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Littoral Characterisation of West Mainland Orkney: the Relationship between Wave Energy, Topography and the Biological Community

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ABSTRACT

The rocky coast of West Mainland Orkney (WMO) is characterised by spectacular, sheer cliffs shaped by exposure to extreme wave energy and inhabited by a suite of organisms adapted to this challenging environment. As part of the UK government's commitment towards developing the renewable energy sector, in March 2010, the Crown Estate announced the leasing of several sites within this area for development of wave energy extraction. Owing to difficulties of access, the biological communities of much of this coastline have never been adequately described. As part of a long-term monitoring programme, we have incorporated boat-based field methodologies to complete the first comprehensive baseline assessment of the littoral community along the entire rocky shoreline of WMO, extending northeast to beyond Costa Head. Within this assessment are: the wave energy converter (WEC) testing site for the European Marine Energy Centre, at Billia Croo; rocky shores within leasing sites potentially impacted by large-scale WEC deployment and subsea cable installation; and areas distant from potential impacts which are serving as control sites. Data collected includes species abundance and several quantitative and semi-quantitative topographical indices which may mediate wave exposure including slope, aspect, openness and complexity. Additional data have been collected for barnacles, patellid limpets and high-energy variant fucoid algae. Comparable sites on the west coast of Lewis have been surveyed by the team and are included in analyses for comparison.

While the relationship between wave energy and the biological community is well known, and the importance of certain topographic features in mediating this interaction are recognised, the ecological consequences of large-scale extraction of wave energy are not well understood. We consider the use of indicator species to provide proxies for wider ecological responses to environmental change. We describe the relationship between several littoral organisms, such as the boreal seaweed *Fucus distichus anceps*, and the topography of the westward dipping sandstone platforms along WMO and suggest a method of predicting biological changes following wave energy extraction. The use of multiple indicators is advocated to allow responses to wave energy extraction to be detected alongside a background of changes due to other systemic forcing agents such as climate change.

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INTRODUCTION

It is well-established that wave energy plays a dominant role in determining community structure on rocky shores and that the topography of the coast modifies the interaction of energy and organism (Lewis, 1964). The ecological consequences of industrial-scale deployment of WECs, however, are not understood (Frid *et al*., 2012). While sublittoral studies suggest that waves begin interacting with organisms on the seabed in depths of up to 75 m (Denny, 1987), it is with decreasing depths that this physical interaction grows, reaching a peak in the littoral zone (Siddon & Witman, 2003).

The earliest approaches to deriving biologically meaningful indices of shore exposure to wave action were based simply on measuring fetch from charts and maps. These models have become more sophisticated with the addition of directional wind data and provide increasingly more accurate habitat predictions (Burrows *et. al*, 2008). Topographical features have also been used to inform and improve fetch based models (Thomas, 1986; Burrows *et al*., 2008). Direct measurements of wave climate become problematic as waves approach the sublittoral fringe owing to a variety of practical issues of survivability and effectiveness.

WMO is characterised by spectacular, sheer cliffs and westward-dipping platforms with only a few, less energetic, embayments. The use of fetch-based models to assess wave energy along this coastline yields little variation because of the open and mostly straight shores. The characteristic platforms do however vary in several topographical features, such as slope and aspect, and the presence of reefs and skerries adds localised complexity which may not be cartographically detected. This cliffscape extends along 23 km from Black Craig north to Birsay Bay with only about 7 km accessible by foot. While a number of important studies have occurred at some sites along WMO, owing to difficulties in access there has been limited scientific evaluation of most of the existing biological community along this coast.

Our research aims are to establish a comprehensive characterisation of the rocky shore fauna and flora along WMO and to collect topographical data which may be of value in better understanding the relationship between exposure to wave energy and the biological community. We are also exploring ways in which these data might be used to provide predictive power for assessing: unsurveyed rocky shores using cartographic and bathymetric data; areas of environmental sensitivity; and the consequences of reduced exposure by WECs.

