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Residency, site fidelity and habitat use of Atlantic cod (*Gadus morhua*) at an offshore wind farm using acoustic telemetry

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ABSTRACT

Because offshore wind energy development is fast growing in Europe it is important to investigate the changes in the marine environment and how these may influence local biodiversity and ecosystem functioning. One of the species affected by these ecosystem changes is Atlantic cod (*Gadus morhua*), a heavily exploited, commercially important fish species. In this research we investigated the residency, site fidelity and habitat use of Atlantic cod on a temporal scale at windmill artificial reefs in the Belgian part of the North Sea. Acoustic telemetry was used and the Vemco VR2W position system was deployed to quantify the movement behaviour. In total, 22 Atlantic cod were tagged and monitored for up to one year. Many fish were present near the artificial reefs during summer and autumn, and demonstrated strong residency and high individual detection rates. When present within the study area, Atlantic cod also showed distinct habitat selectivity. We identified aggregation near the artificial hard substrates of the wind turbines. In addition, a clear seasonal pattern in presence was observed. The high number of fish present in summer and autumn alternated with a period of very low densities during the winter period.

1. Introduction

Offshore wind energy development is the fastest growing energy technology in Europe to produce marine renewable energy (Shaw et al., 2002). In recent years offshore wind farms arose all across the North Sea (Krone, 2012; Reubens et al., 2013a; van Deurs et al., 2012) and member states are planning a further monumental development in the North-East Atlantic Ocean (Wilhelmsson and Malm, 2008).

As a result thousands of wind turbines will be present in the North Sea in the near future. The foundations of these turbines form artificial hard substrates, which in time may turn into artificial reefs (so-called windmill artificial reefs, WARs). The offshore wind farms (OWFs) induce some changes in the marine environment which may influence local biodiversity and ecosystem functioning (Andersson et al., 2009). As a consequence, the OWFs have some environmental costs and benefits (Langhamer et al., 2009) including habitat alteration, changes in sediment characteristics, electromagnetic fields, underwater noise and hydrodynamics. All these ecosystem changes interact with the colonization by epifouling organisms; community composition of soft substrate macro- and epibenthos, demersal and benthic fish; spatio-temporal distribution and migration routes of demersal fish, seabirds and marine mammals (Degraer et al., 2012; Petersen and Malm, 2006; Reubens et al., 2013a; Wilhelmsson et al., 2006). However, the ecological impacts on the marine ecosystem on the longer term are still poorly known and scientific peer-reviewed documentation is just slowly increasing (van Deurs et al., 2012).

Atlantic cod (*Gadus morhua* L., 1758) is one of the species that is affected by some of these ecosystem changes in OWFs. Reubens et al. (2013a) revealed the presence of large aggregations of juvenile Atlantic cod at the foundations of wind turbines during summer and autumn. During these periods Atlantic cod exhibited crepuscular movements related to feeding activity (Reubens et al., 2013b).

Atlantic cod is a demersal fish species that occurs in the North Atlantic Ocean. It is widely distributed throughout the North Sea in a variety of habitats and is a highly valued commercial species, suffering from overexploitation (ICES, 2010). They have a flexible diel cycle in feeding activity and habitat utilization linked to

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spatio-temporal variations in food availability and predation risks (Clark and Green, 1990; Neat et al., 2006; Reubens et al., 2013b; Righton et al., 2001). Migratory behaviour differs between Atlantic cod groups; from sedentary cod with a very small distribution range to dispersing cod moving within large geographical areas (Robichaud and Rose, 2004). They undertake seasonal migrations between spawning, nursery and feeding grounds (Turner et al., 2002) and genetically distinct populations are present in the North Sea (Hutchinson et al., 2001). Four subgroups were found: the Bergen Bank, Moray Firth, Flamborough head and the Southern Bight. The subgroup from the Southern Bight of the North Sea is known to have winter spawning grounds off the coasts of the United Kingdom and the Netherlands and summer feeding grounds in the southern and central North Sea (Righton et al., 2007).

