# CHAPTER 14

# Offshore wind farms as productive sites for fishes?

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Artificial hard substrates in the marine environment have an influence on the local fish community. The new environment may induce some costs or benefits for the fish populations. Since the local evolution of fish stocks and the value of wind farms as management tools completely depend on the extent of the artificial reef effects at the wind farms, it is essential to identify the processes at work. Consequently, community structure, reef ecology and behavioural ecology were investigated for a number of fish species present at the offshore wind farms. The results obtained were integrated and a viewpoint on attraction/production was formulated.

## INTRODUCTION

After the construction or deployment of an artificial reef, fish densities at the reef location tend to increase rapidly (Bohnsack, 1989). Two opposing, yet not mutually exclusive models have been proposed to explain these increased abundances. The attraction hypothesis suggests that fish move from the surrounding environment towards the reef. They aggregate at the reef, but there is no net increase in the local population. The fish are solely concentrated into a smaller area. The second hypothesis, the production hypothesis, assumes that 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, resulting in net production (in terms of biomass and/or abundance) (Brickhill et al., 2005; Lindberg, 1997; Pickering and Whitmarsh, 1997). In the attraction-production issue, the condition of the initial fish stock present might either improve or remain as it was. There is however a third issue, more precisely the issue of the ecological trap. In this scenario, fish are attracted to, and settle preferably in a habitat with suboptimal conditions relative to other available habitats, resulting in a deterioration of the fish stock (see chapter 17).

After the construction of an artificial reef, in this case offshore wind farms (OWFs), three theoretical outcomes are possible (Figure 1). In the case of attraction, fish' growth, reproduction and mortality in the system observed will be comparable to the reference situation. The carrying capacity of the system does not change. However, spatial dispersion of the fish changes, with aggregation in some places and reduced number in others. If an ecological trap occurs, growth is reduced and/or survival rate is lower compared to the reference situation. Although better alternative habitats are available, the suboptimal habitat is preferably chosen, resulting in reduced carrying capacity of the system. In the case of production, fish have an enhanced growth, a higher survival rate or some combination of both compared to the reference situation as a result of increased carrying capacity of the system.

