

Renewables-to-reefs? – Decommissioning options for the offshore wind power industry

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Abstract

The offshore wind power industry is relatively new but increasing globally, hence it is important that the whole life-cycle is managed. The construction–operation–decommissioning cycle is likely to take 20– 30 years and whilst decommissioning may not be undertaken for many years, its management needs to be addressed in both current and future marine management regimes. This can be defined within a Drivers–Activities–Pressures–State Changes–Impacts (on human Welfare)–Responses framework. This paper considers the main decommissioning options – partial or complete removal of all components. A SWOT analysis shows environmental and economic benefits in partial as opposed to complete removal, especially if habitat created on the structures has conservation or commercial value. Benefits (and repercussions) are defined in terms of losses and gains of ecosystem services and societal benefits. The legal precedents and repercussions of both options are considered in terms of the 10-tenets of sustainable marine management. Finally a ‘renewables-to-reefs’ programme is proposed.

Keywords: Decommissioning, Offshore wind power, Ecosystem services assessment, Renewables-to-reefs, DPSIR framework, SWOT analysis

1. Introduction

Although the offshore wind power (OWP) industry has existed for only two decades, it is of growing importance as a source of energy across the globe. There is a European potential for 40 GW of offshore installed capacity by 2020, with an additional 110 GW installed by 2030 (EWEA, 2011, 2013); in the US 54 GW by 2030; and in China 30 GW by 2020 (EWEA, 2011). The increase in renewable energy results from a decreasing reliance on fossil fuels especially as worldwide demand for energy is expected to treble by 2050 (WEC, 2012) increasing carbon dioxide emissions from 30.2bn metric tonnes in 2008 to 43.2bn metric tonnes by 2035 (IEO, 2011). In the European Union (EU) for example, in 2009 only 3% of the UK energy was from renewable sources whereas the EU target is for Member States to collectively achieve 20% of energy from renewable sources by 2020 (Renewables Directive 2009/28/ EC annex 1). Across Europe, Member States have set targets in National Action Plans in support of the EU goals that vary according to their national capabilities: Denmark and Germany have targets of 20% of energy consumption from renewable sources and Finland has a target of 38% (EC, 2010).

Given the increasing growth of OWP, and the need to understand the environmental, economic and social aspects of any development as required by the Ecosystem Approach, it is essential for marine managers to have a complete understanding of the full life cycle of any offshore wind farm (OWF) project. The underlying marine management can be defined within the DAPSI(W)R framework which represents Drivers–Activities–Pressures–State Changes–Impacts (on human Welfare)–Responses (Elliott, 2014). This is modified from the DPSIR risk analysis and risk management (RARM) framework, a systems-based approach to capture key relationships between society, its environmental demands and the natural environment (Atkins et al., 2011; Gregory et al., 2013). It allows the assessment of management options associated with the offshore wind sector and has been recently used for similar evaluations, e.g. in the context of seabed restoration following the cessation of aggregate dredging (Cooper et al., 2013). The DAPSI(W)R approach is consistent with the Ecosystem Approach which is advocated, for example, by the Marine Strategy Framework Directive (2008/56/EC) with the boundary of the system captured by the framework being dependent on the issue of concern (Svarstad et al., 2008). A DAPSI(W)R framework for the management of the UK offshore wind sector is given in Fig. 1.

The framework encompasses the key Drivers, which are the UK and export demands for renewable energy, which results in the building of offshore wind farms. Several Activities are associated with this, namely, the installation, operation, maintenance and ultimately the removal of components and infrastructure. In turn the Activities create several Pressures on the system, for instance maintenance of the subsea cabling is a pressure on the local system. These Pressures may lead to State Changes on the natural system which affects, for example, the physical nature of the seabed, water column and marine organisms, and these State Changes may then produce Impacts on the provision of ecosystem services for society and hence potential changes to human Welfare. There is then a need for management Responses, to control the State Changes and Impacts on Welfare, which in the case of the offshore wind sector include licensing conditions, monitoring and decommissioning. Given the cyclical nature of this framework, the Response then affects the Drivers, Activities, Pressures and State Changes thus producing an iterative system. The content of this figure is further discussed throughout the paper.

The focus of this paper is on decommissioning as a management Response. This paper assesses the possible environmental impacts of infrastructure (turbine monopile, cabling, armouring, etc.) removal on the physical site through a review of decommissioning options and the existing regulatory framework for decommissioning. Future options for decommissioned sites are explored using the Ecosystem Approach within a DAPSI(W)R framework. An evaluation based on a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was undertaken to investigate the potential environmental and economic benefits from the different decommissioning options, leading to an initial assessment of the potential Impact on societal Welfare of the two decommissioning options using an existing ecosystem services framework. The legal precedents and repercussions of partial and complete removal are considered and are described in terms of the 10-tenets of sustainable marine management (Elliott, 2013). This approach is important in order to obtain a holistic view of the system and to allow a full comparison of the effects of any particular decommissioning strategy and has led to our proposal of a renewables-to-reefs programme as an alternative to a traditional site

decommission. Although regional aspects of the North Sea are examined in the context of UK and EU policy and legislation, the discussion here relates to all offshore wind developments.

2. Review of existing decommissioning options

As offshore wind is a relatively new industry and, to date, no wind farms have been decommissioned, to review options for decommissioning, cases from the offshore oil and gas industries are used as a starting point.

The beneficial value of partial removal of offshore structures is illustrated by the novel method of protecting and enhancing the marine environment during decommissioning of oil platforms which began in the 1980s in the Gulf of Mexico (Kaiser and Pulsipher, 2005; Reggio, 1987). This 'rigs-to-reefs' programme is considered to offer significant environmental and commercial benefits given that complete removal can damage the seabed, the habitat and the new equilibrium which has been created. This is especially the case given the habitat created by the armouring to protect the cabling and main structure (Wilson and Elliott, 2009). Leaving an artificial reef, with benefits for commercial and recreational fishing plus the reduced costs for developers, are weighed against operational challenges of leaving parts in place, where these challenges relate to safety of navigation, ongoing maintenance costs, issues in relation to liability of the reef and potential for spread of non-indigenous species. This rigs-to-reefs programme was introduced through the US National Fishing Enhancement Act and is currently governed under the US National Artificial Reef Plan.

One of the most developed rigs-to-reefs programme exists in Louisiana, under permits from the US Army Corps of Engineers (USACE) and the US Coast Guard (via the Rivers and Harbors Act 1899 s10) who use that Plan for decision making. The requirement to remove a disused offshore installation within a year of decommissioning is waived for the development of an artificial reef programme provided the following criteria are met: the structure does not inhibit future development opportunities; the reef complies with the USACE permit conditions as outlined in the Plan and that a state fishing management agency accepts liability for the structure (Kaiser, 2006). The USACE will evaluate and permit proposed projects on a site-specific basis and the US Coast Guard is responsible for navigational safety of the remaining structure. Furthermore, following termination of the federal lease for oil extraction, the platform operator is absolved of all responsibility for the installation if it is accepted into the artificial reef programme provided that a responsible state agency will accept liability (Kaiser, 2006). Consequently, under the Louisiana Fishing Enhancement Act of 1986, the Department of Wildlife and Fisheries acts as an agent for the state and as such will assume ownership and all resulting liabilities of the installation including future maintenance costs.

