



## Aggregation at windmill artificial reefs: CPUE of Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) at different habitats in the Belgian part of the North Sea

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### ABSTRACT

Intensive exploitation of the marine environment by mankind can alter the natural habitat of marine organisms drastically. The addition of artificial hard substrates (e.g. shipwrecks and wind turbine foundations) to soft-sediment sandy bottoms is a pervasive example of an anthropogenic habitat change. To investigate the importance of hard substrate habitats for demersal fish species, we studied the spatio-temporal variability for two commercially important species, Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*), from 2009 to 2011 at three different habitats in the Belgian part of the North Sea (BPNS), i.e. windmill artificial reefs (WARs), shipwrecks and sandy bottoms. Our results showed that population densities of both species were highly enhanced at the hard substrate habitats in comparison to the sandy sediments. The highest catch-per-unit effort values for both species were recorded around the WARs, which indicated distinct aggregation around the wind turbine foundations. In addition, the observed aggregation at the hard substrates differed between seasons. Highest population densities were observed in summer and autumn, i.e. the most intensive feeding period for both fishes.

We conclude that the distribution and behaviour of Atlantic cod and pouting is affected by the presence and complexity of artificial hard substrates on the seabed.

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### 1. Introduction

The marine environment is being intensively used by mankind for offshore activities and exploitation of marine resources. Man-made submerged structures for instance, are present in coastal habitats all over the world (Andersson et al., 2009; Bull and Kendall, 1994; Douvère et al., 2007; Langhamer and Wilhelmsson, 2009). Adding such structures to the marine environment results in an altered habitat composition, which may influence local biodiversity and ecosystem functioning (Andersson et al., 2009; Wilhelmsson et al., 2006). In the Belgian part of the North Sea (BPNS) the seabed is mainly composed of sandy soft sediments, while natural hard substrates are rare (Mallefet et al., 2007). However, the seabed harbours numerous artificial hard substrates. Almost 300 shipwrecks are recorded in the BPNS (Termote and Termote, 2009) and numerous offshore wind turbines are currently being constructed. By 2020 more than 300 wind turbines will be present

in the BPNS (Brabant et al., 2011). The significant development of artificial hard substrates induces a growing interest in the possible effects of these constructions on the surrounding marine environment. Demersal fishes are likely to be affected by the environmental changes related to the introduction of artificial hard substrates (Wilhelmsson et al., 2006). The shipwrecks and windmill artificial reefs (further referred to as WARs) provide a suitable habitat for hard substrate dwelling fish (Bohnsack, 1989; Fabi et al., 2006; Leitao et al., 2007; Reubens et al., 2011). Several fish species such as *Trisopterus luscus* (Linnaeus, 1758) (pouting), *Gadus morhua* (Linnaeus, 1758) (cod), *Dicentrarchus labrax* (Linnaeus, 1758) (sea bass), *Scomber scombrus* (Linnaeus, 1758) (mackerel) and *Trachurus trachurus* (Linnaeus, 1758) (horse mackerel) have been observed in close proximity of shipwrecks and WARs in the BPNS (Mallefet et al., 2007; Reubens et al., 2011; Zintzen et al., 2006). Hard substrates have been reported to attract and concentrate fishes and/or to enhance local fish stocks (Bohnsack, 1989; Leitao et al., 2008, 2009; Pickering and Whitmarsh, 1997). Such aggregation behaviour can be explained by (1) increased shelter against currents and predators (Bohnsack, 1989; Jessee et al., 1985), (2) additional food provision (Fabi et al., 2006; Leitao et al., 2007; Pike and Lindquist, 1994),

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(3) increased feeding efficiency and (4) provision of nursery and recruitment sites (Bull and Kendall, 1994). Atlantic cod and pouting are two demersal fish species with a high commercial value and a high commercial potential respectively (Alonso-Fernández et al., 2008). With regard to conservation measures, environmental impact assessments and the assessment of delivered ecosystem services in the coastal zone, increased scientific knowledge on the behaviour of both species in relation with habitat variability and complexity is paramount. The development of offshore wind farms in the BPNS creates a unique opportunity to investigate the effects of artificial hard substrates on the distribution of both Atlantic cod and pouting.