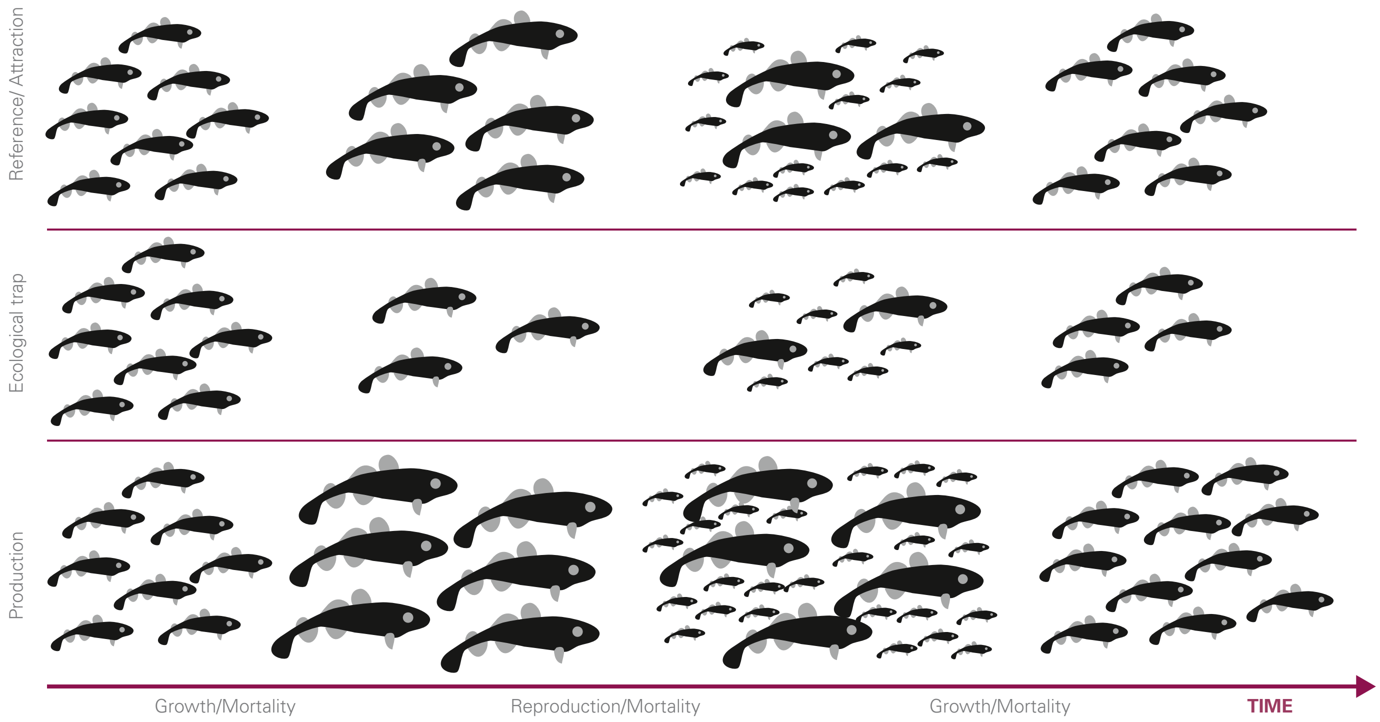



**Figure 1.** Conceptual representation of the 'attraction- ecological trap-production issue). In a reference situation (upper panel) fish grow and reproduce and mortality occurs. If attraction takes place (upper panel), the outcome matches the reference situation, but spatial dispersion differs. In the case of an ecological trap (middle panel), fish have a reduced growth, a lower survival rate or a combination of both compared to the reference situation. If production occurs (lower panel), fish have an enhanced growth, a higher survival rate or a combination of both compared to the reference situation. For reasons of simplicity immigration and emigration were left out of the model.

## RESEARCH STRATEGY

Since the local evolution of fish stocks and the value of wind farms as management tools completely depend on whether attraction, production or an ecological trap occur at the wind farms, it is essential to identify the processes at work. To do so for fish, we developed a research strategy based on four major questions (Figure 2): 1) does attraction of fish occur? 2) Which age groups are attracted? 3) What mechanisms are playing? 4) How do attracted fish behave? To answer each of these questions, specific data were gathered on fish densities, length (at age), feeding habits and fish movement. In a final step, all results were integrated and a viewpoint on attraction/production was formulated. For an analysis concerning the issue of ecological trap, we refer to chapter 17 of this report.
In this chapter two groups of fish are analysed: demersal fish and benthopelagic fish (i.e. Atlantic cod and pouting).

1. **Does attraction of fish occur?**
   To determine attraction of demersal fish to the wind farms, we examined densities of different species according to the (BA)CI (Before After Control Impact) design (see chapter 10, Box 2). Densities in the wind farms were compared with densities in control areas, before and after construction activities at the two examined wind farms (i.e. concessions at the Thorntonbank and Bligh bank). All data were derived from trawl catches and were standardized to numbers of fish per 1000m² of seafloor.For the benthopelagic fish, density data were derived from line fishing at the wind farm on the Thorntonbank. A catch per unit effort (CPUE) was quantified and catches were standardized to number of fish caught in one hour by one fisherman.

2. **Which age groups are attracted?**
   Length-frequency distributions were built to investigate the age composition in the population as it gives clear information concerning the cohorts present and their length distributions.

3. **Which mechanism play?**
   To investigate the trophic relationships between fish species and resident organisms on the wind farm's hard substrates, the diet of soft substrate demersal fishes (focus on dab) and reef fishes (focus on pouting) were analysed. The contribution of potential prey species was estimated through stomach content analysis and their importance in the diet was assessed through several indices (see box fish stomach analysis).

4. **Behavioural ecology**
   *In situ* observations of behaviour and movements may provide valuable insights in the ecology of fish. However, directly observing the behaviour of marine fish in the wild is logistically very difficult. As a result, other methods are needed to infer fish behaviour. We used acoustic telemetry to investigate residency at the wind farm and to empirically quantify movement behaviour of Atlantic cod. We tracked 22 Atlantic cod (year class 1) equipped with an acoustic transmitter (coded V9-1L tag, Vemco Ltd.). The tagged Atlantic cod were tracked with automated acoustic receivers (VR2W, VEMCO Ltd.). The receivers were placed around two wind turbines at the Thorntonbank and recorded the presence of any acoustic transmitter within their detection range (i.e. 250 to 500 m). The study ran from May 2011 until July 2012. The detection information obtained was used to determine spatio-temporal patterns in presence.