As in many European countries, also Belgium invests intensively in offshore wind energy development. At present two wind farms are operational in the Belgian part of the North Sea (BPNS) and five more projects were granted a domain concession (Brabant et al., 2012). Atlantic cod is known to aggregate at these WARs (Lindeboom et al., 2011; Reubens et al., 2013a) as shelter against currents or predators (Bohnsack, 1989) and increased food provisioning (Leitao et al., 2007; Reubens et al., 2011) may turn these substrates into suitable habitats for hard substrate dwelling fish. No information however is available on the possible influences of these OWFs on the temporal movement behaviour (residency, site fidelity) and habitat use of Atlantic cod.

In this research we want to:

(1) Improve the knowledge on individual behaviour of Atlantic cod in relation to WARs. More specifically the residency and site fidelity are investigated during the summer feeding period in an OWF in the BPNS.
(2) Investigate the small-scale habitat selectivity within an OWF. We want to distinguish whether Atlantic cod is strongly aggregated near the WARs or if they are randomly distributed on both the hard and soft substrates within a wind farm.
(3) Investigate seasonal changes of Atlantic cod distribution near WARs in the BPNS.

2. Material & methods

2.1. Study site

The study was performed at the OWF of C-Power (Fig. 1). This wind farm is situated in the BPNS at the Thorntonbank, a natural sandbank 27 km offshore (coordinates WGS 84: 51°33′N – 2°56′E). The construction works started in 2008 and the wind farm should be fully operational by the end of 2013. It consists of 54 wind turbines, with two types of foundations: concrete gravity based (6 turbines) and steel jacket foundations with four legs (48 turbines). The distance between the turbines varies between 500 and 800 m. Water depth varies between 18 and 24 m and the total surface area of the wind farm is 18 km^2.

All Atlantic cod used in the present study were caught at two gravity based foundations (built in 2008). These foundations have a diameter of 14 m at the seabed, at a depth of about 22.5 m at mean low water spring (MLWS). The gravity based foundations are surrounded by a scour protection layer of pebbles and rocks with a maximum radius of 19 m. The total surface area of the hard substrates (turbine foundation and scour protection together) is approximately 1600 m^2.