The aim of this study was to investigate the importance of three different habitats for Atlantic cod and pouting in different seasons. To achieve this, we studied the spatio-temporal variability in catch per unit effort (CPUE) and aggregation of both demersal fish species at WARs, shipwrecks and soft-bottom areas in the BPNS in the period 2009–2011.

## 2. Materials and methods

### 2.1. Study sites

Abundances of Atlantic cod and pouting were estimated from January 2009 till December 2011 at three different habitats in the BPNS: (1) WARs, (2) shipwrecks and (3) sandy bottoms (Fig. 1). Since construction of the wind farm started only in May 2008, the WARs are considered immature artificial reefs where colonization processes (both for benthos and fish) recently started. The shipwrecks on the other hand are considered as “mature” artificial reefs, with a stabilized climax community. The WARs are situated at the Thorntonbank, a natural sandbank 27 km offshore (coordinates WGS 84: 51°33'N–2°56'E) at a depth of 22.5 m at mean low water spring (MLWS). The six wind turbine foundations have a diameter of 14 m at the seabed and are surrounded by a scour protection layer (pebbles and rocks) with a total diameter of 44 m (1520 m<sup>2</sup>) (Brabant and Jacques, 2010). The surrounding soft sediment is composed of medium sand (mean median grain size 374 μm, SE 27 μm) (Reubens et al., 2009).

Two shipwrecks were monitored: the *LCT 457* (coordinates WGS 84: 51°25'N–2°44'E) and the *Kilmore* (coordinates WGS 84: 51°23'N–2°30'E). The *LCT 457* measures 64 m in length and 10 m wide. It is elevated between 1 m and 2.5 m from the seabed. The wreck sunk in 1944 and lies at a depth of 22 m at MLWS. It consists of iron and has little complexity. The *Kilmore* has a higher complexity, is longer (86 m) and wider (13 m) than the *LCT 457*. It is elevated up to 6 m from the seabed. The ship sunk in 1906 and the lowest part of the wreck lies at a depth of 30 m at MLWS (Termote and Termote, 2009).

The sandy bottom areas are located at the Thorntonbank (coordinates WGS 84: 51°31'N–2°52'E) and the Goote bank (coordinates WGS 84: 51°27'N–2°52'E) at approximately 25 m depth at MLWS. They are composed of medium sand (mean median grain size 362 μm, SE 95 and 371 μm, SE 83 respectively) (Reubens et al., 2009).

### 2.2. Sampling method

Line fishing (hooks: Arca, size 4; bait: *Arenicola marina*) was performed at the different sites to quantify the CPUE of Atlantic cod and pouting (Table 1). Sampling was restricted to daytime hours. Fishing time was 45 min on average and the number of fishing people ranged from 2 to 8. At the WAR angling was performed 1–10 m away from a turbine (i.e. within the erosion protection layer radius) just above the bottom of the seabed, to assure that only individuals

hovering at the WAR were caught. At the shipwrecks, the research vessel drifted over the wrecks and a signal was given to start and stop fishing to avoid catching fish from the surrounding soft bottom. At the sandy bottom sites, the research vessel was anchored during fishing.

### 2.3. Data analysis

It is well accepted that CPUE data do present useful information concerning relative abundances (Haggarty and King, 2006). Therefore, CPUE was standardized for both species as:

$$CPUE = \frac{N_f}{N_p * T}$$

with  $N_f$  the number of fish caught (ind),  $N_p$  the number of fishermen (fm) and  $T$  the duration of fishing in hours (h).