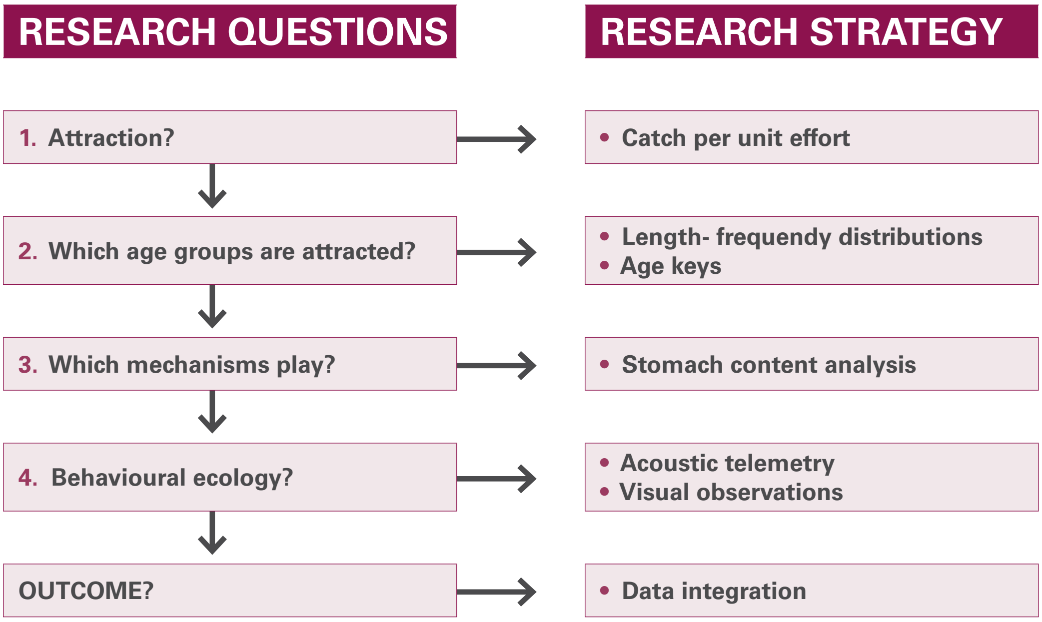



**Figure 2.** Schematic overview of the holistic approach to unravel the attraction-ecological trap-production issue. In the column on the left the methods used for data analysis are enumerated, on the right an outline of the research questions is given.

## DATA OVERVIEW

1. **Does attraction of fish occur?**
In the case of attraction, a persistent increase in densities within the wind farms and a decrease in the surrounding areas is expected. In the samples taken between the turbine rows (at a distance of at least 180 m from the turbines), increases were not observed for any of the analyzed demersal species (see chapter 10). Only for sole (*Solea solea*) in spring, significant increases were observed at the impact stations of the Bligh Bank top, but the resulting densities were still very low (0.2 individuals per 1000 m²) and the persistence of this trend needs to be confirmed by extending the time series. The studies of Bergström et al (2012, 2013) and of Wilhemsson et al (2006) indicated that increased densities were limited to a radius of 20-160 m from swedish turbines, depending on species and that smaller scale studies may be needed to document increases. For the Belgian case study, this may mean that increases between the turbine rows will remain very limited or that it will take a lot of time for the reef effects to expand into the space between turbine rows (>180 m).
Both Atlantic cod and pouting (benthopelagic fish) were clearly attracted towards the wind farm in summer and autumn. In this habitat, the catches were up to more than a 100 times higher compared to sandy reference areas. For more details on the methodology and results we refer to chapter 11.

2. **Which age groups are attracted?**
Analysis of the length-frequency data of all demersal species from trawl catches did not yield any clues of increased recruitment or growth within the wind farms. On the contrary, dab (*Limanda limanda*) seems to move away from the space between turbine rows: in 2011 very few individuals of the year 1 class were seen, but there were still new recruits. In 2012, even the new recruits were gone from the wind farm samples, while individuals of both year classes were still abundant at the reference stations. This can either mean that dab is moving away from the wind farm, or that dab moves closer to the turbines (< 180 m). Observations of dab close to the turbines during diving or angling, however, were rare (Jan Reubens, pers. comm.), so the first hypothesis is probably the right one. For plaice (*Pleuronectes platessa*), length-frequency data showed the presence of a number of larger individuals within the Bligh Bank wind farm, especially in autumn 2011, resulting in an average length increase of 6 cm compared to the reference stations at that time. This is probably the result of a refugium effect due to the absence of fisheries (even though the fishing pressure at the Bligh Bank is rather low compared to areas closer to shore, see chapter 8), rather than an effect of attraction.The length-frequency data revealed that specific age groups of Atlantic cod were present in the Thorntonbank wind farm. Year class 1 and 2 were observed, but the presence of the latter was restricted to winter and spring. Age class 1 was present throughout the year. For pouting, year class 0 and 1 were encountered in the wind farm. The new recruits (year class 0) arrived at the OWF in August/September. For more details on the methodology and results we refer to chapter 11.

3. **Which mechanisms play?**
In wind farms, fish attraction depends on four major mechanisms: (1) food availability and feeding efficiency, (2) the provision of shelter from predators and currents, (3) the presence of a suitable habitat for settlers and immigrants, and (4) stress resulting from wind farm noise and predation pressure (Figure 3). So far, we mainly focused on the mechanism of food availability and feeding efficiency. Artificial hard substrates introduced in wind farms are covered by hard substratum fauna (Petersen and Malm, 2006), that constitute a new source of prey for predatory fish. In the North Hoyle wind farm (GB) for example, large schools of juvenile whiting (*Merlangius merlangus*) were observed while feeding on the tube building amphipod *Jassa falcata*, which was dominantly present on the turbines (May, 2005). Similarly, we expected demersal and benthopelagic fish species to forage on hard substrate prey species in the vicinity of the Belgian wind farms. To investigate the trophic relationships between fish species and resident organisms on the wind farm's hard substrates, we analyzed stomach contents of soft substrate demersal fishes (focus on dab) and reef fishes (focus on pouting).

