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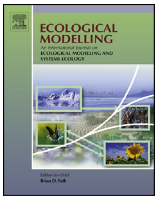

Spatial ecosystem modelling of marine renewable energy installations: Gauging the utility of Ecospace

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ABSTRACT

The deployment of offshore structures for renewable energy generation (wind/wave/tidal) will lead to the alteration of access to the area of installation for several users of the sea including: shipping, fishing, tourism and recreational users. Arguably, the largest impact will be upon the fishing industry where access loss may lead to displacement and reduced catch per unit effort in turn leading to conflict. To prevent conflict, it is important to understand mitigating factors. Marine renewable energy devices (MREDs) and associated infrastructure will be placed on the seabed, affecting benthic infauna and epifauna, important sources of food for many species including those of commercial importance, potentially providing benefits to the fishing industry and mitigating the causes of conflict. Two key plausible benefits of MREDs are the 'artificial reef effect' and the 'exclusion zone effect'. This study investigated the utility of the Ecopath with Ecosim and Ecospace modelling software to address the implications of these 'effects'. Two case study models were developed, one at the whole west coast of Scotland shelf scale and one at a smaller single installation scale. Our results suggested that the Ecospace model could potentially predict the effects of MRED installations, but revealed that there are a number of considerations which should be taken into account before attempting to do this. Key considerations include data availability (an issue in all modelling), spatial scale and resolution. Other limitations to this particular study such as the ability to make changes over time are currently being addressed by ongoing developments of the software. Despite the considerations and limitations, these case studies reveal the usefulness of spatial ecosystem modelling, particularly Ecospace, to investigate this issue.

1. Introduction

As the anthropogenic drivers of climate change become more apparent, the use of renewable energy to move towards a global low carbon economy is gathering momentum. In the past decade, the focus has been on technologies such as solar photo-voltaic and biomass technologies, ocean thermal energy conversion, wind, wave and tidal (Gross et al., 2003). Indeed, energy extraction from the marine environment is currently an area of growth owing to a vast potential source of energy resources. This is due to constantly developing technology (Pelc and Fujita, 2002) and suggestions that moving renewable energy generation offshore reduces issues involved with siting onshore such as visual impact (Gill, 2005; Ladenburg, 2008), planning control and regulation, and limited available onshore sites (Haggett, 2008). It is predicted that 7% of the world's electricity production will come from the ocean by 2050 (Esteban and Leary, 2012). Therefore, it is important that environmental, social and economic impacts of marine renewable energy device (MRED) installations are identified and measured to ensure that decisions regarding offshore energy are sustainable and equitable.

There are several potential negative impacts of MRED deployment. Birds, mammals and fish may collide with MREDs; human-induced noise and electromagnetic fields may affect some marine species; and MREDs may constitute suitable habitats for non-indigenous species, thus facilitating their spread (Gill, 2005). Furthermore, the placement of devices and their associated infrastructure on the sea floor may lead to the displacement of organisms in the local area as well as modifying habitat resulting in changes to local food-web dynamics. It will also lead to changes in access to the area of installation for users of the sea including shipping, fishing, tourism and recreation (Jay, 2010; Nobre

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et al., 2009; Punt et al., 2009). Arguably, the largest impact will be upon the fishing industry where access loss may lead to displacement and a reduction in catch per unit effort (Alexander et al., 2013). Less understood are any potential positive effects of MREDs upon the ecosystem. Fishers have suggested that artificial reefs and exclusion zones may provide potential mitigation for loss of access (Alexander et al., 2013) and it is this concept that we address here.

MREDs and associated infrastructure placed on the seabed will likely act as de-facto 'artificial reefs'. This has received some attention with a focus upon offshore wind farms (Petersen and Malm, 2006; Wilhelmsson et al., 2006; Wilson and Elliott, 2009) and wave power devices (Langhamer and Wilhelmsson, 2007; Langhamer et al., 2009). Although there has not yet been any research into tidal devices and their potential to act as artificial reefs (ARs), the similarities with wind and wave devices in seabed moorings and associated infra-structure means that this will likely occur. Diver observations, fish surveys, photography, habitat plates and settlement panels, has led to proposals that ARs increase local biodiversity, species abundance and biomass, especially of mobile species by providing additional habitat and refuge (Beaumont, 2006; Hueckel et al., 1989; Martin et al., 2005). However, some studies found that diversity and abundance were lower on an AR than control sites (Davis et al., 1982; Fabi et al., 2002), and that some species are depressed while others are not (Barros et al., 2001; Fukunaga and Bailey-Brock, 2008). In a study of ARs installed to enhance artisanal fisheries in Portugal, ARs were suggested to act as recruitment areas and an extension of natural mating/spawning grounds (Leitao et al., 2009). If ARs do increase species abundance, this could be beneficial for commercial fishers by increasing the catch potential in the local area.

