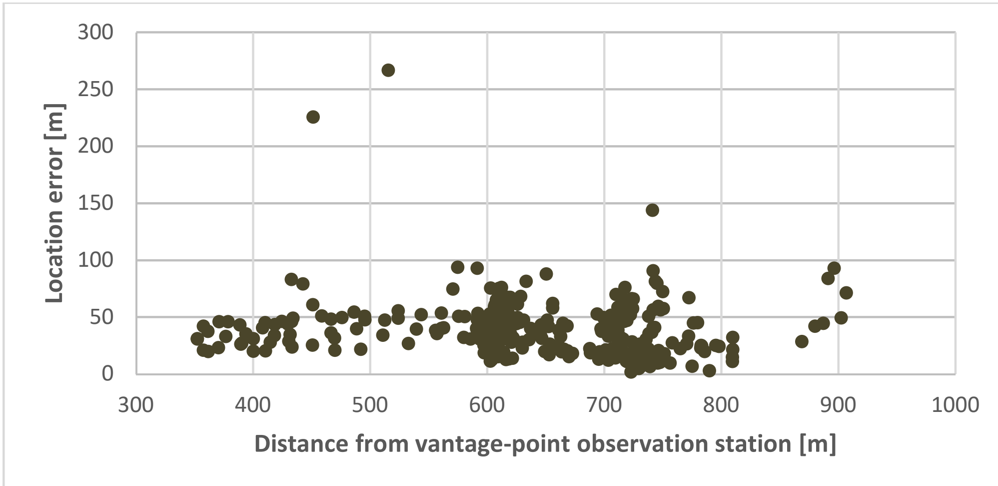

Figure 7: The location error estimates resulting from comparing GPS locations of the playback vessel and DAISY drifts.

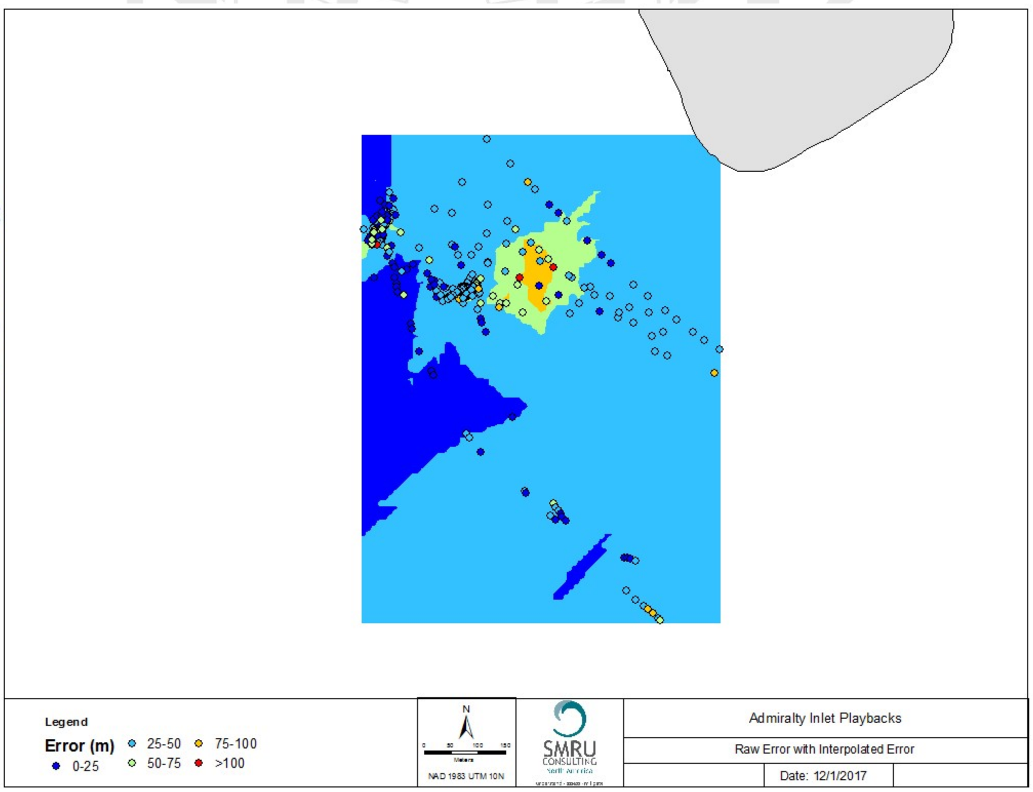

Figure 8: Spatially representation of location error. Error estimates across the study area were interpolated using the individual error points and spatial kriging.

