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Original Articles

Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning?

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ABSTRACT

As part of the energy transition, the French government is planning the construction of three offshore wind farms in Normandy (Bay of Seine and eastern part of the English Channel, north-western France) in the next years. These offshore wind farms will be integrated into an ecosystem already facing multiple anthropogenic disturbances such as maritime transport, fisheries, oyster and mussel farming, and sediment dredging. Currently no integrated, ecosystem-based study on the effects of the construction and exploitation of offshore wind farms exists, where biological approaches generally focused on the conservation of some valuable species or groups of species. Complementary trophic web modelling tools were applied to the Bay of Seine ecosystem (to the 50 km^2 area covered by the wind farm) to analyse the potential impacts of benthos and fish aggregation caused by the introduction of additional hard substrates from the piles and the turbine scour protections. An Ecopath ecosystem model composed of 37 compartments, from phytoplankton to seabirds, was built to describe the situation "before" the construction of the wind farm. Then, an Ecosim projection over 30 years was performed after increasing the biomass of targeted benthic and fish compartments. Ecological Network Analysis (ENA) indices were calculated for the two periods, "before" and "after", to compare network functioning and the overall structural properties of the food web. Our main results showed (1) that the total ecosystem activity, the overall system omnivory (proportion of generalist feeders), and the recycling increased after the construction of the wind farm; (2) that higher trophic levels such as piscivorous fish species, marine mammals, and seabirds responded positively to the aggregation of biomass on piles and turbine scour protections; and (3) a change in keystone groups after the construction towards more structuring and dominant compartments. Nonetheless, these changes could be considered as limited impacts of the wind farm installation on this coastal trophic web structure and functioning.

1. Introduction

Humanity's ever growing energy demands have translated into an increase in fossil fuel combustion and greenhouse gases emissions and, consequently, into global climate changes (OSPAR, 2008; IPCC, 2014). A new focus on renewable energy source research and development arose during the last decades to counter this

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trend. The European Union (EU) has set a target of 20% of energety consumption derived from renewable energy sources by 2020 (Directive 2009/28/EC). With more than 11 million km^2 of waters under its jurisdiction, France holds a huge natural potential for marine renewable energy (MEDDE, 2012). Currently, the construction of six offshore wind farms is planned in metropolitan France. Among them, three should be built in the central-eastern part of the English Channel: the Courseulles-sur-mer (~50 km^2, 75 wind turbines), the Fécamp (~65 km^2, 83 wind turbines) and the Tréport (~67 km^2, 62 wind turbines) offshore wind farms. The implementation of this type of infrastructure is a challenge for developers from technical, legal, social, and environmental points of view. Indeed, these offshore wind farms will be integrated into ecosystems already subjected to a growing number of anthropogenic disturbances such as pollution, transport, fishing, aquaculture, aggregate extraction, or sediment dredging and deposit.

Concern about the potential environmental impacts generated by these new structures on marine ecosystems arose from this development (Lindeboom et al., 2011; Bailey et al., 2014). The exploration, construction, operation, and decommissioning of offshore wind farms can indeed be responsible for temporary and/or permanent impacts on marine ecosystems such as the destruction of seabed or the disturbance of fish and marine mammal populations (Shields and Payne, 2014; OSPAR, 2008; Mueller-Blenkle et al., 2010). During the construction phase, if special care is taken to protect important habitats and spatial and temporal habitat use by sensitive species, impacts can be kept within acceptable levels (e.g. Wilhelmsson et al., 2010). During the operational phase, the anticipated and recorded disturbances caused by noise, vibrations and the electromagnetic fields are also in most cases considered to be of minor importance to the marine environment, at least to date (Westerberg and Lagenfelt, 2008; Petersen and Malm, 2006; Wilhelmsson et al., 2010). However, a noteworthy effect of the introduction of turbines with their associated scour protection is the creation of new habitats and shelters that will be immediately colonized by several marine species resulting in an additional source of food for higher trophic levels (Bergström et al., 2013). This effect, generally known as the "reef effect", is considered as one of the most important effect on the marine environment generated by the construction of offshore wind farms (Peterson and Malm, 2006; Langhamer, 2012; De Mesel et al., 2015). The reef effect has been described for epibenthic and demersal fauna as well as on bentho-pelagic fish (including commercial species) in the direct proximity of wind farm foundations (Wilhelmsson et al., 2006; Wilhelmsson and Malm, 2008; Maar et al., 2009; Reubens et al., 2011, 2013, 2014; Leonhard et al., 2011; Lindeboom et al., 2011; Bergström et al., 2013; Degraer et al., 2013). The reef effect has also been demonstrated for other anthropogenic structures such as shipwrecks and oil platforms (Wolfson et al., 1979; Love et al., 1994, 1999; Wilhelmsson et al., 2006). The choice of material and the shape of the structures introduced in the marine environment both play an important role during the colonization process (e.g. Andersson and Öhman, 2010). All these previous studies provide a vast amount of data on environmental effects at the species or community scales. However, the propagation of the reef effect at the ecosystem scale, impacting the structure and functioning of food webs remains unclear (Boehlert and Gill, 2010).