It is also of note that the Louisiana State artificial reef planning process designated nine sites deemed appropriate for artificial reef operation. These site designations have considered all marine users and been identified as both environmentally and commercially viable and in line with navigational safety requirements.

3. Interdisciplinary analysis of decommissioning offshore wind developments

The 10-tenets framework for achieving sustainable management (Elliott, 2013, 2014) takes the view that a truly interdisciplinary approach is required which encompasses the economy, ecology, technology, governance, etc. Hence, within the context of OWF decommissioning, an interdisciplinary analysis has been undertaken which considers the regulatory framework and

both the natural environmental and the socio-economic impacts of decommissioning options. This evidence-based analysis comprises a comprehensive regulatory review, a SWOT analysis and an assessment of ecosystem service provision, which is discussed in light of the 10-tenets of marine management, and results in a proposal for a renewables-to-reefs programme.

3.1. Regulatory framework for decommissioning [the management Responses in DAPSI(W)R]

A wind turbine reaches its designed life expectancy (20– 30 years) when it cannot function properly due to failure or fatigue, or no longer satisfies the expectations or needs of its user (Ortegon et al., 2013). At this point there are two main options: to repower or decommission. Repowering allows the continued operation of the wind farm, with replacement of certain turbines by higher power capacity units and newer technologies. The size of individual structures has increased from 25–30 m blades to 75 m blades and so the possibility of replacing small monopiles and turbines with larger ones exists as is already done for terrestrial wind farms, for example in Denmark (Munksgaard and Morthorst, 2008). Repowering depends on Government energy policy, continued support for offshore wind and extension of lease or licence options, and is not considered further here. In contrast, offshore decommissioning guidelines were originally developed for oil and gas platforms which, unlike offshore wind turbines, exploit a finite natural resource and after exhausting the oil or gas field the platform cannot be used for its designed purpose (or it has to change its purpose). International regulation under the United Nations Law of the Sea Convention (UNCLOS) and within the Regional Seas Conventions, such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Guidelines, considers decommissioning as the removal of all under- and above-water structures and infrastructure.

Decommissioning for OWP will not be required for a number of years but planning appropriately for decommissioning and management of the site after decommissioning form a fundamental component of the consenting process. Offshore wind farm decommissioning involves environmental protection, safety, cost and strategic opportunity, and the options available to developers depend upon regulatory approval and technical feasibility (Kaiser and Snyder, 2012). Decommissioning plans therefore need to take into account not only the environmental, but also the financial, engineering and societal impacts of removal of offshore installations at the end of operational life (see below). Driven by legal, financial and environmental concerns, procedures for decommissioning are usually built into licensing and consent proposals for all marine developments, including wind farms as part of the Environmental Impact Assessment (EIA) process. Hence an assessment of decommissioning procedures is necessary even at this early stage in global offshore expansion. The two decommissioning options for a wind farm site at the end of its service life are full removal, as total decommissioning, or partial removal, which allows certain parts to be left in situ.

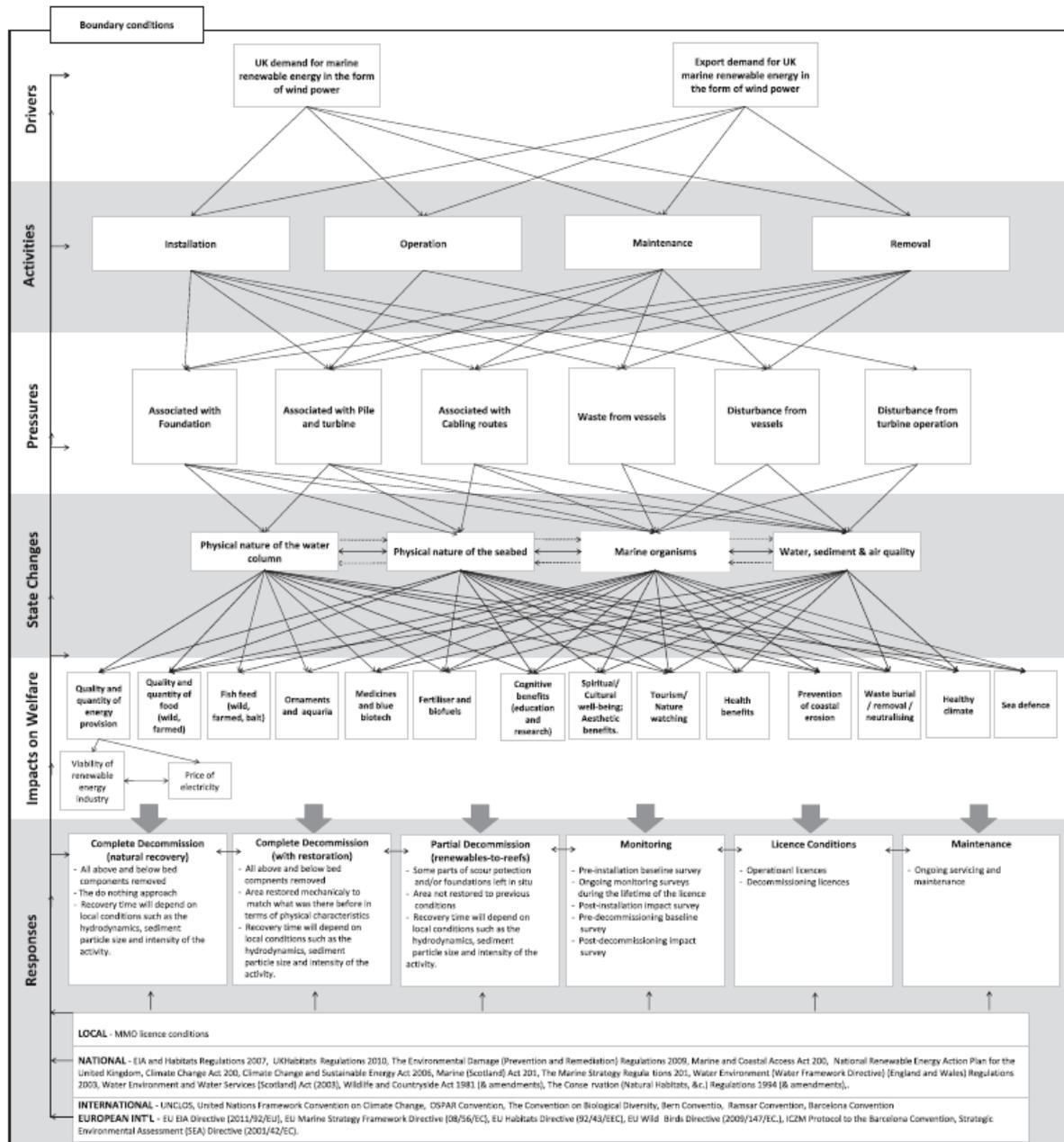


Fig. 1. A DAPSI(W)R framework for the management of UK offshore wind energy development.