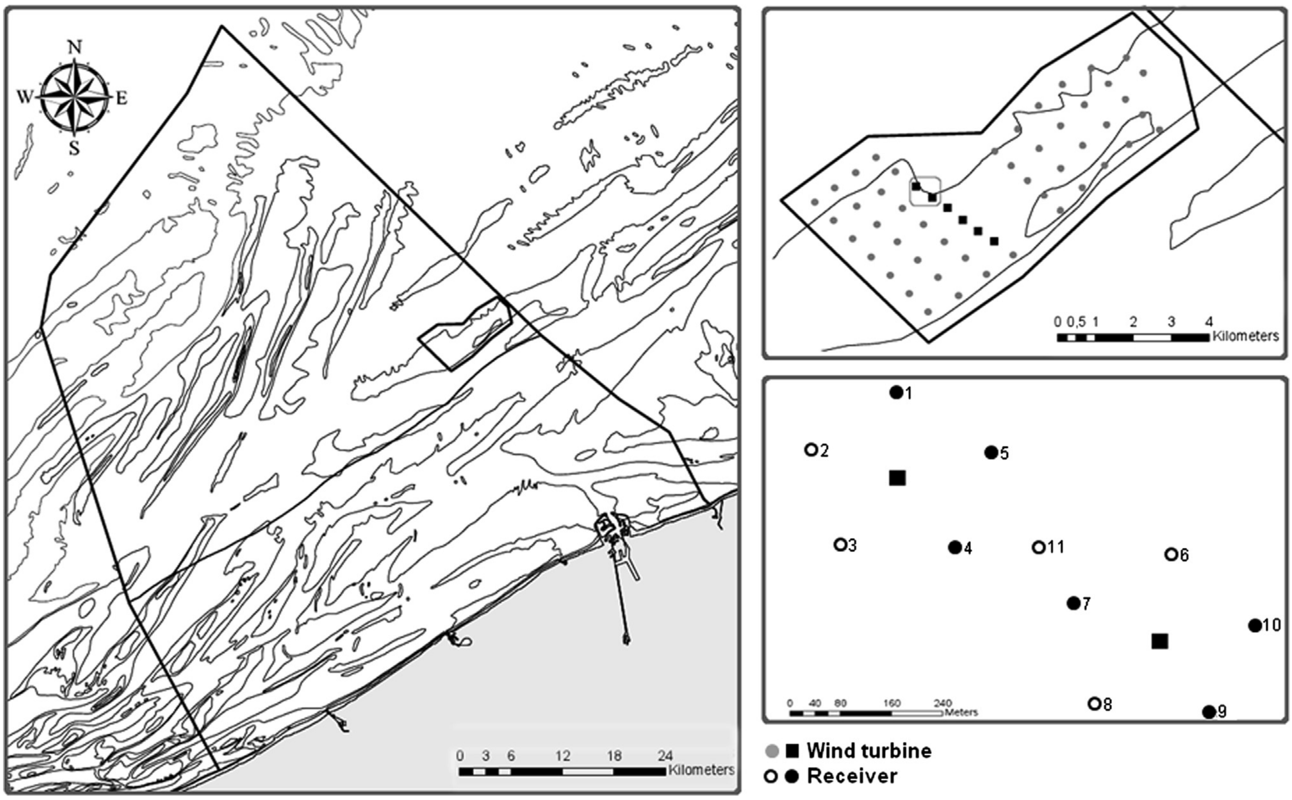

Fig. 1. Overview of the Belgian part of the North Sea, with indication of the Wind farm concession area (left part); wind farm layout and receiver positions (right part). Wind turbines are represented by grey circles (jacket foundations) and black squares (gravity-based foundations). Full black circles indicate receivers that could be retrieved. All six retrieved receivers were used for the short term monitoring. For the longer term only receiver 1 & 5 were used. All fish were caught at the two wind turbines investigated.

Table 1
Summary of acoustic monitoring data for 22 tagged Atlantic cod.

Fish no.	Length (cm)	Date released	Date first detected	Last detected (short term)	Days at liberty	Days detected	Last detected (long term)	Days at liberty	Days detected
T11	/	27/07/2011	/	/	/	/	/	/	/
T14	40	27/07/2011	01/08/2011	12/09/2011	48	43	12/09/2011	48	43
T20	37	27/07/2011	27/07/2011	20/10/2011	86	86	10/07/2012	350	348
T21	28	24/05/2011	24/05/2011	16/07/2011	54	39	16/07/2011	54	39
T22	38	07/06/2011	07/06/2011	22/08/2011	77	67	22/08/2011	77	67
T23	34	24/05/2011	24/05/2011	28/05/2011	5	5	28/05/2011	5	5
T24	36	07/06/2011	08/06/2011	20/10/2011	136	133	20/10/2011	136	133
T25	33	24/05/2011	24/05/2011	20/10/2011	150	150	10/07/2012	414	251
T26	32	24/05/2011	24/05/2011	20/10/2011	150	150	13/06/2012	387	187
T27	34	07/06/2011	11/06/2011	20/10/2011	136	132	25/12/2011	202	198
T28	34	07/06/2011	07/06/2011	20/10/2011	136	136	07/12/2011	184	164
T29	30	07/06/2011	07/06/2011	28/06/2011	22	12	28/06/2011	22	12
T30	31	07/06/2011	07/06/2011	20/10/2011	136	135	23/11/2011	170	153
T31	30	07/06/2011	07/06/2011	17/10/2011	133	115	29/10/2011	367	120
T32	37	07/06/2011	07/06/2011	07/06/2011	1	1	07/06/2011	1	1
T33	38	07/06/2011	07/06/2011	07/06/2011	1	1	07/06/2011	1	1
T34	38	07/06/2011	07/06/2011	11/06/2011	5	4	11/06/2011	5	4
T35	39	27/07/2011	27/07/2011	14/10/2011	80	44	14/10/2011	80	44
T36	41	27/07/2011	27/07/2011	20/10/2011	86	86	24/12/2011	151	151
T37	37	27/07/2011	27/07/2011	27/07/2011	1	1	27/07/2011	1	1
T38	38	27/07/2011	27/07/2011	20/10/2011	86	82	10/05/2012	289	125
T40	32	27/07/2011	27/07/2011	24/08/2011	29	29	24/08/2011	29	29

Short term monitoring ran from May until Oct 2011, while the long term monitoring ran from May 2011 until Jul 2012. Days at liberty is defined as the period between date of release and the date of last detection.