Marine Mammals Observations

Pinnipeds, including harbor seal, Steller sea lion (*Eumetopias jubatus*), and California sea lion (*Zalophus californianus*) were observed throughout the study. Harbor seals were the most common pinniped species detected, particularly during the spring and autumn. Steller sea lions were also recorded during each trial, the majority were observed during the autumn trials. However, the number of individual animals present in the study area over the course of the autumn surveys is likely to have numbered approximately ten. The high counts presented in Table 2 represent the number of sightings and the cumulative numbers of animals seen over each trial. California sea lions were only encountered in May during the spring trials. It is likely that this was a single individual recorded at different times. Harbor seals encountered during useable scan effort periods were seen at distances ranges from 105 m to 940 m, as summarized in Figure 9. The mean distance harbor seals were sighted at was 360 m from the playback location. Steller sea lions were predominantly sighted close to shore where they are commonly observed approximately 10 m off the beach.

In some circumstances, sightings were recorded during useable scans, but images were either of too poor quality (e.g., poor lighting, landmarks not distinguishable), or the animal was not visible in the image. Of the pinniped sightings deemed useable, 78% were successfully localized from images in the PAMGuard landmark module.

Table 2: Useable pinniped sightings collected during each playback trial period. Numbers of animals are detailed in brackets. The locations of these sightings are illustrated in Figure 9.

	Spring Trial	Summer Trial	Autumn Trial	Total
Harbor seal	207 (222)	46 (46)	103 (106)	356 (374)
Steller sea lion	7 (7)	2 (2)	66 (216)	75 (225)
California sea lion	5 (5)	0	0	5 (5)

Preliminary review suggests that a minimum of 102 harbor porpoise groups were observed during the spring trials, 83 porpoise groups were observed during the summer trials, and 126 were observed in autumn trials when sighting conditions met the ‘useable’ criteria. Of these, 21 encounters occurred between scans, allowing for additional opportunistic focal follow data to be collected.

