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A SPATIAL ENVIRONMENTAL ASSESSMENT FRAMEWORK FOR WAVE ENERGY INSTALLATIONS

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INTRODUCTION

An assessment of the potential environmental effects associated with the deployment of wave energy converters (WECs) must begin with an understanding of the baseline site conditions in the absence of previous WEC deployments (e.g., “no action” alternative or variability of site environmental conditions associated with changing seasons, stochastic processes, or other non-anthropogenic factors).

A Spatial Environmental Assessment Tool (SEAT) has been developed by combining numerical and spatial tools to facilitate understanding of the potential risks involved in environmental assessments. In essence, it enables a qualitative and quantitative evaluation of the above-mentioned environmental stressors and receptors in regions affected by a WEC array deployment. The specific stressors evaluated in this paper are sediment mobility and bed elevation change.

This paper sets forth three goals: (1) to provide updates on an ongoing case study that exemplifies tools and techniques for supporting marine environmental assessments, (2) to outline the application of the SEAT at the case study site, and (3) to develop maps and tables of WEC-induced seabed changes as determined in the assessment. The paper discusses how probabilistic spatial maps of physical alterations in an area are developed through the development of quantitative metrics that describe the potential for risk induced by various physical stressors. Results are presented from a case study applied to the Newport, Oregon wave energy test site.

METHODOLOGY FOR ASSESSMENT

The fundamental basis of the SEAT is a coupled wave (Sandia National Laboratories – Simulating Waves in the Nearshore, SNL-SWAN), circulation and sediment transport (Delft3D) model. The coupled Delft3D-SNL-SWAN model allows for evaluating tidal and wave-driven circulation, including wave-current interactions that influence nearshore circulation, wave parameters, and sediment transport.

Model simulations were run over a range of wave conditions to characterize the risk of morphological changes as a result of WEC deployments. The range of annual wave conditions along with the associated probability of each event allows for the calculation of quantitative risk metrics associated with various hydrodynamic and sediment transport variables such as maximum shear stress, bottom velocity, and change in bed elevation.

NEWPORT, OREGON, CASE STUDY

The site of the case study is located offshore of Newport, Oregon, north of Yaquina Head, in approximately 50-m-deep water and 4.5 km offshore. The targeted location constitutes the North Energy Test Site (NETS) of the Pacific Marine Energy Center where future marine renewable energy deployments are planned. Figure 1 shows bathymetry at the site, the location of the NETS, and locations of Oregon State University (OSU) instrumentation sites described in the next section.

The waters off of Newport, Oregon, are characterized by a year-round energetic wave field. Swell heights range from 0 to 7 m, swell directions vary from 180° to 315°, and wave periods range from 4 seconds to 20 seconds. A comprehensive analysis of expected wave conditions on the Oregon coast was conducted by Sandia using 7 years (2005–2011) of modeled wave conditions.

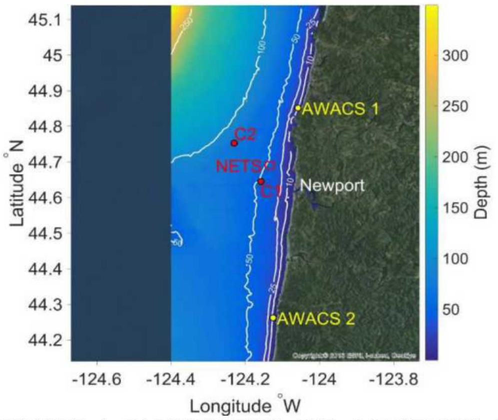

FIGURE 1 BATHYMETRY AND LOCATIONS OF OSU INSTRUMENTATION. LABELS INDICATE LOCATION OF AWACS AND SURFACE CURRENT METERS (C1, C2).

The analysis provides approximately 300 discrete wave events, characterized by significant wave height, peak period, and mean wave direction, along with the probability of occurrence of each event. To make the analysis computationally tractable, the number of events analyzed was reduced to 24 events using a k-means clustering analysis similar to the methodology used in the Wave Energy Prize (Bull and Dallman 2017). Figure 2 shows an example Joint Probability Distribution (JPD) with the wave conditions for a directional window from 260 – 290 degrees. Four other directional windows with six events each were considered for a total of 24 events. The directional windows correspond to 200^{o}-230^{o}, 230^{o}-260^{o}, 260^{o}-290^{o}, and, 290^{o}-320^{o}.