3.1.1. Full removal

From a marine user perspective, the site may be returned to its pre-wind farm state with revocation of all restrictions on shipping and navigation and commercial fishing operations. This is in line with accepted international legal obligations as when obsolete it no longer serves an immediately useful purpose but will represent a potential navigational hazard and an obstacle to fishing (Churchill and Lowe, 1999). As such, international legal obligations require the removal of the installation. Article 60(3) UNCLOS provides that offshore

installations should be 'removed to ensure safety of navigation taking into account any generally accepted international standards established in this regard'.

The generally accepted international standards referred to in UNCLOS are the 1989 International Maritime Organisation (IMO) Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone, IMO Resolution A.672 (IMO Guidelines). While not binding on States, this soft law instrument provides minimum content for national decommissioning regulation and directs state practice in a voluntary manner. The Guidelines provide that States in general must entirely remove disused installations in less than 75 m water depth. As most offshore wind developments are planned for shallow waters of around 50 m depth (although deeper and further offshore structures are possible), complete removal will be required in line with IMO Guidance in most cases.

There are several international and regional instruments which control marine disposal (pejoratively and precursory described as 'dumping') of wastes into the marine environment and which are central to the decommissioning of offshore installations. The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, (the London Convention) is one of the first international instruments in place to protect the marine environment. The Convention, and its 1996 Protocol, regulates the dumping of waste into the marine environment and expressly deals with the disposal of offshore installations. Article 3(1)(a)(ii) provides that the deliberate disposal at sea of platforms or other man-made structures constitutes 'dumping'. While the Convention aims to prevent pollution by dumping, there are certain substances which may be disposed at sea after licensing. Platforms and other man-made structures at sea are treated within Annex II, the 'grey list' of the Convention, and may be permitted for sea disposal. Since the Convention centres on environmental protection, any disposal is subject to a marine impact assessment and the non-availability of alternative land-based disposal. As the London Convention, with 87 contracting parties (42 for the Protocol), is a global instrument with wide-reaching scope, regulation at a regional level may impose stricter obligations on State parties. This is also the case for State parties to the regional OSPAR Convention for example, in which case the stricter provisions in the regional treaty supersede the international obligations.

The 1992 OSPAR Convention established a decommissioning framework for disused installations and unified the 1972 Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (the Oslo Convention) and the 1974 Convention for the Prevention of Marine Pollution from Land-based Sources (the Paris Convention). The Brent Spar incident in 1995, which led to a change in North Sea decommissioning policy (Jørgensen, 2012), centred on the deep-water disposal of a disused oil storage and tanker loading buoy. The highly publicised Greenpeace protest and resulting public pressure gained international exposure, and a UK High Court decision leading to a ban on deep water disposal in the North Sea. This produced the OSPAR binding decision 98/3, which provides that in general offshore installations must be removed in entirety and so dumping and leaving wholly or partly in place installations is prohibited. OSPAR Guidance on Environmental Considerations for Offshore Wind Farm Development 2008-3 (OSPAR OWF Guidance) follows Decision 98/3 and provides that "in line with OSPAR's Policy on waste disposal at sea, the removed components of a wind farm should generally be disposed of

entirely". Both IMO Guidelines and the OSPAR decision have exceptions to the general removal obligation (see Section 3.1.2 Partial removal below).

At a national level within the EU, regulatory requirements for offshore wind farm decommissioning vary greatly. Only Denmark, the UK and the Netherlands have specific guidelines for offshore wind farm decommissioning in place, including a supporting financial framework (Januário et al., 2007). In the UK, the Department for Energy and Climate Change guidance (DECC, 2011) suggests that in line with commitments under UNCLOS, taking into account IMO standards and OSPAR guidance, the 'ideal' decommissioning programme involves removing the whole of all disused installations and structures. Similarly, in the US, decommissioning regulations, Code of Federal Regulations, Title 30, Part 285 – Renewable Energy Alternate Uses of Existing Facilities on the Outer Continental Shelf (30 CFR 285) Subpart I, 285.900-913, provides that for wind farm structures in federal waters, developers must remove all facilities, projects, cables, pipelines and obstructions, clear the seafloor and verify clearance upon the lease termination. This process must be completed no later than two years after the termination of the lease.

3.1.2. Partial removal

The most significant provisions in the international decommissioning framework are those which provide exceptions to the general principle of complete removal. UNCLOS does not require entire removal and both the IMO Guidelines and OSPAR Guidance provide exceptions to the general presumption in favour of removing the whole installation. IMO Guidance (para 3.5) provides that "where entire removal would involve an unacceptable risk to the marine environment, the coastal State may determine that it need not be fully removed". OSPAR OWF Guidance similarly provides that if the "competent national authority decides that a component of the wind farm should remain at site (e.g. parts of the piles in the sea-bed, scour protection materials), it should be ensured that they have no adverse impact on the environment, the safety of navigation and other uses of the sea" (para 93). Of further environmental significance is that the IMO Guidelines aim to ensure that "the means of removal or partial removal should not cause a significant adverse effect on living resources of the marine environment, especially threatened and endangered species". This provision could provide further support for leaving some components of the installation in place to protect the newly created habitat, provided that safety of navigation is ensured. Navigational safety obligations require that all components of the installation must be cut to an acceptable level below the sea bed and continued monitoring would be required to ensure the foundations and cables remain buried. Under the EU EIA Directive (85/337/EEC), decommissioning of offshore wind farms will be considered a 'plan or project' likely to have a potential impact on the marine environment and as such will be subject to an Environmental Impact Assessment (EIA). Offshore wind developments currently in the initial planning stages thus incorporate decommissioning into their Environmental Statements. Similarly, if the wind farm site becomes or is included within a Special Area of Conservation under the EU Habitats Directive (92/43/EEC), an Appropriate Assessment under Article 6(3) would be required prior to decommissioning to assess whether removal is likely to affect the conservation objectives of the site.

As an example, UK DECC (Department of Energy & Climate Change) guidance considers that decisions on permitting some of the offshore installation to remain in situ, should also assess the likely effect to the remaining elements of removing other parts of the installation. Removing the monopile may alter (but not necessarily restore) hydrographic conditions of the site which could ultimately affect the position and continued burial of the foundations. This reinforces the need for continued monitoring of the site after decommissioning. In implementing the international guidelines at a national level, Danish regulation for example, in certain instances permits partial removal; once the lease for the wind farm site expires, or the installation reaches its end of working capacity, Danish Government policy holds the operator legally liable for returning the site to its original state. Under Danish law, if full removal is considered to present an environmental hazard then partial decommissioning may be permitted (CCC, 2010). However in practice, this requires 'environmental hazard' to be defined to allow consistency across all decommissions (Elliott et al., 2014). Furthermore, the ability of the site to naturally recover from such a hazard (the site resilience) needs to be assessed before such a decision on a partial decommission is made (Elliott et al., 2007). In the Netherlands, the Government also holds the operator liable for decommissioning, and during the operational life the operator annually pays into a segregated fund in the event that they go insolvent before the end of service life hence allowing the government to perform decommissioning. The Government presumption is that monopiles must be cut to at least 4 m below sea level and makes no provision for cabling at all (CCC, 2010), suggesting partial removal may be easier to achieve in the Netherlands from a legal point of view, however a 4 m depth minimum for cutting the monopiles is still likely to pose a risk to navigation.

