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**Effects of man-made structures on sedimentary oxygenation: extent, seasonality and implications for offshore renewables.**

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**ABSTRACT**
The number of man-made structures to be placed in the marine environment is set to increase massively in the near future as a consequence of the wide-scale adoption and commercialisation of offshore electricity generation. Marine renewable energy devices (MREDs) interact with their receiving environment and are *de-facto* artificial reefs. The Loch Linnhe Artificial Reef (LLR) complex is a large-scale experimental facility, with the main matrix consisting of 30 separate reef modules deployed in 10 – 30 m depth and over a gradient of hydrographic and sedimentological conditions. The LLR offers potential to examine impacts that are analogous to those likely to occur around MREDs. The aim was to assess changes associated with reef-proximity to inform us about the likely extent and nature of the impacts that are likely to occur around offshore structures that are placed in similar environments.

**INTRODUCTION**
MREDs will act as *de-facto* artificial reefs by providing attachment points for encrusting fauna and flora and shelter from tidal flows [1]. Whilst MREDs are not classified as artificial reefs, because their primary function is not to emulate a natural reef in some way, much artificial-reef impact research is directly relevant to their likely impacts. Once placed on the seabed man-made structures, of any type, interact immediately with the local current regime. This hydrographic interaction may result in the acceleration or baffling of flow around the structures, the formation of various types of vortices and the generation of turbulence and wave breaking. Such hydrographic interactions potentially affect both the particulate transport around reefs and the associated epibenthic and infaunal assemblages (see below). Research into the broader effects of artificial reefs on their surrounding sediment is limited and contradictory. Relatively fine sediments are frequently associated with higher organic contents and greater macrobenthic diversity and biomass compared with coarser sediments [2] but this changes when the organic load becomes excessive (see below).

Over the last ten years there has been increasing concern about the likely impacts of the development of the marine renewables industry with urgent calls for additional research [reviewed in 3, 4] particularly in relation to likely the biodiversity consequences of such a major alteration of the marine environment. In addition there is also interest in the potential positive benefits of offshore structures, in relation to crustacean fisheries, through habitat creation [5, 6]. Crevice obligate species, such as lobsters, often show a preference for the interface between hard substrata and soft sediments as this allows the construction of bespoke burrows that are protected from above [7]. Understanding the mechanisms behind change occurring within this boundary area is, therefore, crucial in predicting the likely fishery consequences of the expanding marine renewable energy sector.

This research was conducted on the Loch Linnhe Artificial Reef (LLR) complex which is one of the largest of its kind in Europe (6,230 tonnes in total). The LLR is a purpose-built research facility, designed to address how man-made structures perform across a gradient of marine environments. The Loch Linnhe Reef most closely resembles the scour protection material ('rip-rap') that may be placed around the bases of turbines or along cable runs [1].

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The purpose of this research was to (1) give an estimate of the spatial and temporal patterns in sedimentary oxygenation in close proximity to the reef modules, (2) to use the redox proxy to infer to the broader consequences of reef-proximity to macrobenthic assemblages and (3) make recommendations with regard the likely benthic consequences of the burgeoning offshore renewables industry

## METHODOLOGY

*Site and dates*

The three reef-groups (18 modules) that were used in this study (termed A, B and D) were deployed during May, August and September 2003, respectively, and were selected on the basis of their age-similarity and their location in contrasting current/ sedimentary regimes (Figure 1).

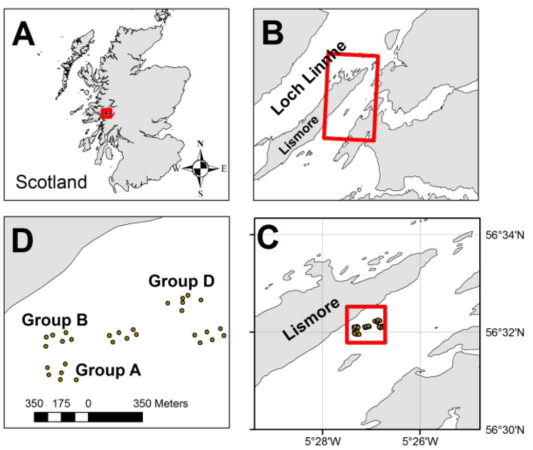


**Figure 1 – Location of the Loch Linnhe Artificial Reef with increasing detail (A to D). A: Scotland (excluding Shetland Isles). B detail from A showing part of Loch Linnhe and the island of Lismore. C – detail from B showing reef location in Loch Linnhe. D detail from C showing the 30 reef units in the main reef-matrix with reef groups, each of six individual modules, marked A to D. The co-ordinates shown in Figure 1C are in degrees and minutes, WGS 84 datum. Figure 1A is shown in the British National Grid projection.**

A waterproof 'redox' probe was used, in situ, by diver. Redox is a measure of oxygenation status, and measurements were taken by inserting the probe 80 mm into the sediment.