The surrounding soft sediment is composed of medium sand (mean median grain size 374 μm, SE 27 μm) (Reubens et al., 2009).

2.2. Sampling methods

2.2.1. Residency, site fidelity and seasonality

One of the techniques used in this research is acoustic telemetry. It is an often used approach to study individual behaviour of undisturbed fish for a long period of time. In this study a design was set up to investigate residency and site fidelity and to quantify the seasonal presence of Atlantic cod at the WARs.

The Atlantic cod tracked were collected between May and July 2011 (Table 1) using hook and line gear. To minimize the probability of barotraumas, fish were hauled in slowly to allow them to release excess gas and prevent swim bladder rupture. In addition hooks without barbs were used to reduce tissue damage from hooking. After capture the individual fish were kept in an aerated water tank for two hours before surgical implantation of the acoustic transmitter (i.e. tagging). Surgical procedures were similar to those of Reubens et al. (2013b, 2012), Arendt et al. (2001) and Jadot et al. (2006). After surgery the fish were measured and externally tagged with a T-bar anchor tag for external recognition if recaptured. After full recovery and up to two hour observation for survival, the fish were released at their capture site. In total 22 cod specimens (age I-group) were tagged (Table 1) with Vemco coded V9-1L acoustic transmitters (Vemco Ltd., Halifax, Nova Scotia, expected lifetime of 405 days). Each transmitter has a unique ID, emitting a signal every 110–250 s. Fish ranged in size from 28 to 41 cm (total length). Tag weight did not exceed 2% of the fish weight.

The Vemco VR2W acoustic monitoring system was used. Self-contained, single channel (69 kHz) submersible VR2W receivers were deployed to continuously monitor the presence of pulse-coded acoustic transmitters within their detection range. The receivers were moored on the bottom with a cast iron heating element. The receiver was attached to a polypropylene rope approximately 1 m above the seabed. The rope was connected to a subsurface buoy. When a tagged fish was detected, information on time, date and code of the specific tag were stored by the receiver. If a fish was detected, it indicates that the fish was present within the detection range of a receiver. If a fish was absent, this indicates that the fish was outside the detection range of the receivers or the signal emitted by the transmitter was blocked before it reached a receiver (e.g. by a boulder or a wind turbine foundation). In the former situation the fish had moved outside the study area (but not necessarily outside the wind farm area), in the latter the fish had moved to a position within the study area where it could not be detected.

The monitoring period was divided in two time intervals: a short term and a longer term interval. Summer–autumn residency and site fidelity were investigated during the short term, while seasonality in presence of Atlantic cod was investigated during the longer term. The receivers were placed around two WARs (Fig. 1) and recorded the presence of any acoustic transmitter within a range of 250–500 m. The short term monitoring period ran between May and October 2011, while the longer term monitoring period ran between May 2011 and July 2012. On October 20th 2011 four receivers (4, 7, 9 & 10) were retrieved for data analysis. The receivers 1 and 5 were retrieved on July 9th 2012. The latter were used for the longer term monitoring period, while all six receivers were used for the short term analyses.

As shown in Fig. 1, the receiver layout in this study was not ideal. The receivers were not equally distributed around the two turbines and no perfect symmetry was obtained. At one of the turbines all three receivers were located at one side. This is the result of some logistic problems. Initially 11 receivers were deployed. Both turbines were bordered by five receivers, positioned at equal distances from each other and the turbine. An extra receiver was placed in between the two turbines. However, due to the unlikely events of storms, theft and/or damage by propellers and beam trawling only six of the receivers could be retrieved. Despite the reduced number of receivers, useful information was obtained concerning habitat use and movements of Atlantic cod near the WARs.