The alternatives to complete removal include leaving in place the scour protection which may be large boulders, gravel/cobbles and artificial vegetation fronds (Wilson and Elliott, 2009) and can itself become a valuable habitat. In sandy sediments, scour can be as deep as 1.38 times the monopile diameter (Whitehouse et al., 2011) and so an extensive amount of scour protection will be required. Hence its removal is likely to create even more adverse change and disturbance to the scour protection may make removal difficult to achieve.

3.2. Environmental impact of decommissioning options

The environmental impact of decommissioning on the marine environment, reflected by State Changes in the DAPSI(W)R framework, needs to address the potential that the wind farm has acted as an artificial reef during its operational life. Any structure placed in the marine environment has the potential to become an artificial reef through colonisation by marine biota (Wilson and Elliott, 2009; Wilson et al., 2010). This can be seen on a number of scales, for example from biofouling of buoys (Huang and Lin, 1993; Huang et al., 1982), to entire functioning communities that develop around shipwrecks (Church et al., 2008; Hiscock, undated; Parulekar, 1991; Zintzen et al., 2006) or oil rig bases (Scarborough-Bull and Kendall Jr., 1994; Stachowitsch et al., 2002; Stanley and Wilson, 2000). Epibiota, such as mussels and barnacles, grows readily on the man-made structures (harbour walls, piers, sea defence structures and along boat mooring ropes) as well as natural materials. The sequence of colonisation of habitat in the marine environment, from hardy opportunistic species to sustainable climax communities has been discussed by many authors (Antoniadou et al., 2011; Connell and Slayter, 1977; Perkol-Finkel and Benayahu,

2005; Wahl, 1989; Wolf and Rumohr, 1982). During the installation of the wind farm, the ecology and environment will have changed and eventually reached a new equilibrium; it is debateable whether there would be a return to a pre-construction state following full decommissioning. Following the removal of stressors, many marine systems do not achieve the pre-stressor state (Duarte et al., 2013; Elliott et al., 2007).

Such artificial reefs can develop around the monopile foundations and armouring which themselves act as a surface habitat (Wilson and Elliott, 2009). The reef effect is thought to cause the largest change to the marine environment and this effect occurs at three different scales: the micro scale, which includes material, texture and heterogeneity of the construction materials; the mesoscale, which includes the revetments and scour protection, and the macro scale, covering the entire wind farm (Petersen and Malm, 2006). Although turbine foundations and scour coverage will remove any infaunal habitat within the footprint (estimated at 61% of the wind farm area, (Petersen and Malm, 2006)), the mono-pile and scour protection can create 2.5 times the amount of area that was lost from its placement (Wilson and Elliott, 2009). In the German Bight, the surface of a hard foundation similar to a wind turbine base (1280 m²) was covered by an average of 4.3 t marine organism biomass. This foundation concentrated on its footprint area (1024 m²) 35 times more macrozoobenthic biomass than the same area of soft bottom in the German exclusive economic zone (0.12 kg m²) (Krone et al., 2013b). This is a potential net habitat gain and although this habitat differs from that lost, after a service life of ca. 30 years, it is probable that any faunal or floral colonisation and utilisation of such habitat (foundations, scour protection, monopile) will be advanced and productive, therefore the decommissioning process may effectively remove this habitat. As with any disturbance, following decommissioning, the system repeats the process of colonisation and succession, before returning to an equilibrium and a new climax community, albeit possibly different from the one with monopile and foundations, from the pre-construction situation and from the surrounding seabed (Elliott et al., 2007).

Current recommendations in the UK are for removal of the monopile and foundations but it is optional for scour protection to be removed and the UK government guidance suggests it can be left in situ (DECC, 2011). Many wind farm decommissioning plans use this option, often citing that removal would contribute an 'unacceptable risk to personnel' as well as mentioning the artificial reef effect (Airtricity, 2007; Centrica, 2010; DONG, 2012; EDF, 2011; SCIRA, 2010). Although not calculated here, the energy costs of removing the infrastructure could also be notable. Despite this, these decommissioning programmes also state that the scour protection, although ultimately left on the sea bed, may be relocated to allow removal of the foundations and monopile.

Marine construction studies have shown that identical habitat to that which was lost to construction cannot always be created as a mitigation or restoration measure (see Mazik and Smyth, 2013), therefore it is unlikely that after a complete decommissioning of a wind farm, the seabed will return completely to its original pre-wind farm state. Additionally, recovery rates of benthic communities tend to depend on the spatial scale, duration and frequency of the disturbance, a greater size means a longer recovery time (Duarte et al., 2013; Gray and Elliott, 2009) although other factors must be considered such as the extent of the defaunation and structure of the surrounding community (which provides adults and larvae for recolonisation) (Mazik and Smyth, 2013). Therefore, if during the

operational life of the wind farm a climax, stable and productive habitat has developed, potentially one that is of commercial value for harvestable species e.g. crab, lobster, mussels (explained further below, see Section 3.6) or contains species of conservation importance, it is questioned whether it is defensible to completely remove all components of the wind farm during decommissioning, or whether other options are available, such as a partial removal of components.

3.3. SWOT analysis of decommissioning options

Given the different decommissioning options and expected effects described above, it is appropriate to objectively assess the alternatives via a SWOT analysis for OWF complete or partial decommissioning (Table 1). The assessment is based on current knowledge and literature and expert judgement. Although overall both options have advantages and disadvantages, the analysis is hampered by the lack of practical experience in wind farm decommissioning. Whilst full decommissioning will be financially expensive, it results in more Strengths and Opportunities for future site use such as restoration of shipping and fishing activity, as well as allowing activities such as aggregate extraction (where appropriate). In contrast, a partial removal is less expensive and the Strengths and Opportunities focus on ecological benefits such as maintaining the new habitat whilst allowing the co-location of less intense commercial activities such as recreational fishing and diving, as well as static gear commercial fishing.

On balance this analysis follows the same rationale which produced the US rigs-to-reefs programme although there are differences such as prevailing governance regimes, agreed limits of engineering, site characteristics, construction materials, installation depth and installation design. For example, in the North Sea, OSPAR guidance on artificial reefs prohibits the use of non-virgin material in reef construction although that concern relates to the release of toxins leaching from structures. Given the age of the foundations, it is likely that either the toxins have already leached out or the surfaces have been 'sealed' with marine fouling organisms. Furthermore, there is the major difference that at present oil and gas rigs may be in deeper waters and so resulting reefs present fewer navigational safety issues than wind farm foundations. In addition, taking a holistic view, it is also emphasised that despite the navigational safety considerations, the energy and manpower costs and safety issues during removal of wind farm structures may mean it is more beneficial to leave structures in place especially where the aim is to protect and enhance the marine habitat at the decommissioned site.

3.4. An ecosystem services approach to assess the Impacts of decommissioning options

If protection measures can be implemented through a regulatory framework, it is valuable to explore the idea of limiting marine use on the site and creating Marine Protected Areas (MPA) at a national level to support the habitat and allow continued growth of existing reef-like habitats. Furthermore, as the OWF Impacts on human Welfare and much marine management is now centred on the principles behind ensuring that delivery of ecosystem services is protected (Atkins et al., 2011; Potts et al., 2014) then these should also be applied to OWF farm decommissioning.

