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Assessing cumulative socio-ecological impacts of offshore wind farm development in the Bay of Seine (English Channel)

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ABSTRACT

As part of the energy transition, the French government is planning the construction of Offshore Wind Farms (OWFs) in Normandy. These OWFs will be integrated into an ecosystem already facing multiple anthropogenic disturbances. A holistic view of cumulated impacts (OWF construction, global warming and fisheries) were developed on the Courseulles-sur-Mer' ecosystem through the use of a qualitative mathematical modelling approach. This modelling approach provides the mean to consider alternative hypotheses about how the ecosystem structure and function affects its dynamics. Alternative models were constructed to address the different hypotheses regarding the behaviour of top predator (whether the top predators will be scared away by the OWF or attracted by the reef effect), impacts of global warming and changes in fisheries activities. Key findings from these analyses are that the OWF construction could lead to an increase in benthos species and fish benthos feeders whatever the perturbation scenario, while the predicted response of top predators was ambiguous across all perturbation scenario. Qualitative modelling results can play a vital role in decision making by improving long term planning for the marine environment but also as a tool for communication with the public and so contribute to a better acceptability of the Marine Renewable Energy (MRE) project.

1. Introduction

Coastal marine ecosystems can be extremely productive and highly valued, but also strongly affected by human activities [1]. The English Channel is among the most affected, being subjected to a high and growing number of anthropogenic disturbances (e.g., fishing, aggregate extraction, dredging and spoil deposition) including contaminant inflow from the Seine river [2]. It is also a hotspot for future Offshore Wind Farm (OWF) development [3].

OWF construction can create new habitats for benthic species through the introduction of hard substrate [4]. This effect is known as the "reef effect", and is considered as one of the most important OWF effects on the marine environment [5]. Raoux et al. (2017) [3] performed simulations to analyse this reef effect in the Courseulles-sur-Mer OWF (Bay of Seine, English Channel) through the use of the Ecopath with Ecosim software. Two hypotheses regarding food-web functioning were investigated: (1) the increased biomass of benthic invertebrates and fish would attract top predators [6], and (2) a system dominated by mussels leads to a more detritivorous food web [7]. Simulation results generally supported both hypotheses [3]. Adding to this reef effect, spatial restrictions such as exclusion zones of fisheries activities (trawl and dredge) are likely to be implemented around turbines and cables for navigation safety, which could lead the OWF to act as a marine reserve [8].

Studies have commonly focused on investigating independent perturbation effects on ecosystems. However, being aware that marine ecosystems are threatened by multiple anthropogenic and natural perturbations, there is a need to understand how multiple perturbations interact to influence ecosystem functioning and stability [9]. Here, a holistic view of cumulated impacts was sought (including in our study the implantation of OWF, global warming and fisheries) on the Courseulles-sur-Mer' ecosystem through the use of a qualitative mathematical modelling [10]. Qualitative mathematical models are useful tools to rapidly understand ecosystem structure and dynamic as they allow to

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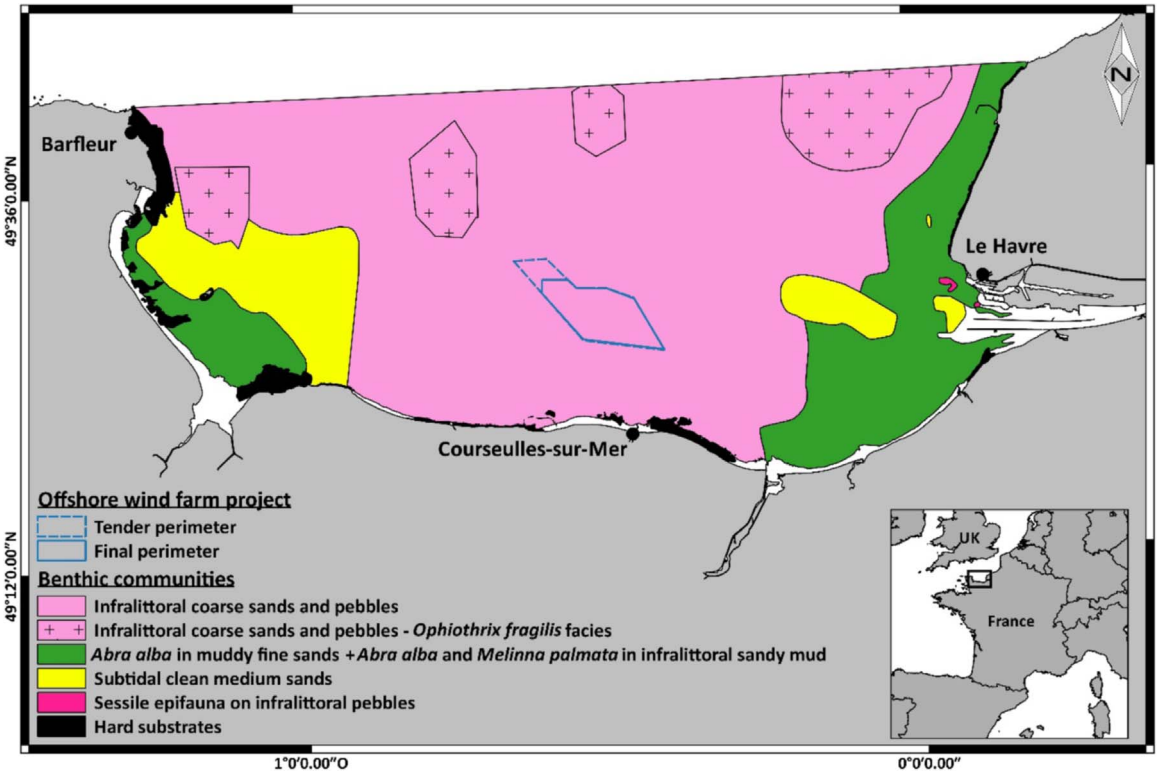