Statistical analyses were performed using the Plymouth Routines in Multivariate Ecological Research (PRIMER) package, version 6.1.6 with PERMANOVA add-on software (Anderson et al., 2008; Clarke and Gorley, 2006). PERMANOVA makes no explicit assumptions regarding the distribution of original variables. Univariate and multivariate ANOVAs are performed with  $p$ -values obtained by permutation (Anderson et al., 2008). To investigate the spatio-temporal effects (i.e. habitats, period of the year and annual differences) on CPUE, a 3-factor design was used with fixed factors habitat (hab), month (mo) and year (ye). As the design was unbalanced at the lowest level (i.e. unequal numbers of replicate samples within each factor level of the design), it was decided to use Type I sums of squares in the analyses (Anderson et al., 2008). The lack of balance means that the various interactions and main effects cannot be estimated independently, and thus the outcome will depend on the order in which the factors are entered in the model (Anderson et al., 2008). For this study, the order used is habitat, month, year. A zero-adjusted Euclidian distance similarity matrix was used after a  $\log(X+1)$  transformation of the data (Clarke et al., 2006). In case of significant factor effects, pair-wise tests were performed to investigate which groups within a factor were significantly different. In case of significant interactions, pair-wise tests within the interaction were performed (e.g. pair-wise tests of hab within hab × mo were performed to investigate in which months the habitats differed and vice versa). Homogeneity of multivariate dispersions was tested with PERMDISP, using distances among centroids. A significance level of  $p < 0.05$  was used in all tests. Results are expressed as mean ± standard error (S.E.).

## 3. Results

### 3.1. Spatio-temporal variability in Atlantic cod populations

The overall mean monthly CPUE of Atlantic cod ranged between 0 and 13.6 ind h<sup>-1</sup> fm<sup>-1</sup> (Table 2). The highest mean monthly CPUE was recorded at the WARs, varying between 0.9 (March) and 13.6 ind h<sup>-1</sup> fm<sup>-1</sup> (July) (Table 2). At the shipwrecks mean monthly CPUE varied between 0.1 (December) and 3.6 (September) ind h<sup>-1</sup> fm<sup>-1</sup>. Almost no Atlantic cod was caught by line fishing at the sandy bottom locations (mean monthly CPUE varied between 0 and 0.4 ind h<sup>-1</sup> fm<sup>-1</sup>) (Table 2).

Significant hab × mo ( $p = 0.001$ ) and hab × ye ( $p = 0.006$ ) interactions in the PERMANOVA model demonstrated that differences in CPUE between habitats depended on year and month of sampling (Table 3). However, pair-wise comparisons among sampling years only revealed significant differences in CPUE between 2009–2010 and 2009–2011 ( $p = 0.012$  and  $p = 0.015$  respectively) at the WARs, whereas no significant differences were present between years at the other habitats. At the WARs, mean CPUE was

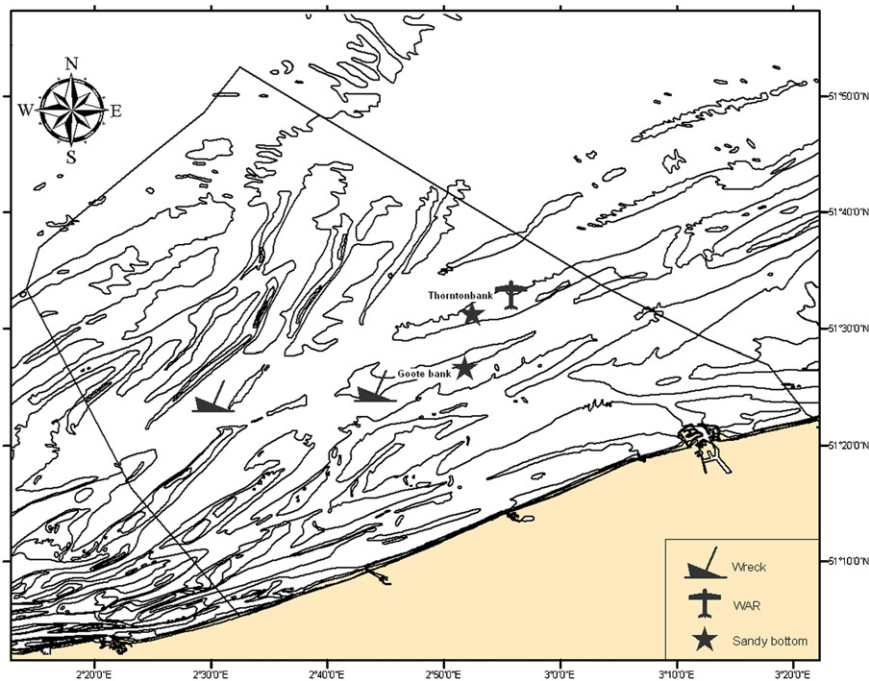


Fig. 1. Map of the Belgian part of the North Sea, with indication of the sampling locations.