Options for environmental and management Responses at the end of operational life of the OWF will partly depend on the nature of the created habitat and the biota it supports. Most importantly, prior to decommissioning, it is essential to distinguish whether the site habitats, biotopes and species are (1) of conservation importance and therefore require protection, (2) are those with a high commercial potential, or (3) are those which amount to biofouling of little importance either commercially or in conservation terms. The first category opens up potential regulatory options involving the use of designated MPAs for site and species protection and enhancement. The second option gives added weight to retaining seabed structures because of financial benefits. The third provides limited scope for regulatory intervention.

Any habitat enhancement or modification will require an EIA especially as unintentionally constructing an inappropriate habitat, e.g. a refuge for predators in a nursery area, can increase, rather than mitigate, the impacts of human developments (Pioch et al., 2011), although a mature habitat needs a complete food web, including the predators. Man-made structures can be beneficial to the recovery of populations, e.g. the dogwhelk *Nucella lapillus* reduced using antifouling paints (Bray et al., 2011) or be stepping stones to aid colonisation and migrations of non-indigenous and invasive species (Olenin et al., 2011). For example, the spread in the Mediterranean of the introduced green algae, *Codium fragile tomentosoides* (Bulleri and Airoldi, 2005) and *Caulerpa racemosa* (Vaselli et al., 2008) has been attributed to the presence of hard breakwaters. However, given the many natural and non-natural existing hard structures (e.g. rock outcrops, shipwrecks, fallen aeroplanes) in shallow coastal waters it will be difficult to detect the effect of wind turbine foundations on alien species spread against a background of natural variability. All of this needs to be considered during the EIA, by including all aspects of the construction, operation and decommissioning, including the benefits of ecological engineering (e.g. deliberately allowing structures to remain because of ecological benefits, or engineering structures in such a way that they promote ecological development from first construction) and in discussions with all stakeholders.

Table 1: SWOT analysis of removing all structures and infrastructures (complete removal) compared to leaving the foundations and scour protection in place (partial removal). Less intrusive on any new habitat that has developed e.g. around the scour protection and foundation.

SWOT	Complete removal	Partial removal
Strengths	<ul style="list-style-type: none"> Restoration of all shipping activity Restoration of all fishing activity Restoration of previous habitat if possible 	<ul style="list-style-type: none"> Less intrusive on any new habitat that has developed e.g. around the scour protection and foundation Reduced cost for developers during the removal stage Less noise/sediment changes likely to have an impact on the wider marine environment
Weaknesses	<ul style="list-style-type: none"> Significant impact on habitats – almost as severe as construction stage – potential loss of created habitats. Increased financial implications for developers Lack of practical knowledge and experience in decommissioning offshore wind farms 	<ul style="list-style-type: none"> Additional costs in future maintenance of the site, continued monitoring and associated costs – where does this cost lie? Limiting potential for future development of site for major alternative use. Lack of practical knowledge and experience in decommissioning offshore wind farms. Possible spread of non-indigenous and/or invasive species by leaving components in place
Opportunities	<ul style="list-style-type: none"> Site can be opened up again for new development opportunities e.g. leasing the site for aggregate dredging 	<ul style="list-style-type: none"> Due to the protection of the habitat the site may present development opportunities for recreational users e.g. tourism, diving, recreational fishing etc. Potential for some commercial activity if site considered suitable e.g. crustacean ranching
Threats	<ul style="list-style-type: none"> Financial liabilities Alienation of certain user groups 	<ul style="list-style-type: none"> Potential collision risk/entanglement of fishing gears due to uncovered elements resulting from sediment change if the site is not effectively monitored Spread of non-indigenous species Alienation of certain user groups

In addition to ecological benefits, there are societal benefits of created reefs, as shown in the case of the ex-British Naval ship HMS Scylla, sunk off SW UK in 2004, which has become an important centre for both recreational diving and scientific research. The first six months following the sinking showed a 200–300% increase in local boat traffic and thus additional income for the local economy. After only 6 years, the wreck closely resembled the nearby reference wreck James Eagan Layne in terms of colonised species (OSPAR, 2010). Similarly in US waters, numerous rigs-to-reefs schemes have been beneficial for tourism with disused structures increasing recreational diving and fishing (Ditton and Stoll, 2008; Roberts et al., 1985; Stanley and Wilson, 1989).

Therefore, as a means of integrating the natural and societal aspects of change associated with a decommissioned site, it is possible to assess the net effects on the ecosystem services resulting from natural marine processes and the societal benefits emanating from those services. Ecosystem services are defined here as ‘the link between ecosystems and things that humans benefit from, not the benefits themselves’ (Fisher et al., 2009). The ecosystem services framework applied here (Fig. 2) was developed for the marine environment through a series of recent UK initiatives (Turner et al., 2014; UK-NEA, 2011; VNN, 2013). The framework distinguishes between marine components and processes, and intermediate and final ecosystem services, and illustrates the flow of services towards the goods/benefits, with the latter referring to a range of human welfare benefits derived from the flow of final services provided (Turner et al., 2014). In turn, for society to gain the benefits from those ecosystem services requires the input of complementary assets and capital, in the form of built, human and social capital. Given the focus of the DAPSI(W)R on energy generation, the viability of this sector and the particular relevance of the price of electricity have been noted within Impacts (on Welfare). Inclusion of an assessment of the viability and prices relevant to other sectors, such as commercial fishing, recreation, and tourism, is of less relevance (though not irrelevant) to the context here.

In the context of decommissioning offshore wind farms (both complete and partial removal of all structures and infrastructure), the possible effects on the change in provision of marine ecosystem services of the wind farm site are assessed (Table 2). It is assumed that partial removal would leave the foundations and scour protection in situ, whereas complete removal would remove all above- and below-water infrastructure, thus attempting to return the site to its pre-OWF state. Using evidence and expert judgement, the assessment is reported in both partial and complete removal cases relative to the level of ecosystem service provision with the wind farm structure and infrastructure still in place.

The results should be interpreted with some caution, as the effects will depend on site-specific factors including the ability to return the site to its pre-OWF state (see Section 3.2). Some further uncertainty is included in the case of aesthetic benefits and spiritual and cultural well-being, linked in part to places and seascapes – for example, it is difficult to consider the extent to which the removal of a wind farm represents an improvement in human well-being. The impacts on health benefits are also uncertain as although removing an OWF may negatively impact health due to a loss of energy from clean renewable sources, health benefits are also linked in part to places and seascapes. It is evident that effects are not in one direction, and in several instances are considered negligible, particularly where the policy measure involves partial removal of the wind farm as the foundations and scour protection are especially important for the provision of certain ecosystem services e.g. fish and shellfish production.

The latter are also of interest since complete removal may lead to a significant negative effect on these local stocks, while it may also create a significant positive effect on food should previous fishing restrictions be relaxed or removed at the site. This last point does not recognise the potential for spill-over effects, i.e. where fishing restrictions at a site allow the target species there to increase and eventually increase regional stocks or, conversely, fishing restrictions at one site increasing the pressure elsewhere; these changes are difficult to assess, and in practice may be non-negligible and dependent upon the boundary conditions of the assessment.