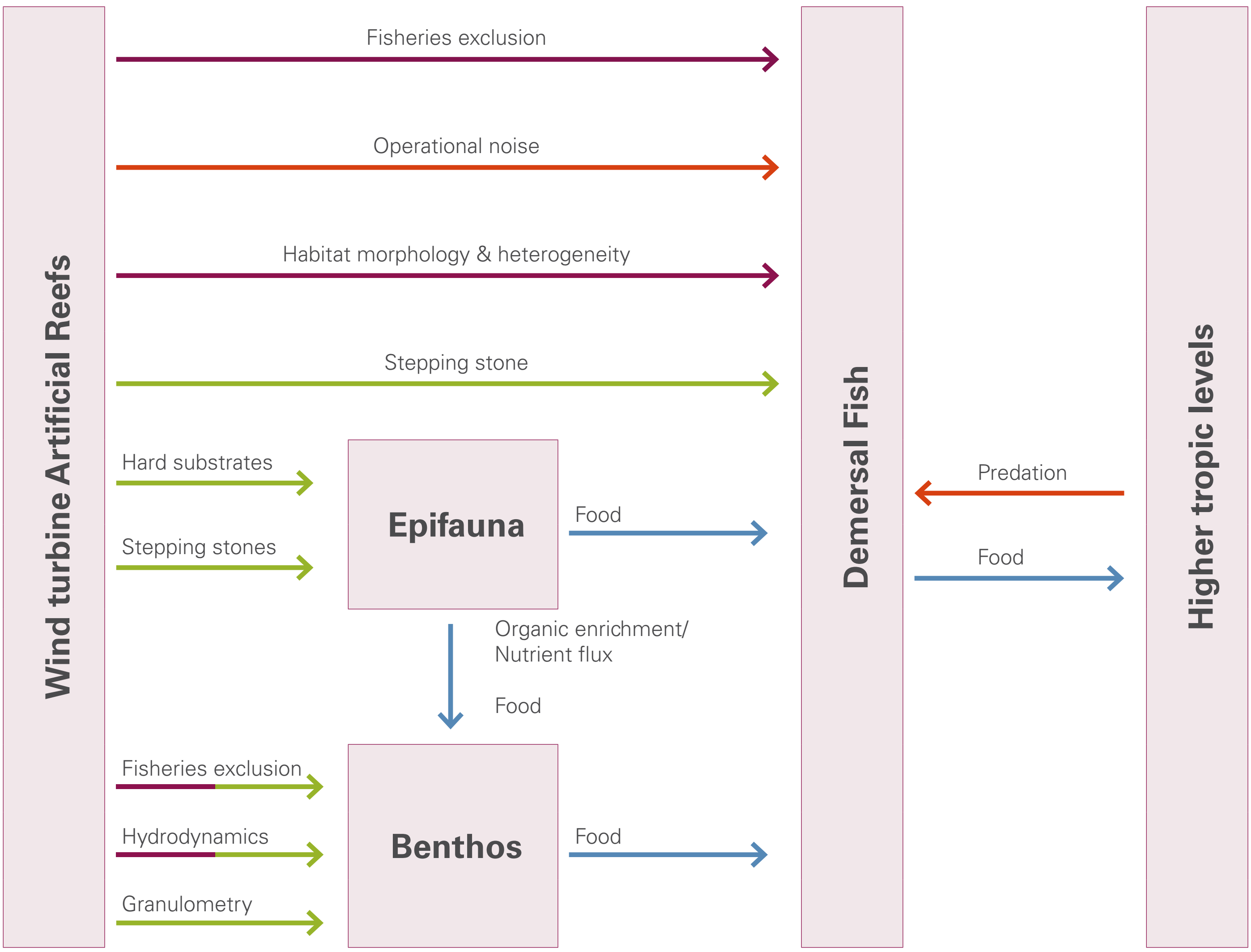



**Figure 3.** Schematic overview of the most important reef effects influencing fish production at wind farms. Each mechanism is indicated by the corresponding colour.