**Table 1**  
Monthly sampling periodicity at the different sites. NA: not applicable. For the sandy bottom and wreck, a frequency >1 means either that the site was sampled several times that month or that more than one site was sampled.

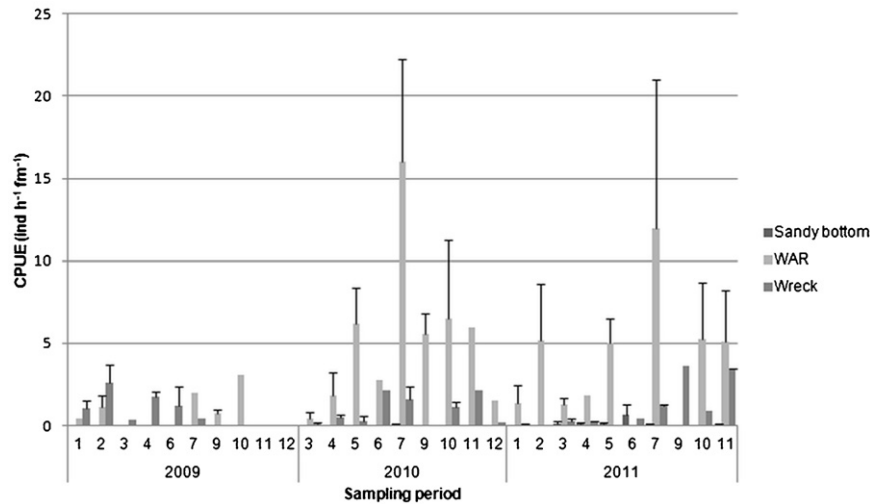
Month	2009			2010			2011		
	Sandy bottom	WARs	Wreck	Sandy bottom	WARs	Wreck	Sandy bottom	WARs	Wreck
January	1	1	2	0	0	0	3	4	3
February	2	4	3	0	0	0	0	3	0
March	1	1	1	2	3	4	4	7	2
April	2	0	4	3	6	2	4	1	2
May	0	0	0	3	5	2	2	3	0
June	0	0	2	1	1	1	2	0	1
July	1	1	1	4	6	3	4	2	2
August	0	0	0	0	0	0	0	0	0
September	0	2	0	3	6	0	2	0	1
October	0	1	0	3	3	4	3	3	1
November	2	1	0	1	1	1	4	4	2
December	1	0	1	1	1	1	NA	NA	NA

**Table 2**  
CPUE (ind h<sup>-1</sup> fm<sup>-1</sup>) for Atlantic cod and pouting per habitat over the period 2009–2011 (mean ± S.E.). No S.E. value indicated the site was sampled only once during that month.

Month	Atlantic cod			Pouting		
	Sandy bottom	WARs	Wreck	Sandy bottom	WARs	Wreck
January	0	1.2 ± 0.8	0.3 ± 0.2	0	1.4 ± 0.9	0.2 ± 0.2
February	0	2.9 ± 1.6	2.6 ± 1.1	0	1.5 ± 0.8	0.06 ± 0.06
March	0.08 ± 0.08	0.9 ± 0.3	0.2 ± 0.06	0	0.3 ± 0.1	0
April	0.04 ± 0.04	1.8 ± 1.2	0.6 ± 0.3	0	0.2 ± 0.1	0.05 ± 0.03
May	0.03 ± 0.03	5.8 ± 1.4	0.3 ± 0.3	0	2.8 ± 1.2	0.2 ± 0.2
June	0.4 ± 0.4	2.8	1.3 ± 0.6	0	1.4	0.2 ± 0.2
July	0.05 ± 0.03	13.6 ± 4.6	1.3 ± 0.4	0.02 ± 0.02	6.5 ± 1.4	0.5 ± 0.2
September	0	4.4 ± 1.2	3.6	0	9.2 ± 1.3	2.1
October	0	5.5 ± 2.3	1.1 ± 0.3	0.4 ± 0.3	8.4 ± 1.7	1.1 ± 0.3
November	0.04 ± 0.04	4.06 ± 1.9	3.0 ± 0.4	0.2 ± 0.2	11.3 ± 3.4	1.5 ± 1.1
December	0	1.5	0.1 ± 0.1	0	12.8	0.7 ± 0.7
Overall	0.05 ± 0.03	4.6 ± 0.9	1.1 ± 0.2	0.07 ± 0.03	4.3 ± 0.6	0.7 ± 0.1

**Table 3**PERMANOVA results from the main test for Atlantic cod and pouting. Hab: habitat; Mo: month; Ye: year. *p*-Values obtained by permutation.