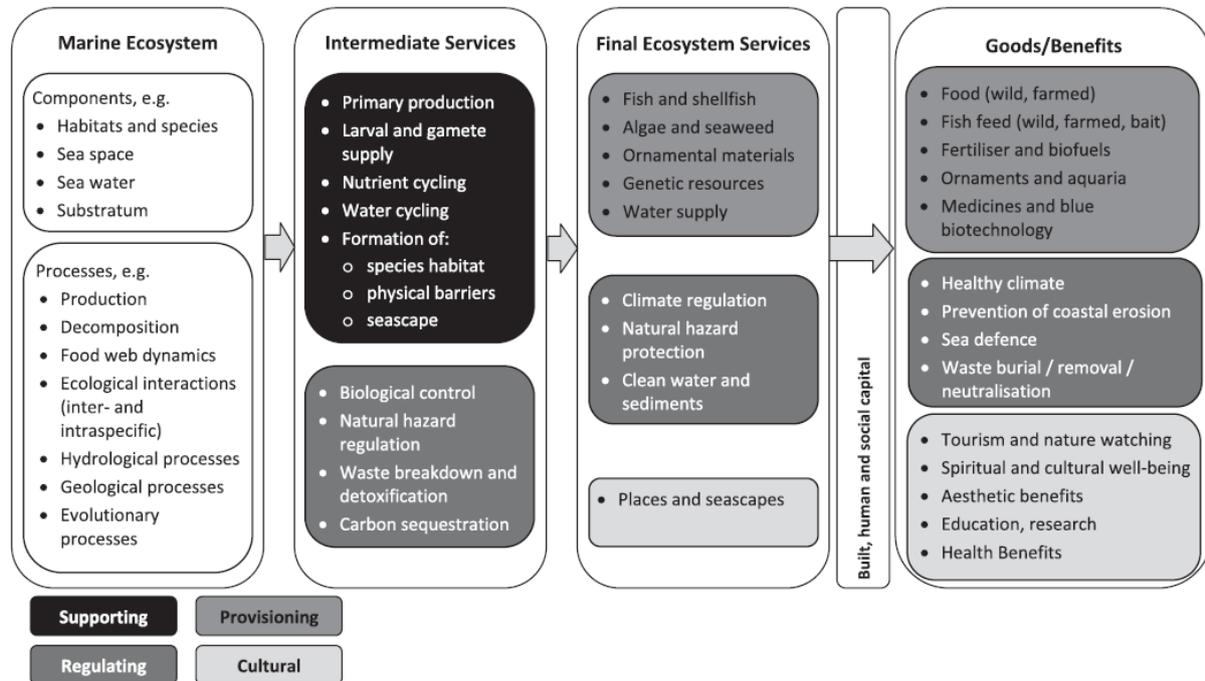


Figure 2: An ecosystem services framework for the marine environment (after Turner et al., 2014).

Table 2: An assessment of the potential effects of partial and complete removal of wind farm structures and infrastructure relative to the provision of ecosystem services and goods/benefits

	Partial removal ^a	Complete removal ^b	Comments
<i>Intermediate ecosystem services</i>			
Primary production	–	– –	More hard substratum, more primary production depending on photic zone
Larval and gamete supply	?	?	Changes dependent on local hydrographic regime
Nutrient cycling	0/?	0/?	Gap in current understanding; unlikely to detect change
Formation of species habitat	–	– –	Less hard substratum, less diverse habitat
Formation of physical barriers ^c	+	++	Removal of structures and any colonising organisms takes away physical barriers
Formation of seascape	0	0	The seascape will be changed
Biological control	0	+	Return to natural food webs, reduction in invasive/alien species
Natural hazard regulation ^c	–	– –	Removal of structures and any colonising organisms takes away potential for energy dissipation
Waste breakdown and detoxification	0/?	0/?	Gap in current understanding; unlikely to be detectable
Carbon sequestration	–	– –	Increased C-sequestration and biomass (C storage) associated with artificial reefs/hard structures; unlikely to be detectable
<i>Final ecosystem services</i>			
Fish and shellfish	0	– –	Removal of artificial reef effect particularly in total removal case
Algae and seaweed	–	– –	Hard substratum allows seaweed/algal growth depending on photic depth
Ornamental materials	0	–	Increased biodiversity associated with structures
Genetic resources	?	?	Current gap in knowledge; depending on habitat formation
Water supply	0	0	Negligible in offshore locations
Climate regulation	0	–	More C-sequestration and storage associated with hard substratum; difficult to be detected
Natural hazard protection ^c	–	– –	Removal of structures and any colonising organisms takes away potential for energy dissipation
Clean water and sediments	0	0	No long term change expected
Places and seascapes	0	0	These will be changed
<i>Goods/benefits</i>			
Food (wild, farmed)	+	++	Some fishing may be allowed after partial removal (dependent on fishing methods applied). Possible removal of fishing restrictions after total removal of structures and infrastructure (excluding spill over effects)
Fish feed (wild, farmed, bait)	–	– –	Increased biodiversity and biomass associated with structures
Fertiliser and biofuels	0	0	Hard substratum allows seaweed/algal growth depending on photic depth but not easily harvested
Ornaments and aquaria	0	–	Increased biodiversity associated with structures
Medicines and blue biotechnology	?	?	Current gap in knowledge
Healthy climate	0	–	Increased C-sequestration and storage on hard substrata
Prevention of coastal erosion ^c	–	– –	Removal of structures and any colonising organisms takes away potential for reducing coastal erosion
Sea defence ^c	–	– –	Removal of structures and any colonising organisms takes away potential for providing sea defence
Waste burial/removal/neutralisation	0	0	No long term change expected
Tourism and nature watching	0	– –	Artificial reef effect retained in partial case (diving, angling, etc)
Spiritual and cultural well-being	0/?	0/?	Changes may be positive or negative (see main text)
Aesthetic benefits	0/?	0/?	Changes may be positive or negative (see main text)
Education, research	0	0	Research opportunities exist for both cases
Health benefits	0/?	0/?	Changes may be positive or negative (see main text)

Key: ++ potential significant positive effect; + potential positive effect; 0 negligible effect; – potential negative effect; – – potential significant negative effect; ? gaps in evidence.

^a Assumes that the foundations and scour protection remain on the seabed.

^b Assumes that all structures and infrastructures are removed and therefore the site is returned to its pre-wind farm state.

^c Interpretation is made problematic since the effect on this service reflects both the man-made structure and any colonising organisms.

3.5. A regulatory and multi-sectoral approach

If it is assumed that a habitat of conservation importance has been created through the artificial reef effect, then MPAs could be used as a legitimate tool to limit human activity within the decommissioned site. Certain types of activity within the site could then be restricted to allow the habitat to recover after the damaging effects of installation were removed. Depending on the nature of the species involved, restrictions could be reduced on a staggered basis as the habitat recovers or could be implemented on a more permanent basis.