The stomach content data of dab originated from a small-scale pilot study at the Thorntonbank wind farm in autumn 2010 (Derweduwen et al, 2012). Data from the wind farm (> 180 m of the GBF's), and outside the wind farm (Thorntonbank reference station) showed little differences. The diet of dab generally consisted of amphipods, decapods, mysids and polychaetes (table 1). The dwarf swimming crab *Liocarcinus pusillus* - which likes coarser sediments- and the hard substratum amphipod *Phtisica marina* were only found in the stomachs of dab originating from the wind farm. However, the most abundant hard substratum species *Jassa herdmani* and *Pisidia longicornis* present on the turbines (Kerckhof et al., 2010a; Reubens et al., 2011) could not be found in the stomachs of dab. This probably can be linked to the small sampling size (limited number of individuals from only two stations), to the sampling distance (>180 m from the nearest turbine) or to different prey preferences of dab.  Dab did generally have fuller stomachs within the wind farm (mean Fullness Index 0.15) than outside (mean FI 0.05). This might be an indication of a higher food availability for dab around the wind turbines. For Danish wind farms, Leonhard and Pederson (2006) estimated that the availability of food for fish around the turbine sites directly increased by a factor of approximately 50 after the introduction of hard substrates, in comparison with the former sandy area. Taking into account that few hard substrate fauna were found in the stomachs but that the stomachs were fuller (due to more sandy substrate prey) at the Thorntonbank, and that density data indicate that dab is moving away from the Bligh Bank wind farm, we believe that food availability is not a driver for attraction in dab.

| | % N | | % FO | |
|---|---|---|---|---|
| | Reference | OWF | Reference | OWF |
| **Amphipoda** | 0 | 66 | 0 | 44 |
| **Bryozoa** | 0 | * | 0 | 11 |
| **Copepoda** | 10 | 8 | 10 | 33 |
| **Cumacea** | 0 | 1 | 0 | 11 |
| **Decapoda** | 25 | 23 | 30 | 56 |
| **Gastropoda** | 0 | 3 | 0 | 22 |
| **Mysidacea** | 55 | 0 | 20 | 0 |
| **Polychaeta** | 10 | 0 | 30 | 0 |
| **Pisces** | * | 0 | 40 | 0 |

**Table 1.** The numerical contribution (% N) and frequency of occurrence (%FO) of prey groups present in the stomachs of dab (Limanda limanda) from a reference station (n=14) and an offshore wind farm station (OWF, n=15) at the Thorntonbank. The asterisks indicate that individuals could not be discerned (bryozoan colonies, body parts of fish but no head counts).

For pouting, the diet was compared for fish caught at the wind turbines of the Thorntonbank and at a sandy bottom reference site (Gootebank). Stomach content differed significantly between the two sites. Amphipods and crabs dominated the diet of fish at the wind turbines, while the fish at the Gootebank were characterized by more diverse diets with fish, crabs, anemones and amphipods as the most important prey groups (Table 2). A more detailed analysis of the individual prey species showed that pouting at the wind farms mainly fed upon hard substrate associated prey species (i.e. *Jassa herdmani, Pisidia* longicornis) while at the sandy area they fed both on hard and soft substrate associated prey species (i.e. *Callionymus* sp., Actiniaria sp., polychaeta sp. and *Liocarcinus holsatus*). The diet of the fish caught at the wind turbines was quite similar (average similarity 59 %), while the ones from the Gootebank had a more diverse prey composition (average similarity 37 %). In addition, pouting at the wind turbines generally had fuller stomachs compared to the Gootebank (mean Fullness Index of 1.5 ± 1.4 and 0.6 ± 0.8 respectively).

**Table 2.** Overview data from stomach content analysis of pouting (Trisopterus luscus) from the Gootebank (sand) and the offshore wind farm (OWF). The gravimetric contribution (% G) and frequency of occurrence (%FO) of prey groups present in the stomachs of pouting are listed in the left column. In the right column the 5 most important prey species (in terms of weight) are listed.

| | % G | | %FO | | % G | | | |
|---|---|---|---|---|---|---|---|---|
| | Sand | OWF | Sand | OWF | | Sand | | OWF |
| **Amphipoda** | 8.1 | 66.8 | 64.7 | 94.1 | ***Callionymus* sp.** | 43.14 | ***Jassa herdmani*** | 61.97 |
| **Anthozoa** | 9.7 | 0.0 | 5.9 | 0.0 | **Pisces spec.** | 9.82 | ***Pisidia longicornis*** | 10.22 |
| **Detritus** | 0.1 | 0.3 | 5.9 | 5.9 | **Actiniaria sp.** | 9.69 | **Pisces sp.** | 8.42 |
| **Echinodermata** | 0.1 | 0.0 | 5.9 | 0.0 | **Polychaeta sp.** | 4.72 | ***Liocarcinus holsatus*** | 5.45 |
| **Mollusca** | 0.1 | 0.0 | 17.6 | 5.9 | ***Liocarcinus holsatus*** | 4.28 | ***Necora puber*** | 3.05 |
| **Mysidacea** | 1.4 | 0.0 | 11.8 | 5.9 | | | | |
| **Natantia** | 4.4 | 0.3 | 29.4 | 2.9 | | | | |
| **Pisces** | 53.0 | 8.4 | 23.5 | 5.9 | | | | |
| **Reptantia** | 15.8 | 22.9 | 76.5 | 79.4 | | | | |
| **Rest** | 7.4 | 1.2 | 76.5 | 55.9 | | | | |