Factor	Atlantic cod				Pouting			
	df	MS	Pseudo- <i>F</i>	<i>p</i>	df	MS	Pseudo- <i>F</i>	<i>p</i>
Hab	2	23.54	79.79	<0.001	2	23.58	119.52	<0.001
Mo	10	1.42	4.82	<0.001	10	3.03	15.37	<0.001
Ye	2	0.60	2.02	0.13	2	0.40	2.01	0.14
Hab × mo	20	0.82	2.77	0.001	20	1.05	5.30	<0.001
Hab × ye	4	1.16	3.93	0.006	4	0.25	1.27	0.29
Mo × ye	16	0.13	0.44	0.96	16	0.19	0.94	0.51
Hab × mo × ye	17	0.10	0.34	0.99	17	0.14	0.70	0.73

**Fig. 2.** Mean monthly CPUE (with S.E.) of Atlantic cod per habitat substrate over the period 2009–2011.

much lower in 2009 ( $1.05 \pm 0.4 \text{ ind h}^{-1} \text{ fm}^{-1}$ ) as compared to 2010 ( $6.3 \pm 1.5 \text{ ind h}^{-1} \text{ fm}^{-1}$ ) and 2011 ( $3.9 \pm 1.0 \text{ ind h}^{-1} \text{ fm}^{-1}$ ) (Fig. 2).

A seasonal trend in CPUE was present at the WARs in 2010–2011 (Fig. 2) with significantly higher values from late spring to late autumn (with a peak in summer) compared to the winter–early spring period (December–April) (pair-wise comparisons:  $p < 0.05$ ). At the shipwrecks a comparable, trend was visible, although CPUE was lower compared to the WARs. At the sandy bottoms, CPUE of Atlantic cod was always low and did not vary significantly over months. Pair-wise comparisons among habitats revealed that CPUE was significantly lower at the sandy bottoms as compared to the WARs from March onwards, and during summer and autumn months as compared to the shipwrecks.

### 3.2. Spatio-temporal variability in pouting populations

The overall mean monthly CPUE of pouting ranged between 0 and  $12.8 \text{ ind h}^{-1} \text{ fm}^{-1}$  (Table 2). Again, very low values (mean monthly CPUE 0 during eight months and a maximum of  $0.4 \text{ ind h}^{-1} \text{ fm}^{-1}$ ) were noted at the sandy bottoms (Table 2). At the shipwrecks slightly higher values were obtained, with mean monthly CPUE varying between 0 and  $2.1 \text{ ind h}^{-1} \text{ fm}^{-1}$ . The highest mean monthly CPUE for pouting was recorded at the WARs ( $0.2\text{--}12.8 \text{ ind h}^{-1} \text{ fm}^{-1}$ ) (Table 2) with the highest CPUE registered in July 2009 ( $15.6 \text{ ind h}^{-1} \text{ fm}^{-1}$ ).

A seasonal trend in CPUE was present at the WARs (Fig. 3) with significantly higher values in summer and autumn (July–December) compared to winter and spring (January–June) (pair-wise comparisons:  $p < 0.05$ ). At the shipwrecks a comparable, but less clear trend was present, except for 2009, when almost no pouting were caught at the shipwrecks. At the sandy bottom CPUE was very low during all months.

The spatial distribution of pouting also differed between months and habitats (hab × mo,  $p = 0.0001$ ) (Table 3). Pair-wise comparisons among habitats demonstrated that CPUE was significantly higher at the WARs as compared to the shipwrecks in April, July and October; and in April, July–November when compared to the sandy bottom locations.