To ensure that limits on access to the site are followed in practice, legal rather than voluntary agreements should be used in most cases. In English inshore and offshore waters for example, the Marine Management Organisation (MMO) under the Marine and Coastal Access Act 2009, has the power to create byelaws within MPAs to ensure the protection of the individual site (Boyes and Elliott, 2014). For example, two byelaws in place within English waters, for the sites at Portsmouth Harbour European Marine Site and the Solent European Marine Site (MMO, 2013), can impose restrictions on certain types of harmful activity. These byelaws aim to restrict certain damaging fishing practices and so byelaws with licence restrictions for certain fishing vessels e.g. bottom trawling vessels, could be used to restrict access to the decommissioned site. As certain types of fishing, mostly bottom trawling and dredging, will in general not be possible within the OWF safety zones during the operational phase, formal restrictions upon decommissioning will have less of an impact.

While restrictions on fishing have been used as examples, bye-laws could limit any human activity which may impact on the integrity of the protected site although there are two key points. Firstly, this option is entirely dependent on whether the decommissioned site has a feature worth conserving and meets the legal criteria for MPA designation, for example either as a Marine Conservation Zone under the Marine and Coastal Access Act (in UK waters) or a European Marine Site under the EU Habitats Directive (92/43/EEC). Secondly, restrictions on site access will be assessed on a site-specific basis. As such, while certain fishing techniques might be prohibited to avoid disturbance to the protected species within the wind farm components protection left in situ, certain other types of fishing may be permitted, especially if the created habitat increases the yield of commercially valuable stocks such as crab and lobster. Access for traditional fixed fishing methods such as pots/creels rather than mobile trawling gears may be allowable, as will be recreational fishing; this is regarded as the co-location of activities within the decommissioned protected site (Christie et al., 2014). Furthermore, given that the preferred habitat for crabs and lobster is where rock and boulder areas abut sedimentary seabed, then scour protection margins may enhance these populations (see below).

The decommissioning of offshore wind turbines is subject to the same multi-sectoral and multidisciplinary considerations as any set of actions aimed at sustainable marine management. This has been summarised ensuring that all aspects are monitored and that a set of 10-tenets is maintained (Elliott, 2013). In interpreting these 10-tenets for offshore wind farms (Table 3), the view is that many of the potential problems, whether ecological, technological or legal can be overcome. Furthermore, if the successful decommissioning, for example by leaving in place a reef structure, ensures delivery of conservation objectives and ecosystem services and is economically viable for the operators, then it is likely that it will be sanctioned by the statutory marine management bodies. However as yet a rigorous analysis of these 10-tenets and the cost-benefit analysis related to the delivery of ecosystem services and societal benefits for decommissioned OWF has not been done.

3.6. Proposal for a renewables-to-reefs programme

A similar approach to the rigs-to-reefs programme for offshore wind farms, here proposed as a renewables-to-reefs programme, examines the artificial reef effect and the way in which decommissioning may enhance the marine environment. Although the overall structure differs from offshore rigs, the principles of artificial reef enhancement apply and a comparable

renewables-to-reefs programme may be beneficial, especially in terms of the goods/benefits conferred through changes in ecosystem services and their links with recreation possibilities and fisheries potential, in addition to ecological benefits (see Tables 1 and 2).

Changes in local food webs due to a hard structure being placed on a soft bottom may enhance fish and crustacean stocks of commercial and recreational value (Bohnsack and Sutherland, 1985; Langhamer et al., 2009). Over the next few decades, for example, in the southern North Sea, up to 4.3 times the existing amount of hard bottom habitat will be created on artificial structures, increasing mobile demersal megafauna, which may be commercially-important, by 25–165% (Krone et al., 2013a). This effect has already been noted in a Swedish coastal area where hard foundations increased fish and crab stocks compared to adjacent soft bottoms (Langhamer et al., 2009). Furthermore, when the habitat complexity was increased by creating holes in the foundations to provide refuges, the commercially important *Cancer pagurus* (brown/edible crab) showed a fivefold increase (Langhamer et al., 2009).

Table 3: The 10-tenets for successful and sustainable environmental management (modified from (Elliott, 2013)).

Tenet <i>environmental management should be...</i>	Wind farm examples
Ecologically sustainable: measures will ensure that the ecosystem structures and functioning and provision of ecosystem services are safeguarded Technologically feasible: methods, techniques and equipment for ecosystem and society/infrastructure protection are available	The natural ecology is maintained where possible and so not disrupted during decommissioning Mechanisms to prevent scour; adequate shielding for cabling to reduce EMF; navigational systems notified of any potentially hazardous undersea infrastructure left in place after decommissioning; methods for removal of all or part of the structure are sanctioned
Economically viable: a cost-benefit assessment of the environmental management indicates (economic) viability and sustainability	Compensation schemes for those people and areas affected; that industry in the national interest and large urban areas are protected; ongoing monitoring costs are included from the outset to ensure future costs are covered; that measures for pollution reduction are funded; that during decommissioning the costs of full or partial removal are economically justified
Socially desirable/tolerable: environmental management measures are as required or at least are understood and tolerated by society as being required; that society regards the protection as necessary Ethically defensible (morally correct): the wishes and practices of individuals are respected in decision-making	Society is educated regarding the effects and implications of renewable energy and its linkages with the marine environment; that if partial decommissioning occurs then society sanctions the structures left in place Dealings with individuals are at the highest level and that no single sector is favoured unduly; that the costs of present action to be borne by the future generations are considered (e.g. economic discounting)
Culturally inclusive: local customs and practices are protected and respected	That indigenous peoples, habits and customs are incorporated into decision-making; aboriginal (first nation) rights are defended; that effects of full or partial decommissioning on indigenous fisheries are taken into account
Legally permissible: there are regional, national or international agreements and/or statutes which will enable and/or force the management measures to be performed	That due consideration is given to environmental regulation at a national, regional and international level for the protection of marine habitats and risk mitigation plans are in place; shipping and navigational safety are ensured, in line with international obligations and standards; that there is legal sanctioning of partial decommissioning and links to the MPA framework
Administratively achievable: the statutory bodies such as governmental departments, environmental protection and conservation bodies are in place and functioning to enable successful and sustainable management Effectively communicable: all horizontal links and vertical hierarchies of governance are accommodated and decision-making is inclusive Politically expedient: the management approaches and philosophies are consistent with the prevailing political climate and have the support of political leaders	That there is horizontal and vertical integration between national and international administrators; communication between statutory, planning, legal and environmental bodies ensures coherent implementation That all sectors are aware of the important issues and involved decision making; that all stakeholders have the opportunity to participate in decision-making That there is pressure on politicians to carry out measures; that politicians are aware of the risks and the consequences of either not being prepared nor having suitable responses for the hazards occurring

The transition zone between an artificial structure and the surrounding soft bottom habitat is inhabited by many mobile mega-crustaceans which exploit resources from both habitats (Krone et al., 2013a). The commercially-important species *Cancer pagurus* and *Necora puber* (velvet swimming crab) accumulate around both a rig jacket and shipwrecks to feed on the biofouling and the adjacent soft substratum species (Krone et al., 2013a). There is thus the potential for offshore energy installations to create both habitat and commercial and recreational fishing opportunities and hence co-location for socio-economic gain is possible (Christie et al., 2014). Indeed, artificial reef structures have been widely used for both stock enhancement and conservation, (Fabi et al., 2011), for example: for lobsters (Herrnkind and Butler VI, 1994; Jensen et al., 1994), fish (Santos et al., 2007; Zalmon et

al., 2002), molluscs (James et al., 2007; Martins et al., 2010), and eco-tourism (Brock, 1994). Furthermore, safety zones required around underwater structures will prevent bed-damaging activities such as beam trawling, again creating de facto MPAs and No-Trawl Zones.