Each of the 24 wave conditions are applied as JONSWAP boundary conditions to the SNL-SWAN wave module. The use of JONSWAP wave conditions allows for the evaluation of the effects of specific swell conditions on hydrodynamic and sediment transport parameters.

Model Setup and Calibration

A 3-dimensional nested model was developed to represent the Oregon coast from -124.4^{o}W to -124^{o}W and 44.14^{o}N to 45.14^{o}N. The flow and wave models consisted of two nested grids with increasing grid resolution. Flow grids consisted of five vertical sigma layers. The number of layers was found to strike a balance between computational efficiency and accuracy of modeled currents.

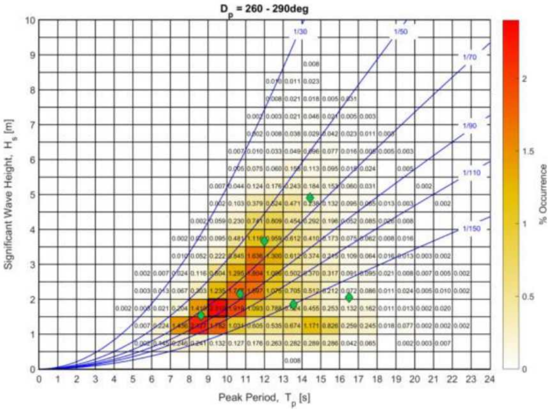

FIGURE 2 JPD FOR A 260-290 DEGREE DIRECTIONAL WINDOW N THE OREGON COAST. GREEN DIAMONDS SHOW WAVE CONDITIONS SELECTED FROM K-MEANS CLUSTERING.

The circulation and wave model was first calibrated to the time period between October 1 and 28, 2009, a period during which surface current and AWAC (Acoustic Waves and Currents) wave data were available. Overall, the modelled circulation and waves compared favorably with measurements. Computed wind driven surface currents compared favorably with coastal surface radar measurements, provided by the OSU Ocean Currents Mapping Lab. The differences in modeled data with respect to the measured values were attributed to the lack of spatially varying wind fields and mesoscale currents that are not currently included in the model.

While muds and cohesive sediments exist in the environment, the majority of the modeled area consists of sandy sediments. The sandy bed sediments were characterized with three sand classes with grainsizes of 350, 200, and 100 microns in equal parts. A morphology model was included with the sediment transport, which incorporates bed elevation changes due to erosion and deposition.

A single type of WEC device was considered for this study, a floating oscillating water column (F-OWC) inspired by the OE Buoy developed by Ocean Energy Ltd. (Barbarit et al. 2012), which has a maximum dimension of 50 m. The maximum power output of the modeled WEC is 3,310 kW. The power matrix represents the energy extracted from the environment, by the device, given a specific sea state prescribed by the significant wave height (Hs) and peak period (Tp). This study evaluated one array configuration confined to the NETS site. Each of the 18 modeled devices had a diameter of 50 m spaced ~200 m (4 diameters [D]) apart in both the east–west and north–south directions.

ENVIRONMENTAL METRICS

To evaluate the potential impact and risk associated with WECs at a site, environmental risk metrics were developed. Changes in bottom shear stress have the potential of either increasing or decreasing sediment erosion or accretion, depending on the relation of the modeled shear stress to the critical shear stress associated with the sediment layer at the sediment–water interface. For example, the introduction of WECs into the environment can have the effect of lowering shear stress in the lee of the WEC array. If the baseline shear stresses are greater than the critical shear stress, and the introduction of WECs lowers shear stresses below the critical shear stress, then a mobile sediment environment is transformed into a depositional environment.