## 4. Discussion

In the Belgian part of the North Sea, both Atlantic cod and pouting are frequently observed near artificial hard structures (Mallefet et al., 2007; Reubens et al., 2011; Zintzen et al., 2006). However, information concerning aggregation differences at different substrate types (i.e. sandy bottoms, shipwrecks and WARs) is lacking. Our results suggest aggregation differences, affected by seasonal aspects, for both Atlantic cod and pouting. This result is based on the analysis of a three-factor PERMANOVA model. It should be noted that, for both fish species, the assumption for homogeneity of multivariate dispersions was not fulfilled for hab within hab × mo; PERMDISP had a *p*-value below 0.05. This means that a significant result for one of the given factors is caused by a significant difference in location, dispersion or some combination of both between the groups (Anderson et al., 2008). Pair-wise comparison showed that CPUE at both WARs and shipwrecks differed significantly from those at the sandy sediments. However, very low within-group dispersion was present for the latter habitat (CPUE mostly near zero), which increases the differences among the centroids of the different habitats. Based on these findings we are confident that multivariate dispersions did not compromise our general conclusions. In addition, we are aware that catch per unit effort (CPUE) not only depends upon fish densities, but also upon fish behaviour (e.g.

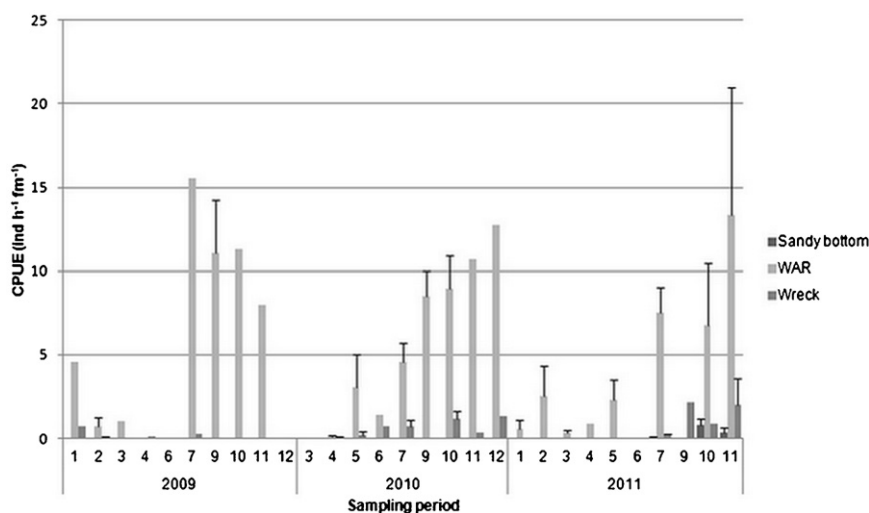


Fig. 3. Mean monthly CPUE (with S.E.) of pouting per habitat substrate over the period 2009–2011.

hyperaggregation and habitat selection) (Linløkken and Haugen, 2006; Olin et al., 2004).

#### 4.1. Seasonality

The study revealed a seasonal pattern in CPUE for both species in all habitats, which was related to life-history characteristics (i.e. reproductive behaviour of adults). Both species are known to spawn in winter and early spring (Alonso-Fernández et al., 2008; Mello and Rose, 2005a) during which they migrate to distinct spawning areas outside the study area (Franca et al., 2004; Hutchinson et al., 2001). In winter and early spring, CPUE was very low at the different habitats in the BPNS. Late spring to late autumn is the feeding and growing period for both species (Alonso-Fernández et al., 2008; Mello and Rose, 2005b), resulting in much higher CPUE, especially at the WARs and shipwrecks. Both types of artificial reefs harbour a diverse and abundant epifaunal community (Kerckhof et al., 2010; Zintzen et al., 2008) with many potential prey species for Atlantic cod and pouting. Comparable seasonal variations in fish abundances at artificial reefs have been observed in other studies (Fabi and Fiorentini, 1994).