2.2.2. Habitat selectivity

The Vemco VR2W positioning system (VPS) was used to investigate small-scale habitat selectivity of Atlantic cod within an OWF. The study area harbours both artificial hard substrates (i.e. WARs) and soft sediments (i.e. surrounding medium sand) and to distinguish whether or not the fish were strongly aggregated towards

WARs VPS data can help. VPS uses an array of VR2W receivers and synchronization transmitters to calculate the position of the transmitters. The positioning is based on the time-difference-of-arrival of an acoustic signal to at least three receivers (Espinoza et al., 2011). VPS positions are not determined in real time, but calculated using Vemco VPS software. For each calculated position the VPS provides a horizontal position error (HPE). The HPE estimates are based on the error sensitivity of the receiver layout used and calibrated for local environmental conditions (i.e. depth, salinity and water temperature) (Vemco Ltd, Nova Scotia). Based on the VPS calculated positions of the transmitters, a fish could be assigned to a specific location and thus habitat type.

2.3. Data analysis

2.3.1. Residency and site fidelity

In acoustic telemetry studies, residency and site fidelity are frequently quantified. Both terms are often used as synonyms and relate to '*presence of fish over time*'. It is the degree to which an animal returns to a specific site. However, their meaning may slightly differ depending upon the time frame investigated. In the current research residency is defined as presence over time on a daily basis, while site fidelity is defined as presence over time on an hourly basis (i.e. residency over a smaller time scale) (Schroepfer and Szedlmayer, 2006). Fish may for instance have a high residency, but low site fidelity (e.g. present every day, but only for short time during each day).

Before the acoustic data was analysed, data were filtered for spurious detections. A fish was defined as being present in the study area on a given day if it was detected at least twice on that day. Single transmitter detections were considered false detections and removed from the analyses (Meyer et al., 2007).

For the data from the short term monitoring period a residency index was calculated, by dividing the number of days a fish was detected by the days at liberty. Days at liberty is defined as the number of days between the date of release and the date of the last detection. The residency index ranges between 0 (completely absent in the study area) and 1 (permanently present in the study area). Further, a monthly residency index was determined for each tagged fish, to investigate presence in the study area over time. The monthly residency index is defined as the number of days a fish was present during a specific month as a fraction of the total number of days in that month. The monthly residency index ranges between 0 (completely absent during a specific month) and 1 (permanently present during a specific month). Only fish observed at least once during a specific month were included in the analysis. Differences in presence were compared between periods using the non-parametric Kruskal–Wallis test.

An individual detection rate was calculated as well, to investigate site fidelity. This detection rate is defined as the number of hour bins a fish was detected within the study site as a fraction of the total time at liberty (expressed in hour bins) (Winter et al., 2010).

Analyses for residency and site fidelity were performed on data of 18 Atlantic cod as the remaining fish had insufficient detections (fish that were detected less than five days were left out). The Kruskal–Wallis tests were performed in R 2.15.1 software (www.r-project.org).

2.3.2. Habitat selectivity

To assign a fish position to a habitat type, the distance from the centre of a wind turbine foundation to the transmitter position was calculated. As the WARs extend to a distance of approximately 25 m from the centre, a fish is present at the WAR if its calculated position is less than 25 m from the centre. As such, fish positions were assigned to hard substrates, transitory or soft substrates if they were less than 25 m, 25–50 m or more than 50 m away from the centre of a wind turbine respectively.

Average relative percentages of detections were measured per distance. The relative percentage was calculated as the percentage of detections divided by the relative surface. The relative surface was calculated as a percentage of the total surface (i.e. the area covered by a distance of 150 m).

Precise position calculations are only possible if a transmitter is present within a receiver triangle. Outside the triangle there is much larger imprecision or even no position calculation possible (Vemco Ltd, Nova Scotia). As a result, only VPS estimates inside the VPS triangle (i.e. position calculations within 150 m from a turbine) were included in the analysis. Additionally only VPS estimates with an HPE value of <25 were included in the analysis. Only fish with more than 100 calculated positions were allowed for analysis.