The sediment transport parameter is therefore defined for each model grid point as:

$$T_b = \sum_i P_i \frac{\tau_b}{\tau_c} \qquad (1)$$

where P_i is the probability of occurrence of the event, τ_b is the bottom shear stress and τ_c is the critical shear stress for erosion. A similar transport parameter, T_w is defined in the presence of WECs. The risk of sediment mobility R_τ can then be defined in terms of a non-dimensional number as:

$$R_\tau = \; int\left(\frac{T_w - T_b}{|T_w - T_b|}\, T_w\right) + [T_w - T_b] \qquad (2)$$

The first term in Eq. 2 can be thought of as constraining the risk into one of four regimes ($R_\tau \leq -1$, represents a reduction in erosion; $-1 < R_\tau \leq 0$, represents an increase in deposition; $0 \leq R_\tau < 1$, represents a reduction in deposition; and $R_\tau \geq 1$ represents an increase in erosion). The *int()* operation represents the integer value of the term. The second term then indicates the magnitude of risk within a particular regime, generating the resulting risk metrics for sediment mobility.

Physical processes such as tides, waves, and sediment transport result in a change in effective bottom elevation relative to that of a quiescent ocean. This change in bottom elevation can be altered in the presence of WECs, which makes it necessary to incorporate bottom elevation changes into the risk framework associated with SEAT.

The risk associated with bottom elevation changes associated with WEC deployments is defined as:

$$R_\eta = \sum_i P_i\,(\eta_w - \eta_b) \qquad (3)$$

where η_b and η_w are the bed elevations in the absence and presence of WECs. As seen in Eq. (3), R_η has units of elevation (meters) unlike the non-dimensional risk metrics for sediment mobility. This difference is primarily due to the difficulty in defining a critical depth of importance to habitat. For example, one could define a critical depth of sedimentation below which kelp cannot grow. However, the inability of kelp to grow below a certain depth is governed not only by depth, but also by other parameters such as photosynthetically available radiation, water column nutrient concentrations, ambient currents, and a host of other physical parameters. However, if such a depth were defined, then a revised risk metric for kelp growth (similar to Eq.2) can be defined for bottom elevation changes. Other metrics, such as larval and fish motility have been developed, but are beyond the scope of this abstract.

RESULTS

Using the probabilistic SEAT framework, the risk of sediment mobility (R_τ) can be computed and mapped as shown in Figure 3. Habitats of interest are also demarcated on the map, with locations as defined by CMECS (2016). As can be expected, there are modest changes to sediment mobility in the lee of a WEC array. However, all of these changes are in the regime where there is increased potential deposition due to shear stresses. Most importantly, little to no risk of sediment erosion or deposition is seen in habitats of particular concern. An increased risk of deposition in the lee of the WEC array indicates a lowering of shear stresses relative to the baseline case, with shear stresses in both cases less than the critical shear stress for erosion. As a result, while there is a greater risk for deposition, no sediment erosion or deposition takes place until shear stresses exceed the critical shear stress, indicated by colors greater than 1 or less than -1.

A map of bottom elevation change risk is shown in Figure 4. The risk metric is scaled by the probability of occurrence for a particular swell event and summed over all likely events (24 events in total that describe wave variability over a 7-year period). As discussed in Section 3.3, bottom elevation risk is expressed in changes in elevation (in meters). There is generally no net change in bed elevation in the majority of the model domain. In the shallow coastal areas, changes on the order of 1 cm are seen, which is largely insignificant when considering coastal bed elevation changes on the order of 5 m are seen on a seasonal basis. As mentioned in the preceding paragraph, while there is an increased risk of deposition in the lee of the WEC array, critical shear stresses for the both the baseline and WEC case remain less than the critical shear stress, resulting in no bed elevation change.