Fig. 1. Location of the Courseulles-sur-Mer offshore wind farm (OWF) and benthic communities in the Bay of Seine, north-western France (modified from Baffreau et al., 2017).

take into account ecosystem component and processes that are difficult to measure [11]. They also allow one to understand and predict how a system will respond to cumulative impacts, which is a key component of monitoring programs and ecosystem based management [11].

In this study qualitative mathematical modelling was used to assess the cumulated impact of three kinds of human and natural pressure changes in the Bay of Seine: (1) an increase in benthic organisms (reef effect) through the construction of OWF, (2) a decrease in fishing pressure exerted by the different fleets previously operating within the OWF (for navigational safety) and (3) due to effects of global warming, changes in the distribution of populations of *Solea solea*, *Gadus morhua* and *Pecten maximus*, which are among the main species fished in the Bay of Seine.

2. Materials and methods

2.1. Study area

The Bay of Seine, where the offshore wind farm will be built in the next years (presently scheduled from 2020), is located on the north-western French coast and opens onto the eastern English Channel (Fig. 1). It forms an approximate quadrilateral of 5000 km^2, with a mean depth of about 30 m. The water depth never exceeds 50 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 diminishes toward the eastern Bay of Seine [12,13]. The distribution of superficial sediments and benthic communities are strongly correlated to these currents [14,15]. There is an offshore-inshore gradient in the Bay, with the dominant offshore sediment generally consisting in pebbles, gravel and coarse sands and the inshore sediment in the coastal zones consisting mostly of fine sands and muddy fine sands [16]. Benthic communities of the Bay of Seine are well described in terms of composition and spatial distribution [17]. Coastal marine, estuarine and mixed systems along the French coasts are predicted to be high sensitive to climatic variations [18].

2.2. Courseulles-sur-Mer OWF

The project is owned by "Eoliennes Offshore du Calvados", a subsidiary of Eolien Maritime France and wpd Offshore. EMF was allowed to operate the OWF off from Courseulles-sur-Mer by the Ministerial Order of April 18th, 2012. The proposed OWF will be located 10–16 km offshore from the coast of Calvados – Normandy. The depth range is 22–31 m. The OWF will have a total area of approximately 50 km^2. This OWF will be located on the infralittoral coarse sand and pebbles benthic communities (Fig. 1). It will comprise 75 turbines of 6 MW giving a combinated nameplate capacity of 450 MW. The wind farm turbines will be connected via an interarray network of 33 kV Alternative Current (AC) cables which will link at one offshore transformer substation located within the wind farm. From this station power will be exported via two 225 kV AC marine cables. The turbines will be supported by 7 m in diameter monopiles driven into the sea bed. In the Environmental Impact Assessment (EIA) the OWF owners proposed a scenario in which scour protection will be installed around the 75 turbines and the converter station, and that 33% of the cables will be rock-dumped. Thus, the foot print would amount to 0.342 km^2 or around 0.70% of the OWF area.

2.3. Qualitative modelling

2.3.1. Qualitative courseulles-sur-Mer OWF model

A qualitative model of the Courseulles-sur-Mer OWF (Fig. 2) was derived from the structure of an Ecopath model developed by Raoux et al. (2017) [3] following the same method as Lassalle et al. (2014) [47]. The food web was simplified from 37 groups to 9 groups. The selection and aggregation of functional groups was based on biological and ecological characteristics of the species such as their predator and prey relationships. The four marine mammals, the two seabird, and two cephalopod groups were combined into one group called top predators.