METHODS

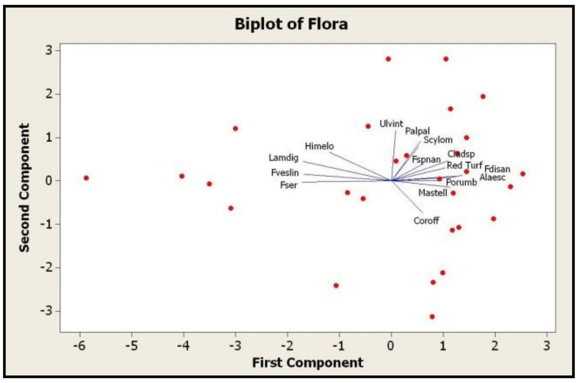
40 rocky shore sites along West Mainland Orkney were accessed at low spring tides between April and July, 2013. The inaccessible nature of most of this coast required the use of a rigid-hulled inflatable boat for about half of the sites. Topographic assessment included determination of slope, aspect, openness, median site bearing, complexity and exposure. In this study, ‘aspect’ refers to the orientation of the shoreline with respect to cardinal direction; ‘openness’ is the maximum angle of exposure to open ocean; median site bearing is the average fetch direction; ‘complexity’ is based on a 10-point scale to semi-quantitatively assess the presence or absence of rock features which would be expected to complicate the interaction of waves and substrate, i.e. an unbroken, planar surface would have a complexity of 1, while more broken shores will score higher; and ‘exposure’ is a semi-quantitative value, based on a 5-point scale, determined by the experienced observer prior to any biological measurements.

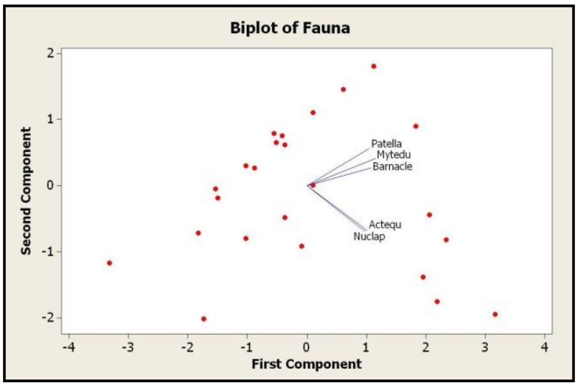
Species abundance was made at each site using a modification of the SACFOR scale described by Crisp and Southward (1958). SACFOR scores were enumerated to a 0-6 point scale, with 0 assigned to species not observed and 6 assigned to ‘super-abundant’ species. At each rocky shore site, in addition to abundance measurements, species identifications were recorded in imaged quadrats (1m x 1m) of patellid limpets and quadrats (10cm x 10cm) of barnacles were imaged at upper, mid and lower shore heights. In addition, 8 rocky shore sites on the north-west facing shore of Lewis were surveyed using these methodologies in June 2013.

Principal component analysis (PCA) was performed on abundance data for about 20 littoral rocky shore species separated into fauna and flora. Stepwise regression was performed on the first three principal components against the topographic indices. Generalised additive modelling and generalised linear modelling were used to investigate the relationship between the abundance of certain organisms (e.g. limpets and fucoids) and environmental variables.

OBSERVATIONS

The rocky shores of WMO are home to an assemblage of littoral organisms associated with, and adapted to, high wave energy exposure. Characteristic fauna include: Patellid limpets, *Mytilus edulis*, *Nucella lapillus*, *Actinia equina*, and a guild of *Semibalanus balanoides* and Chthamaloid barnacles. Typical flora includes: high-energy variant fucoids, a turf of filamentous red algae, *Corallina officinalis*, and, towards the sublittoral fringe, larger brown algae such as *Himanthalia elongata*, *Alaria esculenta*, and *Laminaria* sp.. The distributions and abundances of these organisms is not homogenous; while all of these species are found along much of WMO, localised differences exist where certain species are more or less likely to be found in association with one another. One example of this would be the observation that *Fucus distichus anceps* is typically associated with *Mytilus edulis* and *Alaria esculenta* but rarely with *Nucella lapillus* or *Laminaria digitata*.