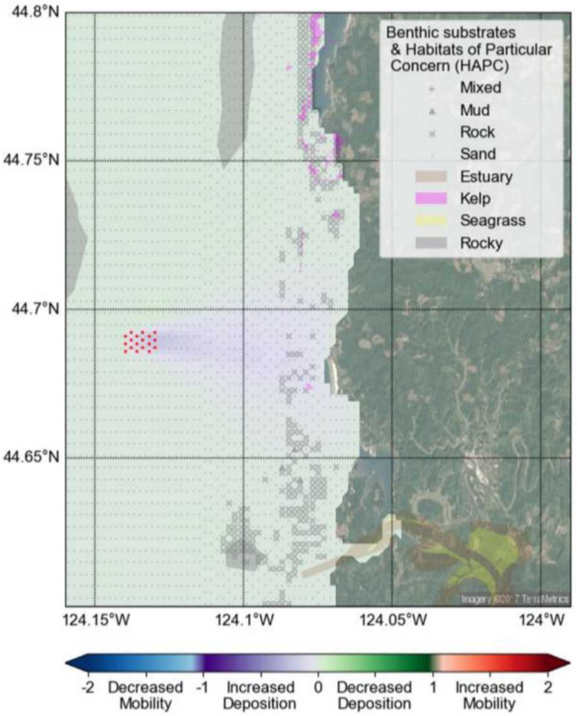

FIGURE 3 RISK METRICS COMPUTED FOR CHANGES IN SEDIMENT MOBILITY

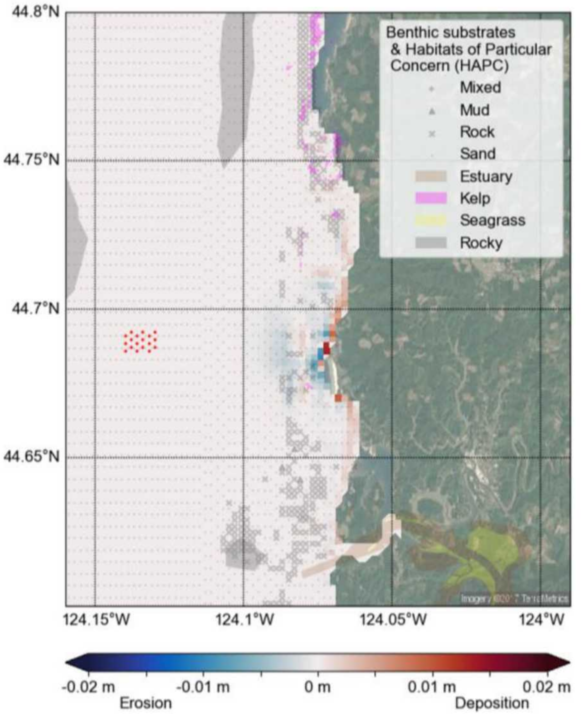

FIGURE 4 RISK METRICS COMPUTED FOR CHANGES IN BOTTOM ELEVATION

DISCUSSION AND SUMMARY

The SEAT facilitates understanding of potential risks posed by WEC arrays through the development of probabilistic spatial maps of environmental stressors at sites of interest. The evaluation requires analysis of a long-term wave record in order to represent inter- and intra-annual variability at the site. Through the probabilistic evaluation of site variability, a comprehensive picture of the site is developed.

Spatial quantification of stressors posing potential risk for several key parameters such as sediment mobility bed elevation change are of particular interest when considering seabed habitat risk. The spatial visualization of these risks allows for rapid identification of potential changes in each habitat type. Overall the findings of this study for one WEC array configuration show that the risk values are low, with no significant changes that affect sediment mobility or bed elevation change. While minimal risk is seen for small deployments, the SEAT provides a method for evaluating any size array a developer may be considering. Future work will include further linkage between other physical stressors and receptors (e.g., larval motility) for use in environmental assessments.

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REFERENCES

Barbarit, A., Hals, J., Muliawan, M.J., Kurniawan, A., Moan, T., Krokstad J., 2012. Numerical benchmarking study of a selection of wave energy converters. Renew. Energ. 41, 44-63

Bull, D., and A. Dallman. 2017. Wave Energy Prize experimental sea state selection. ASME 2017 36th International conference on ocean, offshore and arctic engineering, Vol. 10: Ocean Renewable Energy.

IEC. 2015. Marine energy—Wave, tidal and the other water current converters. Part 101: Wave energy resource assessment and characterization, IEC TS 62600-101:2015.

Leis, J.M., and B.M. Carson-Ewart. 1997. In situ swimming speeds of the late pelagic larvae of some Indo-Pacific coral-reef fishes. Mar. Ecol. Prog. Ser. 159:165-174.