Exclusion zones (EZs) are likely to be placed around MRED installations, as has happened at the Cornwall Wave Hub (Campbell et al., 2014), closing the areas to certain fishing gear types or creating no-take zones. Limited research has focused upon the potential EZ effects of offshore development (Shields and Payne, 2014 and references therein) however, it is possible to draw parallels with marine protected areas (MPAs). MPAs were developed primarily as a conservation tool due to the decline of fish stocks and deterioration of habitats worldwide; they are also suggested to be a fishing management tool used to control the spatial distribution of fishing pressure (Halpern, 2003; Hilborn et al., 2004). Some argue that when fishing is stopped, species become more abundant and diverse, as well as larger and more fecund, and that the protection of spawning stock biomass can increase recruitment and re-stock fished areas (Roberts and Polunin, 1993). In addition, connectivity (a consequence of which can be the exchange of populations through larval dispersal) can enhance fish production outside of MPAs leading to a 'spill-over effect' and enhanced catches in adjacent areas (Sale et al., 2005). Roberts et al. (2001) found that over five years, St Lucian marine reserves led to an improvement in neighbouring fisheries catches despite a 35% decrease in fishing ground area. Spill-over from EZs was a significant although variable factor in the dynamics of the fishery in Mombasa Marine Park, Kenya, although spill-over also interacted with fisheries gear, morphology and tidal patterns (McClanahan and Mangi, 2000). In another study, approximately 7% of spiny lobster emigrated annually from the Mediterranean Columbretes Islands Marine Reserve to an adjacent fishery (Goni et al., 2010). If EZs enhance catches in adjacent areas, this will also be of benefit to local fishers.

Empirical exploration of the potential benefits of MREDs caused by the AR and EZ effects is prohibitively expensive. Alternatively, computational models can be used to represent a marine ecosystem and provide indications of how the ecosystem is likely to change in response to these effects as well as how the fishing industry will subsequently be affected. Most ecosystems are complex and creating a suitable model is challenging. Should a credible model be developed, model parameters can then be changed to explore a range of scenarios that can be tested empirically for verification. There are several ecosystem models in use (e.g. Baretta et al., 1995; Fulton et al., 2004; Shin and Cury, 2001), however the most used and tested ecosystem modelling tool for investigating how ecosystems respond to changes in fishing (and other pressures) is Ecopath with Ecosim (EwE) (Christensen, 2009). EwE is a dynamic food-web modelling suite which describes ecosystem resources and their interactions (Christensen and Walters, 2004).

To investigate AR and EZ effects, spatial models are required. Ecospace, a spatial modelling algorithm for EwE, was developed to investigate the effects of marine protected areas (e.g. Beattie et al., 2002; Chen et al., 2009; Salomon et al., 2002). Colléter et al. (2014) used Ecospace to investigate the potential spillover effect from MPAs, showing that potential exports from small scale MPAs are limited and thus may only benefit local fishing activities. Ecospace has also been used to investigate the effects of ARs on marine ecosystems and fisheries: Pitcher et al. (2002) found that small protected areas with human-made reefs would achieve little to avert a collapse of the fisheries in the area or a shift towards lower value species, however larger protected areas may do much to restore valuable fisheries in the South China Sea. This would suggest that Ecospace is an appropriate tool to investigate the EZ and AR effects of MREDs.

Our aim was to guage the utility of Ecospace to address the question of whether MREDs can benefit, and thus mitigate a potential loss of access for the fishing industry by providing: (a) habitat through the 'reef-effect' and (b) protection through the 'exclusion zone effect'. To do this we developed two model 'case studies' representing the west coast of Scotland, an area of key interest in the UK for offshore renewable energy extraction-building upon the Ecopath with Ecosim (EwE) model of the west coast of Scotland (Alexander et al., 2015).

2. Materials and methods

2.1. Area of study

The first case study model represents the west coast of Scotland ecosystem (wcoS), which covers the continental shelf, defined as all sea area above the 200 m contour within ICES Division VIa (Fig. 1(a)). The wcoS area covers approximately 110,000 km^2, and includes the waters around the Outer Hebrides, Skye, the Small Isles, Mull, Islay, and the Firth of Lorn and Firth of Clyde island groups. The second case study model (Great Race) (Fig. 1(b)) occurs within the first case study area and covers approximately 6.25 km^2 of water and coastline off the west coast of the island Jura, within the Firth of Lorn. This is an area of potential interest to tidal energy producers due to the strong tidal stream within the site. Bordering the Great Race to the east and north are the Gulf of Corryvreckan and the Garvellachs respectively. These features are part of the Firth of Lorn SAC, where tidal developments would not be permitted inside and within 1 km of the site; therefore an area of outside of the SAC was chosen. The purpose of the second model was to test a fine-scale alternative to the coarser-scale wcoS site study.

Commercial fisheries operating in the wcoS area include demersal trawls, pelagic trawls, dredges, gillnets, longlines, creels and scallop fishing by hand with 1799 fishers operating 950 vessels as of 2013; providing 34 per cent of the total value of all Scottish landings (Scottish Government, 2014). The majority of fishers on the wcoS occupy the '10 m and under' section of the Scottish fleet, and focus upon demersal (mainly cod, haddock and whiting) and shellfish (mainly *Nephrops* and scallops) species, although mackerel is also of importance (Scottish Government, 2011).

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