#### 4.2. Habitat characteristics

A second important finding in this study is the difference in CPUE between habitats, interacting with seasonality, for both Atlantic cod and pouting. CPUE was highly enhanced (mainly in summer and autumn) at the WARs in comparison with the sandy bottom sites. This is in accordance with results for pouting presented in Reubens et al. (2011). Although no information is available on the efficiency of catching Gadidae at different substrate types, our results clearly indicate an aggregation effect of the WARs on pouting and Atlantic cod populations. This aggregation effect was also seen at the shipwrecks, but to a lesser extent. Local factors, such as the availability of prey species (Reubens et al., 2011), predator pressure (Brickhill et al., 2005), habitat complexity and refuge possibilities (Wilhelmsson et al., 2006; Wilson et al., 2007) likely contribute to the observed differences in aggregation between the artificial hard substrates and the sandy bottom areas.

Several studies revealed that artificial reefs harbour higher densities of fish species compared to natural reefs or older artificial reefs. At the same time, small artificial reefs generally have higher fish densities than larger ones (Ambrose and Swarbrick, 1989; Bohnsack et al., 1994; Leitao et al., 2008). The WARs are rather small

units with a high perimeter-to-area ratio. This implies that WARs can be seen as small reefs that attract fish from a larger area, relative to reef size, compared to larger reefs. This argument only applies for fish aggregation, not for production (Ambrose and Swarbrick, 1989).

Maturity of the system may influence fish assemblages. Older, more mature reefs exhibit lower fish density, diversity and biomass (Leitao et al., 2008). Fish colonization on artificial reefs is known to be associated with the epifaunal colonization (Svane and Petersen, 2001). The investigated shipwreck artificial reefs are known to have a mature and stable epifaunal community (Zintzen et al., 2008), while the epifaunal community at the relatively young WARs is still in a transitional situation (Kerckhof et al., 2010), which surely influences the associated fish assemblages.

#### 4.3. Construction effect

A third striking result of this study is the aberrant low CPUE rates in 2009 at the WARs for Atlantic cod (Fig. 2) compared to 2010–2011. This was not the case at the other habitats. As the WARs are relatively new structures (built in 2008) constructed in an area previously dominated by soft sediments, a construction effect is suggested to explain the variation in CPUE at the WARs between the different years for Atlantic cod. This corroborates other long-term investigations carried out at artificial reefs, where qualitative and quantitative increments in fish assemblages over time were shown (Bohnsack and Sutherland, 1985; Fabi et al., 2002; Leitao et al., 2008). For pouting no such construction effect was seen. From the first year onwards high CPUE rates were found at the WARs, indicating that the colonization rate of both species differed.

Currently the WARs in the BPNS are de facto marine protected areas. A study has however been performed to investigate the possibilities for aquaculture, blue energy development and small-scale passive fisheries inside these concession areas (Verhaeghe et al., 2011), but currently no shipping nor fishing activities are allowed inside the wind farms. Fish aggregations, as e.g. found at the WARs for both pouting and Atlantic cod, are particularly vulnerable to fishing pressure and overexploitation (Rose and Kulka, 1999). Changes in spatial distribution of a species can not only contribute to overfishing, but also to inappropriate interpretation of CPUE data. Rose and Kulka (1999) hypothesized that a concentration of fish and fishing activities can lead to an extreme hyper stability of the relation between CPUE and abundance. Consequently, CPUE will reflect local densities and therefore incorrectly assess stock

abundance (Rose and Kulka, 1999). Therefore it is important to carefully monitor the aggregations of Atlantic cod and pouting in the long term. If, in the future, small-scale fisheries or aquaculture activities would be permitted within the WARs, thorough management restrictions should be implemented to mitigate possible negative effects of these activities on the fish populations.

In conclusion, the present study disclosed that the habitat type plays an important role for the distribution of Atlantic cod and pouting. Both species aggregated at the WARs and to a lesser extent also at the shipwrecks, mainly during summer and autumn, but were almost not caught through line fishing at the sandy bottoms. The aggregation is related to specific habitat characteristics (e.g. bottom type, maturity of the system and prey availability), while the seasonal patterns are related to life-history characteristics (i.e. feeding versus spawning period). A construction effect of the wind turbines was present for Atlantic cod, the first year after the wind turbines were built. This was not the case for pouting, which immediately aggregated in higher numbers around these hard substrates.

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### Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.fishres.2012.10.011>.

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