## **BOX 1:** stomach analyses of fish

From trawl samples (dab) or angling samples (pouting), all fish were measured and where possible weighed. Depending on the number of fish and weather conditions, fish were either dissected on board or were injected with formaldehyde and stored for laboratory analysis. On board or in the lab, intact stomachs were removed by cutting above the oesophagus and below the large intestine. An incision was made along the longitudinal axis and the contents were emptied onto a Petri dish with a few drops of deionised water. All prey items encountered in the stomachs were counted and identified to the lowest possible taxonomic level. After identification, the stomach contents were dried and incinerated to obtain dry weight and ash free dry weight.

Specifications on the fish (length, weight) and prey items (species, number, weight) were used to calculate a number of indexes that give information on the amount of food in the stomach and the importance of the different prey items (Hyslop, 1980; Pinkas 1971, Hureau 1970):

- Fulness Index: the ratio of the weight of the stomach content versus the weight of the fish
- Frequency of occurrence: the percentage of the total number of stomachs in which the specific prey species occurs
- Numerical percentage: the ratio of the number of individuals of a certain prey item to the total number of prey items
- Gravimetrical percentage: the ratio of the weight of an individual prey item to the total weight of prey items
- Index of relative importance: an index to assist in evaluating the relationship of various food items. Takes frequency of occurrence and numerical and gravimetrical percentages into account
- Feeding coefficient: the product of the gravimetrical and numerical percentage. It shows the relative importance of the different prey items in the diet.

Total length measurement on board of the RV Belgica.


