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Linking ecosystem services with epibenthic biodiversity change following installation of offshore wind farms

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ABSTRACT

The growing awareness of climate change and the recognised need to secure energy production has been a driving force behind the expansion of the offshore wind industry across the world. Benefits from offshore wind farms (OWFs) may extend further than low CO_2 energy production. Wind turbine substructures introduce hard surfaces that are rapidly colonised by epibenthic marine organisms, altering biomass and biodiversity within the local ecosystem. Biodiversity plays a critical role in supporting ecosystem processes and functions that maintain ecosystem services. As offshore wind development continues to grow and modify marine habitats, changes in biodiversity could affect the provision of ecosystem services. In this context, this review sets out to capture the current understanding of epibenthic biodiversity change following the installation of OWFs and attempt to link these changes in biodiversity with marine ecosystem services through the associated processes and functions.

1. Introduction

A growing awareness of the effects of climate change and concerns over energy security have been driving forces for renewable energy (Mangi, 2013; Szulecki et al., 2016; Voormolen et al., 2016). Owing to much larger installed turbines, as well as the stronger, more consistent winds offshore, offshore wind farms (OWFs) have a higher potential to harness renewable energy than their terrestrial counterparts (Petersen and Malm, 2006; Lange et al., 2010). As a result, the offshore wind energy industry has seen considerable investment. In European waters, the cumulative installed capacity of OWFs rose from 0.8 GW in 2006 to 12.6 GW by the end of 2016 (Corbetta and Miloradovic, 2016). The European offshore wind industry is expected to continue to expand and may contribute more than 10% of Europe's energy (around 140 GW) by 2030 (Zervos et al., 2009; Langhamer, 2012). Growth has been slower outside of Europe, but substantial expansion is still expected. Japan's cumulative installed offshore wind capacity was 59.6 MW by the end of 2016 with around 2.5 GW more in various stages of development (GWEC, 2016). In China and North America, offshore wind capacity is expected to achieve 5 GW (up from 1.6 GW in 2015) and 10 GW by 2020 respectively (GWEC, 2016; Zhao and Ren, 2015; Lü et al., 2017). That expansion is set to increase in North America to 54 GW by 2030 (Zhao and Ren, 2015).

Whilst it is largely accepted that OWFs provide net benefit to the global environment by reducing direct CO_2 emissions, it is not clear how large-scale installation of OWFs may influence local ecosystems. Modification of marine habitat following the installation of an OWF is expected to change local and regional biodiversity. Key ecosystem processes are supported by biodiversity, which are crucial to the delivery of multiple functions that affect the provision of ecosystem services (Wilhelmsson and Malm, 2008; Mace et al., 2012; Snelgrove et al., 2014). Ecosystem services are goods and benefits humans derive from nature, emphasised as components of wealth, well-being and sustainability (Mace et al., 2012; Carpenter and Turner, 2000; Liquete et al., 2013; Costanza et al., 2014). Identified as provisioning (e.g. food), regulating (e.g. carbon sequestration), cultural (e.g. tourism and recreation) and supporting (e.g. nutrient cycling) (Millennium Ecosystem Assessment, 2005; Beaumont et al., 2007); they are, in essence, by-products of ecosystem processes and functions that are recognised as being beneficial to people, particularly in relation to health and well-being (Sandifer et al., 2015). Such processes and functions are supported by biodiversity at local and regional scales.

It is generally considered that high biodiversity supports high ecosystem functionality, with declines in biodiversity having a negative effect on ecosystem functions (Loreau, 2001; Hooper et al., 2005; Balvanera et al., 2006; Cardinale et al., 2012; Lefcheck et al., 2015; Gamfeldt et al., 2015). For instance, ecosystems with high biodiversity typically have greater resistance to disturbance (Purvis and Hector,

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2000; Tilman et al., 2006; Isbell et al., 2015). Worm et al (Worm et al., 2006) support this observation; they demonstrated that lower rates of collapse and higher rates of recovery in commercially important fisheries occurred where there was higher regional species richness. It has been suggested that the presence of species with similar ecological roles and traits effectively provides biological redundancy and protects against changes to ecosystem function (Levin, 1999; Duarte, 2000; Palumbi et al., 2009). Thus, a reduction in species richness could result in an ecosystem that is less resilient. Whereas increased biomass and biodiversity due to introduced hard substrate may create resilience in epibenthic populations, which may further support higher trophic levels.

In recent decades, ecosystem services have become a major area of research, development and policy attention in terrestrial systems (Naidoo et al., 2008). In marine environments however, ecosystem services have received less attention, beyond fisheries and related industries (Liquete et al., 2013; Gee and Burkhard, 2010) and only recently have the effects of OWFs on the delivery of ecosystem services been studied (Mangi, 2013; Busch et al., 2011; Hattam et al., 2015; Wilding et al., 2017). However, linkages have not been made between biodiversity, ecosystem functions, and ecosystem services. With the evident expansion of offshore wind energy across the world there is a common need to consider how the associated large-scale habitat modification, through the installation of OWFs, and subsequent changes to biodiversity, could affect the provision of ecosystem services. Determining how changes in biodiversity would impact processes and functions is central to determining the effect of OWFs on the delivery of associated ecosystem services. As such, this review aims to specifically link changes to biodiversity, in relation to OWFs with ecosystem services through associated processes and functions.