In general, artificial reefs are considered to have commercial and recreational fishing benefits (Polovina and Ichiro, 1989) although one questions whether they increase the abundance and/or biodiversity or merely act as fish-attracting devices without any net overall gain in productivity (Pickering and Whitmarsh, 1997; Powers et al., 2003). In Japan, artificial reefs increased catches of octopus but only aggregated flatfishes without increasing catches (Polovina and Ichiro, 1989). In contrast, in the Red Sea, an 18-month study showed clear differences in the diversity and abundance of species between adjacent artificial and natural reefs (Perkol-Finkel and Benayahu, 2007) indicating an increase in biota, rather than a relocation from existing reefs nearby. Similarly, in Japan artificial cedar wood reefs developed their own fish biomass without an associated reduction in fish abundance on nearby natural reefs (Masuda et al., 2010) and in Sydney Harbour, Australia, where pontoons and pilings developed a different community to adjacent rocky reefs (Connell, 2001). The evidence that artificial reefs develop their own communities and productivity rather than aggregating species from the surrounding area thus has conservation and commercial implications.

However, whilst wrecks and specifically-designed artificial reefs provide a large, complex surface to allow a diverse colonisation of species, monopile foundations provide a more limited area and habitat (Wilson and Elliott, 2009) although they could be engineered to produce a given habitat and encourage colonisation. Ecological engineering is increasingly used to produce such benefits (Chapman and Underwood, 2011), for example: construction of seawalls for habitat complexity instead of a uniform surface (Browne and Chapman, 2011; CMA, 2009); pipeline construction in the Indian Ocean to include habitat and nursery areas (Pioch et al., 2011); habitat restoration and creation schemes using reef-balls (Barber, 2012), and the creation of refuges on foundation structures to increase stocks of the crab *Cancer pagurus* (Langhamer et al., 2009). Hence ecological engineering can be cost-effective for developers and, with careful planning, does not have to increase greatly the original planned construction cost (Pioch et al., 2011).

4. Concluding comments

Decommissioning for the offshore wind industry will not be required in a practical sense for a number of years but, despite this, the procedures for decommissioning and management of the site after decommissioning are integral to the permitting process. Decommissioning plans should consider the financial, engineering and environmental impact of removal of offshore installations at the end of operational life. Environmental considerations and the provision of ecosystem services and societal benefits are particularly important for the wind industry, with sustainability central to its purpose as this study illustrates. This particularly relies on an interdisciplinary approach for integrated marine management.

International obligations and legislation at the national level currently provide that decommissioning will ideally involve the complete removal of the installation and all components, with any access restrictions for certain types of fishing, navigation and

recreational usage being revoked. Depending on the resilience of the site, the area would (also ideally) then return to, or near to, its original pre- wind farm state and community structure. However while the removal of the monopile may be easily, if perhaps expensively achieved, the removal of the cabling and scour protection will be difficult if at all possible. Furthermore there is no guarantee of a return to a pre-construction ecological state.

Just as the initial construction of the OWF is regarded as a plan or project requiring an Environmental Impact Assessment under EIA law and an Appropriate Assessment when in a natural conservation area under, for example the EU Habitats Directive, removal is also regarded as a plan or project. Hence the developer has to demonstrate no or, at most, acceptable environmental impact of the construction, operation and decommissioning and thus show the balance of impacts and benefits to the natural system as well as society.

Consequently, the potential for the bed structures of a wind farm to act as an artificial reef has been highlighted as a possible benefit to the marine environment and must be considered, especially in terms of the additional stress and disturbance on the new and stable ecological system due to a complete decommissioning. During decommissioning it will be necessary to achieve a balance between international obligations to ensure safety of navigation and to protect and preserve the created ecosystem within the marine environment.

Related habitat enhancement and protection measures such as the well-established US rigs-to-reefs programme in the Gulf of Mexico have been considered here as good practice to assess the potential for linkages with the wind industry. Following this highly successful programme, we propose a renewables-to-reefs scenario which is based on the knowledge that leaving in place scour protection is thought to be of particular benefit since the artificial fronds, and boulders, gravel or cobbles used may act as a valuable habitat. In addition, this requires incorporating the principles of ecological engineering into the development process to provide an enhanced habitat which can then be left in place upon decommissioning. Due to the siting of most offshore wind farms in shallower waters, it will not be possible to leave any component of the installation in situ much above seabed level, it is suggested that foundations are cut at an acceptable level for navigation and scour protection should be left in place. This is in line with international decommissioning guidance, based on environmental exceptions.

The SWOT analysis and assessment of ecosystem services and societal benefits given here have highlighted several factors, both positive and negative, that need to be considered during the decommissioning of any offshore wind farm. With this in mind, in interpreting the 10-tenets in terms of offshore wind farms, we take the view that many of the potential problems, whether ecological, technological or legal can be overcome. Furthermore, despite the navigational safety considerations, the energy and manpower costs and safety issues during removal of wind farm structures may mean it is more beneficial to leave structures in place especially where it is also required to protect and enhance the marine habitat at the decommissioned site. Given the current international and national legislative frameworks, this can be sanctioned under powers given to statutory marine management bodies.

The renewables-to-reefs scenario will be entirely site specific and dependent on the nature of the created habitat, the indigenous species, the use made by highly mobile species, and the benefits to society and the wider ecology provided by the site. MPAs enforced by byelaws could act as a valuable tool for providing legal protection to the site, although MPA designation will require the distinction to be made between species of conservation or high commercial importance, and non-important biofouling. Reintroduction of some activities could be achieved on a staggered basis as the site recovers from the impact of decommissioning procedures, taking into account the needs of other sea users.

Based on the evidence for potential positive results of artificial reef enhancement, albeit site specific, and that of the above interdisciplinary analyses, it is argued here that the OSPAR rigs-to-reefs exclusion for monopile foundations should be reconsidered and viewed as a means of recycling to support environmental aims rather than dumping (Jørgensen, 2012). Hence a renewables-to-reefs programme would require the same approach, and could thus confer the same benefits, as for offshore rigs although there is the major difference that at present rigs may be in deeper waters and so resulting reefs present fewer navigational safety issues than wind farm foundations. In addition, taking the energy and manpower costs as well as safety issues concerned with removal of wind farm structures may mean it is more beneficial to leave structures in place, rather than fully decommission them, despite a potential increased navigational risk.

If implemented appropriately these measures could ensure protection for valuable sites and allow for the regeneration of the disturbed marine environment. This could be achieved with an integrated marine management framework (Elliott, 2014). Regardless of all of this, nature conservationists can argue that irrespective of whether more biodiversity or production has been created, the area still differs from the original and pristine site. This philosophical point is difficult to counteract unless overridden by economic and health and safety considerations. It is emphasised that the ecosystem services approach used here indicates the societal benefits and although, as shown in the Table 2, there are many aspects that require further quantification, this and the 10-tenets approach allow a rational decision to be taken.

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