Prinicpal Component Analysis: abundance of flora and fauna against the first two principal components

The first principal component for flora (above, top) produced highest loadings for high energy species and was interpreted as relating to wave energy exposure; faunal PCA results (above, bottom) indicate ‘abundance of fauna’ and ‘wave exposure’ as the strongest correlates with the first two components. On more open coastal sites, lower gradients slopes are associated with lower energy species assemblages. Generalised additive modelling of exposure relating to other environmental variables along WMO produces a best-fitting model associated with: overall openness; orientation of openness along the north-south axis; and complexity. In this model, higher wave exposure is associated with sites of greater openness, towards a more northerly orientation and with reduced complexity. Despite the openness of the north coast of Lewis and the high wave energy resource offshore, greater topographical complexity is correlated with reduced exposure in the littoral zone and is associated with species typically found on more sheltered shores.

CONCLUSIONS

Our research has focused on the intertidal zone on exposed rocky shores. While there are certain advantages in studying the sublittoral environment (i.e. proximity to WECs, less variation from terrestrial and atmospheric influences, etc), in general the littoral zone: is easier to access and to relocate specific sites; requires less expensive equipment and boat hire; and, with regards to exposure, is where wave energy effects are most manifest. The observations made more readily at intertidal sites may serve to reveal important processes occurring in harder to access nearshore waters.

Fetch-based models of wave exposure have proved useful in rocky shore ecological studies. Cartographic and wind-based indices are further improved when complemented by topographical data (Thomas, 1986). We have developed our approach which captures the main facets of variability in wave energy interaction with the shoreline. This relates to local topography at the scale of metres rather than a broader approach based largely on fetch. Our data support the postulation that topographically determined variation in exposure is the main determinant in observed differences in the littoral community along WMO.

While the geomorphology of the skerries, reefs and platforms along WMO are typically similar, the precise slope, orientation and aspect are not identical. These differences are expected to influence the dissipation of wave energy along these shores and influence the assemblages. Even relatively small shifts in a species' optimal conditions may result in observable changes in distribution (Blanchette *et al*., 2008). Furthermore, comparisons between sites of varying exposure can provide examples of associated biological communities which may augment our ability to predict impacts following energy extraction. Models of surf-zone interactions between energy and substrate may be useful and improvements in quantitative assessments of wave energy in the littoral zone are welcomed.

WECs modify the energy resource reaching rocky shores 'down-stream' by capturing passing wave energy. A damping effect is also observed by bottom vegetation in shallow waters (Mork, 1996) and lower gradient slopes are associated with less exposed assemblages (Lewis, 1964) with energy reduced as the waves interact with the sublittoral substrate. The role of increased substrate complexity in wave energy dissipation is also supported by our data. The complexity and low slope of Lewis shores results in sufficient wave energy reduction prior to reaching the shore that organisms associated with relatively lower exposure can survive. In contrast to WMO, we would not expect wave energy extraction to have observable effects on the littoral community of Lewis and would recommend nearshore sublittoral studies to monitor environmental impacts of wave energy extraction on this shoreline.

In summary, our research along WMO and Lewis is helping to provide the following:

- a greater understanding of the relationship between wave energy, topography and the organisms living on these rocky shores;
- a comprehensive assessment of pre-development biological communities;
- baseline and control data to compare potential future changes from reduced wave exposure (including other long-term forcing agents such as climatic change);
- identification of potential sentinel species for study;
- identification of physical features which may be of monitoring value, and;
- establishment of a long-term monitoring programme.

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