Fish stomach

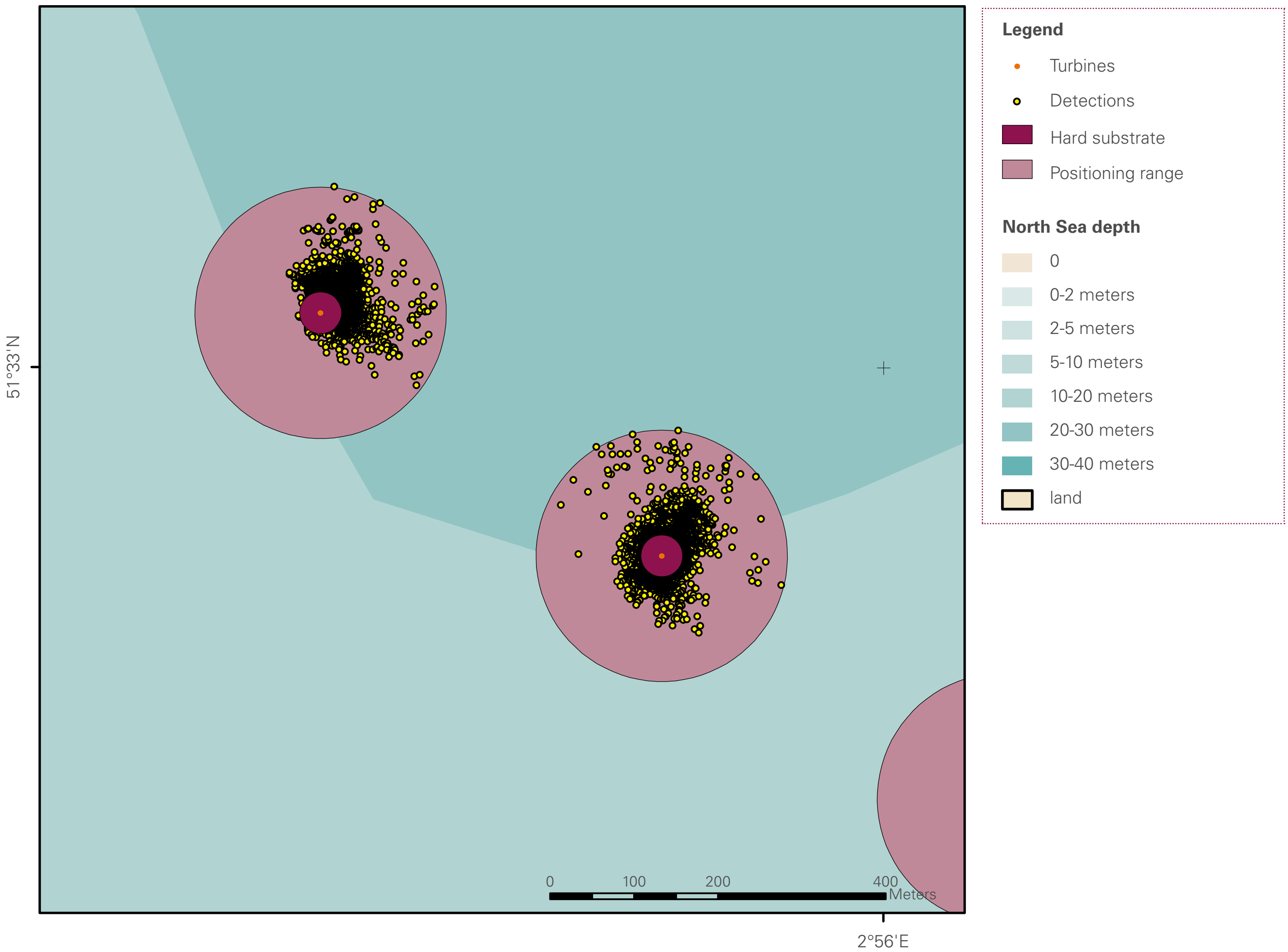
## 4. Behavioural ecology

Acoustic telemetry revealed a strong seasonal variation in occurrence of Atlantic cod within the wind farm. During summer and autumn fish were present for an extended period of time. By the end of December however, most fish were no longer detected and throughout the winter months (December-March) few detections were encountered. In spring some fish reappeared, although most were not detected anymore in the study area (see box telemetry).

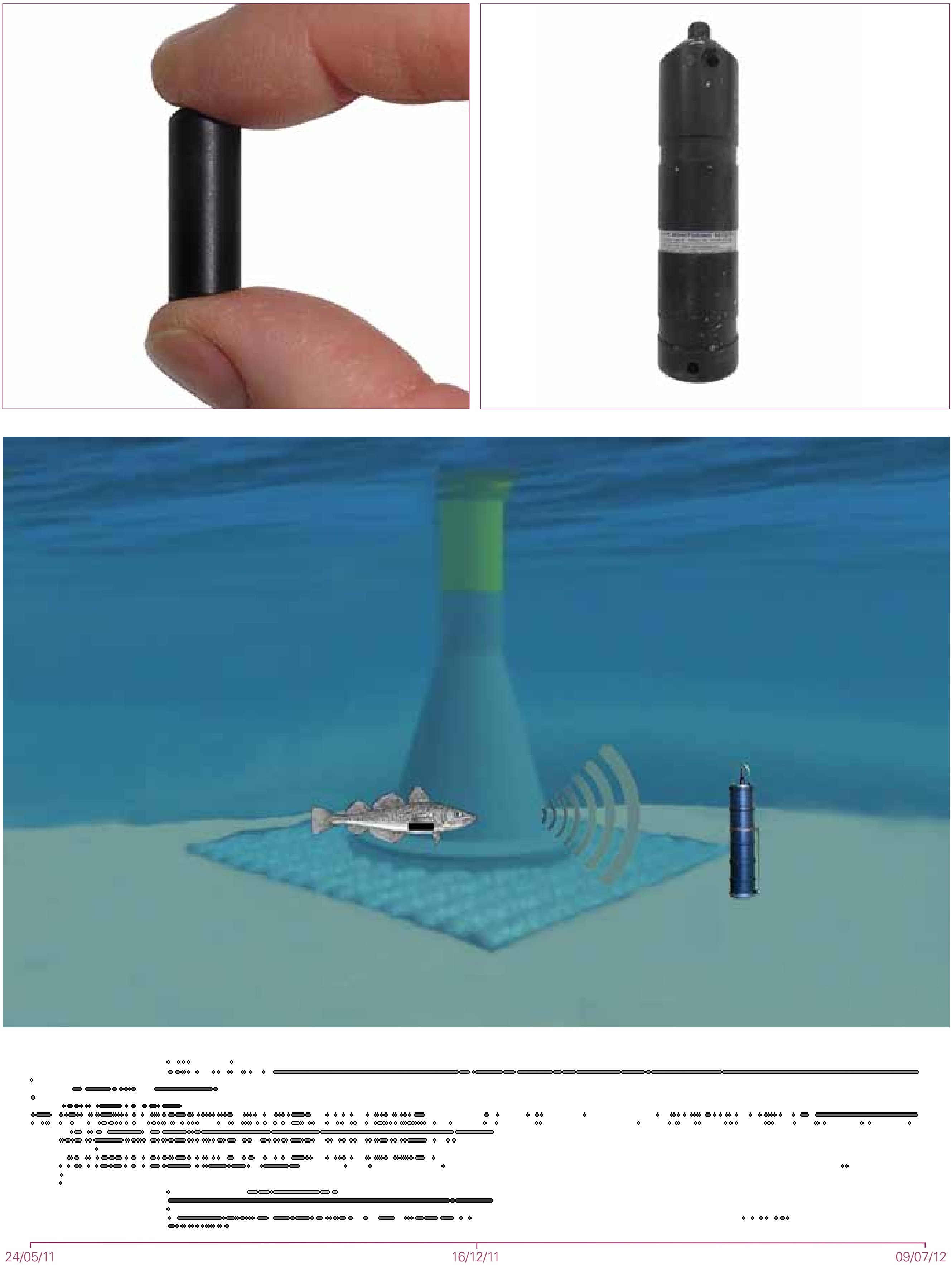
During summer and autumn, many of the tagged fish were encountered (almost) daily at the OWF throughout a long period of time, indicating strong residency (see box on acoustic telemetry). More detailed detection data revealed even that many fish were present at the wind farm for more than 75% of the time. They resided in a small area without making extensive migrations (Reubens et al., 2013b).