Until now, there is no holistic study on the effects of the construction and operation of offshore wind farms on an ecosystem taken as a whole. Here, we propose to develop a holistic view of offshore wind farm impacts on ecosystems functioning through the use of trophic web modelling tools. Our work will provide information on the food web change in response to the construction and operation of marine energy infrastructures, information which is essential to the sustainable development and management of renewable energy sources. The main feature of this work will be to propose a methodology that is complementary to what it is currently applied in Environmental Impact Assessments by using: (1) a holistic approach in which the ecosystem represents the management unit, (2) a functional perspective based on flows of energy circulating between ecosystem components, and (3) a high level of functional diversity to describe the food web.

Among the different existing modelling approaches, Ecopath with Ecosim (EwE) has been intensively developed and used over the last three decades and applied on hundreds of aquatic ecosystems throughout the world (Polovina, 1984; Christensen and Walters, 2004; Christensen et al., 2008). This approach, in which all biotic components of the system are considered at the same time, provides measures of the ecosystem emergent properties through the calculation of Ecological Network Analysis (ENA) indices (Ulanowicz, 1986). These joint analyses have been frequently applied to coastal and marine systems to assess changes in their functioning in response to environmental perturbations (Ortiz and Wolff 2002; Rybarczyk et al., 2003; Patrício et al., 2006; Niquil et al., 2012; Tecchio et al., 2013, 2015). Some ENA indices, such as the redundancy, have also been linked to notions of stability (Christensen et al., 2005) such as the resilience of trophic webs to perturbations (Heymans et al., 2007). Finally, ENA indices have also been proposed as trophic descriptors of ecosystem health for the EU Marine Strategy Framework Directive (Dame and Christian 2007; Niquil et al., 2012; Rombouts et al., 2013; Niquil et al., 2014).

The objective of the present study was to model the potential impacts of the construction and operation of the Courseulles-sur-mer (southern part of the Bay of Seine along the Calvados coast) offshore wind farm on the local trophic-web functioning. Special attention was paid on the consequences of the introduction of additional hard substrates from the piles and scour protections and the foramation of artificial reefs, in form of benthos and fish aggregations and their possible consequences on the food-web functioning. To analyse the impact of additionally available hard substrates, an Ecopath model was first built to describe the food web before the construction of the Courseulles-sur-mer offshore wind farm. Then, an Ecosim model was derived to project the ecosystem evolution over the next 30 years after the forced increase in biomass of some targeted benthic and fish compartments in relation to the wind farm construction. For this, expected observations of species changes in wind farm areas obtained through extensive literature searches and expert knowledge were adapted to the Courseulles-sur-mer site. Two hypotheses regarding the food-web functioning were particularly investigated with Ecosim simulations: (1) a system dominated by mussels leads to a more detritivorous food web (Norling and Kautsky, 2008), and (2) the increased biomass of benthic invertebrates and fish, as generated by the reef effect, would attract apex predators (Lindeboom et al., 2011; Henkel et al., 2014). This is, to our knowledge, the first attempt to study the potential impacts of the construction and operation of an offshore wind farm on the local trophic web structure and functioning using an integrated ecosystem modelling approach.

2. Material and methods

2.1. Study area

The Bay of Seine, where the offshore wind farm will be built in the next years (from 2018) is located on the north-western French coast and opens onto the eastern English Channel (Fig. 1). The Bay of Seine forms an approximate quadrilateral of 5000 km^2, with a mean depth of about 20 m. The water depth never exceeds 35 m. The maximum tidal range is 7.5 m in the eastern part of the Bay near the mouth of the Seine estuary. Tidal currents average between 1 and 2 knots in the southern sector of the Bay, and their intensity gradually