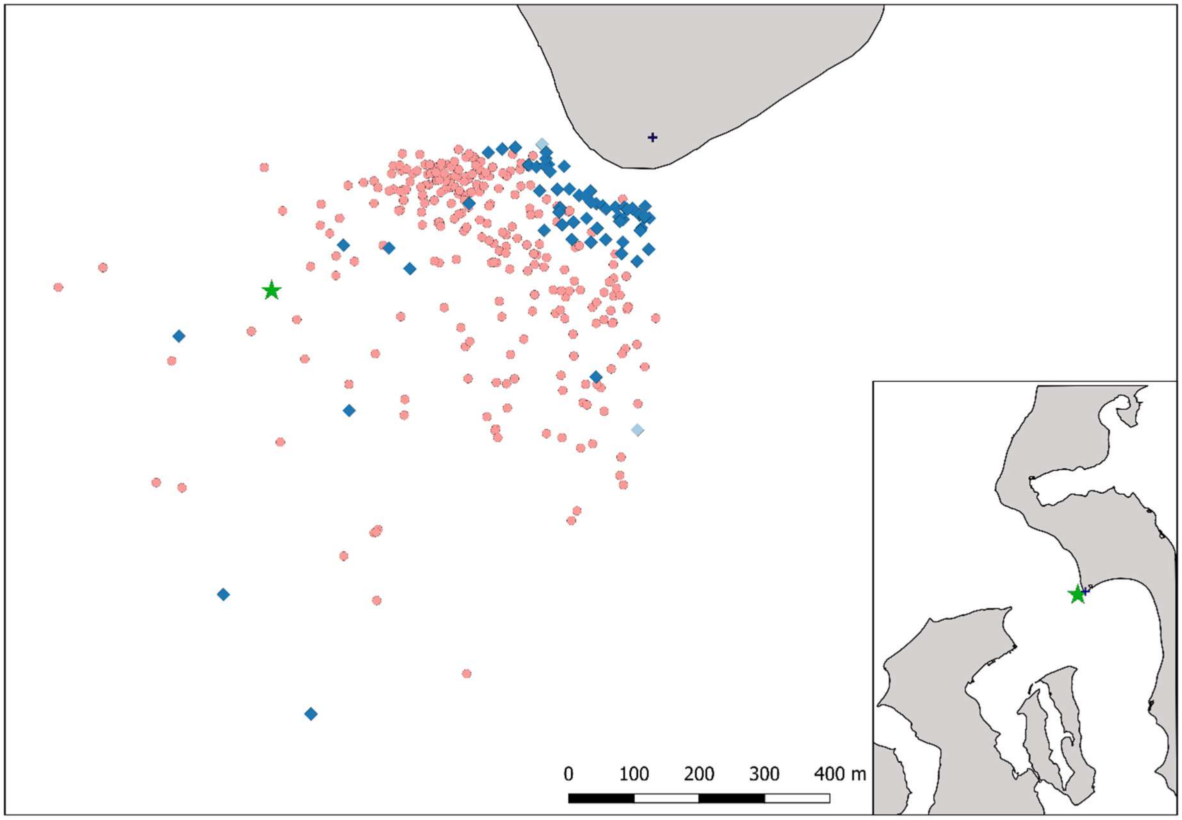

Figure 9: Distribution of useable pinnipeds sightings from the land-based observation station across the spring, summer and autumn playback trials. The green star denotes the average playback location and the black cross denotes the land-based observation station. Harbor seals are shown as pink circles and sea lions as blue diamonds. The two useable California sea lions are shown as light blue diamonds and the Steller sea lions as dark blue diamonds.

Foraging activities were commonly observed during the spring trials, particularly during the flood tide. Fewer porpoise groups were detected during the summer trials. However, of those sighted, many included mother-calf pairs. During the autumn trials in late September, porpoise groups were regularly observed traversing through the study area. These observations of number of encounters, predominant activity state and group compositions indicates that there are seasonal variations in how harbor porpoise utilize the study area.

In total, 208 focal follows were attempted during the spring trial, 139 focal follows were attempted during the summer trials, and 106 focal follows were attempted during autumn trial. However, focal follow tracks have not yet been filtered for usable sighting criteria and thus the number of focal follows of sufficient quality and that meet the useable criteria are expected to below lower than the number of attempts.

In addition to harbor porpoise and pinniped species, there was one sighting of a gray whale (*Eschrichtius robustus*) in May, 8 sightings of minke whales (*Balaenoptera acutorostrata*) (thought to be the same animal), one sighting of a humpback whale (*Megaptera novaeangliae*) and two sightings of killer whales, including both transient and Southern Resident killer whale ecotypes (*Orcinus orca*). No baleen whales were sighted during surveys in September. Three playback shutdowns occurred due to sightings of baleen whales within the vicinity of the study area. No mitigation shut downs were required for killer whales as sightings occurred during a control period.

DELIVERABLES/DATA TRANSMISSIONS

1. **National Security**: Not applicable.
2. **Economic Development (e.g., new product lines, businesses, practices, increased efficiency, new manufacturing techniques)**: The project has demonstrated cost-effective land-based monitoring methods for marine mammal observations.
3. **Quality of Life (e.g., public health, ecosystem health, coastal resource management)**: The data developed under this project may suggest improved practices for assessing the environmental effects of tidal turbines (and other forms of marine energy) by studying their environmental stressors in isolation (e.g., sound in the absence of other stressors).
4. **Science Education and Communication**: During the observations, the research team had a number of interactions with the public at the vantage-point observation site (a state park), which afforded an opportunity to provide education about tidal energy and marine mammals. The observations involved two University of Washington undergraduate students and one Western Washington University student, who were trained in vantage-point data collection methods, marine mammal identification, and behavior interpretation. Members of the project team also lectured two undergraduate classes at the University of Washington's Friday Harbor Labs and presented the study and vantage-point methodologies in a number of public lectures, including for the tidal energy sector.

IMPACTS AND APPLICATIONS

1. **National Security:** The project has the potential to reduce the environmental uncertainty associated with deployment of tidal turbines in areas frequented by marine mammals. This could facilitate energy security with a predictable, sustainable source of energy generation.
2. **Economic Development (e.g., new product lines, businesses, practices, increased efficiency, new manufacturing techniques)**: Tidal energy has the potential to enable new economic opportunities through the provision of electrical power in marine environments where power is not currently available. These opportunities includes persistent sensor networks, aquaculture, and underwater data centers.
3. **Quality of Life (e.g., public health, ecosystem health, coastal resource management)**: The marine mammal observational data will improve the understanding of marine mammal use of Admiralty Inlet, a key ecological location in Puget Sound.

4. **Science Education and Communication:** Three undergraduate students were trained and assisted with the vantage point data collection, thus exposing them to a set of skills that they can apply later in life.

RELATED PROJECTS

A group of colleagues in Scotland have conducted a playback of tidal turbine sound to harbor seals[10]. They used similar vantage-point techniques to quantify seal distribution within their study area, and attached GPS tags to a number of seals to analyze the finer scale movements of individual seals. They used a binary explanatory variable (silent control vs turbine signal) in their statistical models and found no significant change in the number of seals in the study area, but did find a reduction of seal usage of the area around the turbine sound of between 11 and 41%. This reduction decreased to almost zero at 500 m from the simulated turbine sound.