Further, the telemetry study revealed that the tagged Atlantic cod were strongly attracted towards the wind turbine artificial reefs. Although the wind farm concession area is dominated by soft-bottom sediments and only small patches of hard substrates are available, most of the detections were encountered on the hard substrates of wind turbines or in their close vicinity (Figure 4). About 90 % of the calculated positions (relative measure) were within a 40 m range from a wind turbine (note that the hard substrates extent to approximately 25 m from the wind turbine.

**Figure 4.** Positions of tagged Atlantic cod at the wind turbines. The pink circle represents the area in which position calculation can be performed. The purple circle represents the hard substrate and the yellow dots show the exact positions of the fish.



## **BOX 2:** Acoustic Telemetry




An acoustic transmitter (upper left) is implanted in Atlantic cod and the signals emitted are recorded by a receiver (upper right and middle). In this way, long term monitoring of fish presence can be performed. The graph shows the presence of 20 tagged Atlantic cod in the period May 2011- July 2012.

## CONCLUSIONS

Bohnsack (1989) stated that production enhancement at artificial reefs is most likely for demersal fish species, since they are ecologically more closely tied to the benthos. At the Belgian wind farms however, no persistent and statistically significant signs of attraction could be derived from density data for demersal fish, and diet analysis does not indicate an intense use of the food sources present at the vicinity of the turbines. Still, these conclusions are based on data from trawl samples taken during a short period of post-construction processes and at a relatively large distance from the turbines (>180 m). Since it takes around three to five years before stable faunal communities are established after deployment of artificial hard structures (Jensen, 2002; Gray, 2006; Petersen and Malm, 2006), and since it takes time for the local (turbine level) effects to expand into the sandy substrate between the turbine rows (20 – 160 m as in Bergström et al (2012), or even further), we expect a different picture to form within the next few years of wind farm construction and exploitation.

Based on the presented results (see also chapters 11 and 17), we can conclude that pouting and Atlantic cod are strongly attracted towards the wind farm. On a local scale and in terms of extra biomass, we can assume that there is production. Specific age groups are attracted towards the wind farm artificial reefs (WARs). They show high residency and feed upon the dominant epifaunal prey species present (see chapter 12). Growth is observed throughout the period the fishes are present. In addition, the fish are certainly not caught in an ecological trap in terms of habitat quality (see chapter 17).
On a regional scale however, the situation might be different. So far, no changes in production of Atlantic cod or pouting were observed (Reubens et al, 2013c). Inter-annual variations in catch rates are present, but could not be linked to effects of the OWFs. A multitude of factors; such as environmental conditions, food availability, larval predation, spawning stock structure (Köster et al., 2003; Vallin et al., 1999); influence fish stocks, impeding the assignment of causal relations. Even though no effects of the OWFs are observed on a regional scale yet, this does not necessarily imply that they are not present. In some cases, the first signs of increased production are observed soon after deployment, while in others it may take many years before changes can be observed or measured (Gell and Roberts, 2003). The time frame within which changes are expected to be measurable depends upon the species investigated, their life-history behaviour and their turnover rate (Pérez-Ruzafa et al., 2008).

Surgical implantation of acoustic transmitter

## FUTURE MONITORING

- Fish attraction towards wind farms depends on several mechanisms. In this study we focused on food availability and feeding efficiency. In future research however, the other main mechanisms (i.e. shelter, suitability of habitat for settling and stress) should be integrated in the research objectives as well. The impact (stress) of noise during construction of wind turbines on fish larvae is currently being investigated (E. Debusschere, unpublished data).

- Currently, the attraction-ecological trap-production issue is investigated for some demersal and benthopelagic fish species. The number of fish species investigated should be expanded to be able to assess the impact on the ecosystem level instead of on individual level.

- Stomach content analyses give valuable information concerning the fish diet, however they do not render any information on the quality of the prey. Therefore energy profiling and fatty acids profiling (of both fish and prey items) should be performed to estimate the energy transfer from prey to consumer on the long term. De Troch et al. (in prep.) did a first assessment for Atlantic cod and pouting (caught at a wind farm) and some of their dominant prey species.