*Statistical analyses*

The response variable was redox. The distance effect was the main factor of interest. Distances of 0, 1 and 4 m from the reef edge were chosen on the basis of prior observations [8] and Distance was, therefore, considered fixed. The effect of location (Reef Group) on the distance effect was also of interest. The reef groups were chosen on the basis of their differing characteristics (current exposed or unexposed) and were, therefore, considered fixed. The reefs were sampled over time in order to estimate temporal effects. Of primary interest were major seasonal differences in the effect of location and distance. Two seasons were considered, nominally referred to here as winter and summer reflecting water temperature (less than 10°C and more than 10°C respectively). Season was, therefore, also considered fixed.

## RESULTS

*Physical description*

The physical environment around each of the reef groups was, visually, very different despite their close proximity. Around Group A the sediment was flat, soft and muddy while around Group B the sediment consisted of numerous cobbles and stones in a muddy matrix. The sediment surrounding Group D consisted of coarse sands and gravels intermixed with mud and overlain with large stones and occasional boulders. There was no evidence (by visual inspection) of any sediment-scouring around any reef at any time. Further site details are provided in Wilding and Sayer [9].

The water column at the experimental site was often seen to contain drifting phytodetritus consisting of detached macroalgal fronds (mostly *Laminaria* sp). The phytodetritus was, periodically, seen to accumulate around the modules in Groups A and B but not Group D. The patches of accumulated phytodetrital material varied in extent, from simply being trapped in among the blocks at the module edge, to accumulations of approximately 0.5 m depth which were patchily distributed along the reef edge extending outwards by 1 – 2 m.

The influence of the fixed effects is shown in Figure 2: the impact of reef-proximity was greatest at reef group A, during the summer, and resulted in an approximate 80 mV reduction in redox. Impacts decreased from reef group A to B to D and was less in all reef groups during the winter.

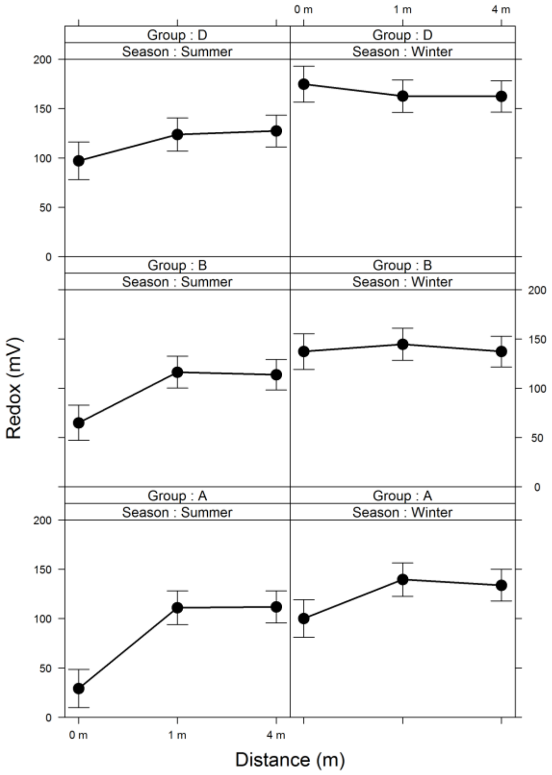


**Figure 2 Model output (mean expected values and 95% confidence interval for that mean) for each combination of Distance, Season and Group. The major change occurs during summer, Group A between Distances 0 and 1 m.**

## CONCLUSIONS

MREDs and associated infrastructure will become *de-facto* artificial reefs. Where located in temperate coastal waters, on cohesive sediments, the results presented here indicate that reef- proximal sediments are likely to remain relatively unchanged, in terms of oxygenation status, except in cases where significant quantities of macroalgal detritus are trapped by the reef structure. This is likely to occur in areas subject to moderate water flows, where there is a supply of detached macroalgae (e.g. following infrastructure cleaning operations or storms) and where there is significant baffling of water currents around the structures. The consequence of moderate organic enrichment, by phytodetritus or other debris, is likely to be an increase in localised benthic productivity, potentially benefiting some fishery species. However, in areas already subjected to oxygen stress, for example the Baltic Sea, the accumulation of organic matter around offshore structures may exacerbate pre-existing sedimentary hypoxia leading to a localised reduction in benthic productivity and the exclusion of some fishery species. Additional research is required to identify other factors that are likely to influence the utilisation of the proposed MRED structures by valuable commercial species and how to maximise this potential through design modification and site selection.

NOTE: This work has now been published. Wilding, T. A. (In press). "Effects of man-made structures on sedimentary oxygenation: Extent, seasonality and implications for offshore renewables." Marine Environmental Research.

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