The ecology of benthopelagic fish at offshore wind farms - Towards an integrated management approach

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The use of wind power by mankind has a long history and dates back about 3000 years in time. For an extended period windmills were mainly used for grinding grain and pumping water and it lasted until 1891 before the first electricity generating wind turbine was constructed. By the end of the 1990s, wind energy production had become one of the most important renewable energy resources in the world. Offshore wind farms on the other hand are a relatively new concept. The first large scale offshore wind farm in the world was built in 2000 off the coast of Denmark and from that time onwards offshore wind power development expanded rapidly. All across the North Sea wind farms are planned, under construction and operational. Thousands of wind turbines will be present and as a result new hard substrate habitats, through the wind turbine foundations, arise. In the Belgian part of the North Sea, the wind turbine foundations form artificial reefs in a marine environment formerly dominated by a sandy seabed. These artificial reefs, the so-called windmill artificial reefs (WARs) influence the ecosystem functioning and the local biodiversity; and interactions within and between the reef and the surrounding soft substrate habitat will occur.

In this study, we focused on the reef effects influencing benthopelagic fish in the Southern North Sea. It is known that (windmill) artificial reefs attract and concentrate fishes. However, whether the fishes are merely attracted or if production or an ecological trap occurs is difficult to unravel. In case of attraction, the fish move from the surrounding environment towards the reef. They aggregate at the reef, but there is no net increase in the local population. If production occurs, the carrying capacity of the environment increases as a result of the new habitat. More fish are able to settle, survive, grow and contribute to the local population. The fish can also be caught in an ecological trap, if they are attracted to, and preferably settle in a habitat with suboptimal conditions relative to other available habitats. A set of questions related to fish community structure, behavioural ecology and reef mechanisms involved in fish production in the specific environment need to be answered to unravel the issue. Based on the outcome of the issue we also discussed whether small-scale fisheries should be allowed inside the offshore wind farms.

From 2009 until 2012 we investigated the attraction-production hypothesis for dominant fish species related to the WARS. Information on length-frequency distribution, diet, community structure and movements of Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) was gathered in an offshore wind farm in the Belgian part of the North Sea. A multitude of techniques (i.e. visual observations with divers, hand line sampling campaigns, acoustic telemetry and stomach content analyses) were applied and integrated to gain insights on their behavioural ecology and to unravel whether production occurs at the WARs.

We found that both Atlantic cod and pouting are strongly attracted towards the WARs. Much higher average catch rates were recorded at the WARs in comparison to the reference areas. For Atlantic cod average catch per unit effort was 4.6 ± 0.9 ind h^{-1} fm^{-1} at the WARs, while it was 0.1 ± 0.03 and 1.1 ± 0.2 ind h^{-1} fm^{-1} for the sandy areas and wrecks respectively. For pouting it was 4.3 ± 0.6, 0.1 ± 0.03 and 0.7 ± 0.1 ind h^{-1} fm^{-1} at the WARs, sandy areas and wrecks respectively.

A more detailed investigation of the community structure of both species revealed that especially younger age groups of both species are attracted towards the WARs. For Atlantic cod mainly age group I and II were encountered, while for pouting it was age group 0 and I. The fish are not present throughout the year. There is a clear seasonal pattern in aggregation behaviour. The highest numbers of fish were noted during summer and autumn (with a mean monthly catch rate of up to 13.4 and 12.8 ind h^{-1} fm^{-1} for Atlantic cod and pouting respectively). In winter time almost no individuals were encountered. Probably movements related to spawning explain the seasonality in presence at the WARs.

Further, we demonstrated that, during the period they were present near the WARs, Atlantic cod exhibited strong residency and high site fidelity. Most of the tagged fish were present on a daily basis for 75% of the time of the monitoring period.

Stomach content analyses revealed that both Atlantic cod and pouting fed on the epifaunal species present at the WARs. The dominant prey species in the diet of pouting were *Jassa herdmani, Pisidia longicornis,* Pisces sp. and *Liocarcinus* spp. In the diet of Atlantic cod *J. herdmani, P. longicornis, Liocarcinus* spp., *Necora puber*, and Pisces sp. were most dominant. Some amphipod species (i.e. *Phtisica marina* and *Monocorophium acherusicum*) had a high frequency of occurrence as well and reached high abundances, but contributed less to the total prey biomass for both species. The predominant prey species in the diet were all present in high densities at the WARs.

To acquire more information on the quality of the food, energy profiling of both fish species was performed. The fishes had more energy available than required to maintain their metabolism. Thus, enough energy was left for growth and reproduction. As a result the WARs are considered a suitable feeding ground with sufficient, good quality food available. In addition, the fitness of pouting and Atlantic cod was compared between the WARs and the reference areas. No significant differences in fitness were found, indicating the WARs are not inferior in quality to the reference habitats. Based on the integrated results it was concluded that production occurs on a local scale (i.e. at the WARs). However, so far no changes in productivity were observed on a regional scale.

The results obtained during this study allowed to describe the life-history of Atlantic cod and pouting at the WARs. The age group I Atlantic cod arrive at the WARs in April-May. They feed on the epifaunal prey species present, grow and stay in the area until the end of the year. By winter most I-group individuals have left the WARs and only few specimens come back after the spawning period. For pouting the 0-group arrives at the WARs in September and feeds on the epifaunal prey species. They leave the area by January but by May the I-group is back at the WARS and stay again until the end of the year. During this period feeding and growth are observed.

The offshore wind farms in the Belgian part of the North Sea are closed to fisheries. However, pressure groups aiming at the facilitation of passive fisheries inside the wind farm concession areas, are active in Belgium. Based on the current knowledge on the ecology and population structuring of Atlantic cod and pouting at the WARs, we conclude that no fisheries activities should be allowed inside the offshore wind farms in the Belgian part of the North Sea. We support this statement with several arguments: 1) no indication of regional production was observed yet; 2) juvenile fish dominated the catches; 3) there is a seasonal pattern in presence and 4) fisheries exclusion areas will benefit both fish populations and fisheries.

In conclusion, we demonstrated that WARS influence the behavioural ecology of Atlantic cod and pouting. They benefit from these artificial hard substrates and thrive well in this environment closed to fisheries. We support this fisheries closure, because the benefits are exported beyond the boundaries of the wind farm concession since the fish leave the protective area once they grow older. Proper management, through well-thought-out marine spatial planning and regulations, should be implemented to reduce conflicts and use the marine resources in a sustainable way.