2. Habitat modification by offshore wind farms

By introducing hard substrate in the form of the turbine towers, foundations, cables and scour protection, OWFs increase the complexity of the seabed and the water column and present opportunities for food and shelter for benthic associated organisms at various life stages (Petersen and Malm, 2006; Langhamer, 2012; Coates et al., 2011). Thus, in effect OWFs act as artificial reefs, increasing local biomass and promoting biodiversity (Mangi, 2013; Langhamer, 2012). This is not unexpected; hard substrate in the marine environment, such as OWFs and oil and gas platforms, have been shown to be rapidly and intensively colonised by epibenthic species (Connell and Slatyer, 1977; Kerckhof et al., 2009, 2010; Degraer et al., 2012; Kerckhof et al., 2012). Indeed, artificial structures, including shipwrecks, sea walls, oil and gas platforms and purpose built artificial reefs, have been shown to support diverse reef communities (Zintzen and Massin, 2010; Lengkeek et al., 2011; Schrieken et al., 2013; Lengkeek et al., 2013; Whomersley and Picken, 2003; Wolfson et al., 1979; Forteath et al., 1982; Guerin et al., 2007; Mallat et al., 2014). In the southern North Sea, up to 250 taxa have been recorded on shipwrecks, which was similar to the species richness recorded by soft substrate surveys of the entire Dutch continental shelf (Lengkeek et al., 2011; Schrieken et al., 2013; Daan and Mulder, 2006). In addition, fish species are known to aggregate around hard-structures largely due to the provision of food through the development of species rich epifauna-communities (Reubens et al., 2011; Svane and Petersen, 2001). Atlantic cod, *Gadus morhua*, have shown a preference for hard substrate habitats and it has been noted that close proximity to shipwrecks provides protection from bottom trawl fisheries (Lengkeek et al., 2013).

Fish, including commercial species, have been shown to aggregate around wind turbine foundations (Reubens et al., 2013, 2011), which may have added benefits for exploited populations. As offshore wind turbine foundations present a hazard to fishing gear they may, over time, encourage recovery of commercially exploited fish stocks and lead to over-spill to surrounding areas (Langhamer, 2012; Busch et al., 2011; Lengkeek et al., 2013). However, evidence of benefits of OWFs to fisheries have so far been inconclusive. In the North Sea, reported catches before and after the construction of Kentish Flats and North Hoyle wind farms showed no significant changes, although catch per unit effort (CPUE) from survey trawls within the Kentish flats wind farm were higher for all species except sole (Mangi, 2013).

Typically, wind turbines have been installed in regions characterised by a soft sandy benthic environment, such as the North Sea, where hard substrate and intertidal regions are uncommon (Hooper et al., 2015; Kerckhof et al., 2011; Mangi, 2013; Lengkeek et al., 2013). Therefore, OWFs represent a large-scale increase in local habitat heterogeneity that may lead to a regional shift from sediment associated benthic to hard bottom and intertidal communities (Kerckhof et al., 2011; Mangi, 2013; Lengkeek et al., 2013). Indeed, several studies have indicated that epifauna assemblages found on artificial reefs, including wind turbine piles, differ from those on nearby reefs and natural substrate (Connell and Glasby, 1999; Petersen and Malm, 2006). Moreover, there is evidence artificial reefs may act as stepping stones for non-native species (De Mesel et al., 2015; Gill, 2005; Glasby et al., 2007). Kerckhof et al (Kerckhof et al., 2011) demonstrated that OWFs in the Southern North Sea were rapidly colonised by non-indigenous species, particularly in the intertidal region.

The introduction of epibenthic assemblages can also modify the local hydrodynamic regime, biochemistry and benthic sediment composition (Boehlert and Gill, 2010; Coates et al., 2011; Miller et al., 2013; Vaissière et al., 2014). Hiscock et al (Hiscock et al., 2002) suggested that alteration of local hydrodynamic regimes may lead to turbulences that cause resuspension of fine sediments, reducing light penetration and smothering existing benthic communities.

There is concern around the potential for this large-scale reef effect to modify marine ecosystems (Petersen and Malm, 2006; Langhamer, 2012) as OWF developments introduce an significant hard substrate surface area to a previously open water and an often sedimentary sea bed habitat (Boehlert and Gill, 2010; Coates et al., 2011). To date, on European coastlines, more than 3500 turbines have been installed (Byrne et al., 2017). It is important to note that OWFs differ from other structures in that modification of the local environment spans multiple devices. Expressly, rather than a single large reef, an OWF represents a network of interconnected smaller artificial reefs. A single turbine has a relatively small ecological footprint. To illustrate, recent monopile designs have a diameter of 8 m (Byrne et al., 2017), leading to a footprint on the seabed of 50.3 m^2 (not including scour protection). Jacket foundations have a larger footprint. For example, a foundation with a base of 20 m (Seidel, 2007) would have a footprint of 400 m^2. However, this remains relatively small when compared with that of an OWF array, which may be several square kilometres with turbines separated by distances of 500–1000 m (Snyder and Kaiser, 2009). Many of the proposed larger developments with hundreds of turbines will have footprints of several hundred square kilometres (Boehlert and Gill, 2010; Gill, 2005).

Changes to the habitat on the scale of a single turbine may have minor effects in isolation, but cumulative effects across the scale of an OWF may be substantial and are, at present, highly uncertain (Willsteed et al., 2017). The level of complexity and variation would make scaling ecosystem services across OWFs and estimating cumulative impacts very challenging. There would be variations in local conditions, such as hydrodynamic regime. Additionally, the installation of OWFs span across seasons. As a result, the oceanographic conditions and species richness in the water column would vary between turbine installations. As such, it is likely that multiple stages of development may be seen on turbine substructures within a single OWF. Further, as with any natural reef, communities on turbine substructures will change and adapt over time. Therefore, it is not unreasonable to expect the delivery of ecosystem services to vary over the lifespan of turbines.

Based on existing evidence it is expected that the OWFs would dramatically change local biodiversity, and hence the associated