The primary differences between the Hastie et al. 2017 study and the one discussed here are the playback signal, the explanatory variable, and the inclusion of two primary species. The Hastie et al. 2017 playback was a filtered and modified recording of the Marine Current Turbines SeaGen turbine that was deployed in Strangford Lough, Northern Ireland. The signature is substantially more tonal than the one used here with h at least seven tonal peaks between 100 and 4,000 Hz. These tones also exhibit frequency modulation over time. The playback here is broadband, with a single tonal peak around 100 Hz.

Our decision to develop a signal excess model (i.e., a continuous variable) for our explanatory variable should provide improved statistical power over the binary explanatory variable used by Hastie et al. 2017. Our playback will also help validate their results on harbor seals and extend our knowledge to a species of odontocetes (harbor porpoise).

Three of the Hastie et al. 2017 team are members of the Sea Mammal Research Unit (SMRU) at the University of St. Andrews. SMRU Consulting is a commercial spin off of SMRU and is fully owned by the University of St. Andrews. In addition, Hastie is a former SMRU Consulting staff member.

PUBLICATIONS

Not applicable.

PATENTS

Not applicable.

WORK PLAN

The next steps in this study involve the statistical analysis of the marine mammal presence and absence data and behavior data. To assess the potential effects of turbine sound on marine mammal distribution and behaviour, marine mammal observations will be stratified by a series

[10] Hastie, GD, Russell, DJF, Lepper, P, Elliott, J, Wilson, B, Benjamins, S. and Thompson, D. 2017. Harbour seals avoid tidal turbine noise: Implications for collision risk. *Journal of Applied Ecology*. 00:1-10. https://doi.org/10.1111/1365-2664.12981

of temporal and spatial variables (e.g., month, time of day, tidal state, presence of prey and operational state of the tidal turbine) – harbor porpoise and harbor seal data will be addressed independently.

For harbor seal data we expect to use a similar approach to that used by Hastie et al. 2017 to investigate how harbor seal presence varied within the study site with respect to the playback signal. We will use a generalized additive model with a general estimating equation framework to account for the temporal autocorrelation. In addition to the estimated received levels derived from the signal excess model, season, Julian day, time of day, depth, current speed, tidal state and lunar cycle will be included as covariates in the model. These analyses will allow us to determine if harbor seal presence within the vicinity of the playback location varies with signal excess and whether or not any variation in presence is also influenced by temporal and spatial covariates.

Harbour porpoise focal follow data will be processed to determine the closest point of approach of the focal individual/group to the playback source and measures of path predictability will be calculated following the methods outlined in Williams et al. 2000[11]. These measures include a directness index and deviation index. In addition, swim speed and respiration rates for each focal group will be calculated. These behavioral responses will be modeled within a mixed effects modeling framework to determine potential fine scale behavioral responses of harbor porpoise to turbine operational noise. Similar to the harbor seal model, additional covariates that may influence the behavior of harbor porpoise may be included in these models as fixed effects and will enable us to determine the importance of a variety biotic and abiotic related variables, including, porpoise activity state, group size and composition, time of day, season, depth, tidal state, current speed, lunar cycle, and estimated received level at the closest point of approach.

The signal excess model will allow any effects on marine mammals we identify as part of this study to be scaled to different array sizes. This is because the response will be related to how much louder the turbine is than the background noise, instead of simply a fixed range from our sound source. We plan to explore a few scenarios with scaled-up arrays of turbines by altering the contribution of turbine sound to the signal excess model and estimating how this might change the behavioral response of pinnipeds and odontocetes.

The results of this study are expected to be submitted for publication in the peer-reviewed literature in 2018.

[11] Williams, AW Trites, and D Bain (2000) Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. J. Zool., Lond. 256: 255 - 270

OUTREACH MATERIALS

Figure 10: Vantage point station on Admiralty Head. Credit: Frances Robertson (SMRU Consulting)

Figure 11: Project study area, as viewed from vantage point. Credit: Frances Robertson (SMRU Consulting)

Figure 12: Moored playback vessel with individual harbor porpoise. Inset shows enlarged image. Credit: Frances Robertson (SMRU Consulting)

Figure 13: Moored playback vessel with group of harbor porpoises. Inset shows enlarged image. Note cargo vessel transiting at Admiralty Inlet at right edge of image. Credit: Frances Robertson (SMRU Consulting)

Figure 14: Group of harbor porpoises during control period. Inset shows enlarged image. Credit: Frances Robertson (SMRU Consulting)