2.3.3. Seasonality

During the longer term interval, the seasonality in presence of Atlantic cod at the WARs was investigated. Therefore, the mean number of tagged fish present in the study area was calculated for each month. Differences in presence between periods were compared using the non-parametric Kruskal–Wallis test.

Statistical tests were performed in R 2.15.1 software (www.r-project.org). A significance level of $p < 0.05$ was used in all tests. Results are expressed as mean ± standard deviation (SD).

3. Results

3.1. Short term monitoring period: residency and site fidelity

18 of the tagged fish were detected for 5 up to 150 days (Table 1). Most of the fish were present within the study area for an extended period of time, with many of the tagged fish still present at the end of the monitoring period (Fig. 2).

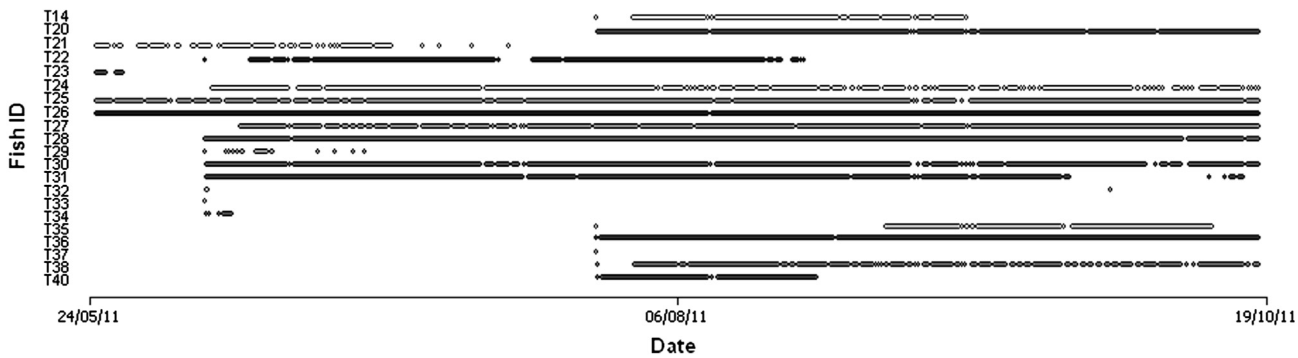

Fig. 2. Overview of detections from all tagged Atlantic cod; from 24th of May until 20th of October 2011 (based on information of 6 receivers). Each line represents the detections of one fish.

Table 2
Residency and site fidelity of tagged Atlantic cod from May until October 2011. Only fish detected for more than one day are listed in the table. Site fidelity is explained by the individual detection rate. This individual detection rate is expressed as proportion of one hour time bins individual cod were detected during their time at liberty; residency is defined as the proportion of number of days a fish was detected by the days at liberty.

Fish no.	Site fidelity (%)	Residency (short term)
T14	73	0.90
T20	93	1.00
T21	37	0.72
T22	73	0.87
T23	53	1.00
T24	63	0.98
T25	85	1.00
T26	95	1.00
T27	83	0.97
T28	93	1.00
T29	13	0.55
T30	83	0.99
T31	78	0.86
T34	32	0.80
T35	46	0.55
T36	96	1.00
T38	70	0.95
T40	89	1.00

Residency was high for most fish, with 83% having an index higher than 0.75 (Table 2). Many fish were present on a daily basis throughout almost the entire monitoring period (Fig. 2) within the study site. Further, cod showed high individual detection rates (median = 75%). The observed proportion of hour bins that specimens were detected during their time at liberty ranged between 13 and 96%; with half of the individuals being present more than 75% of the time (Table 2). This indicates that many individuals showed high site fidelity.

Mean monthly residency stayed fairly constant between May and October (between 0.8 ± 0.4 and 0.9 ± 0.2). As a result, no significant differences in monthly residency could be revealed (Kruskal–Wallis, $p = 0.63$) during the short term monitoring period.

3.2. Habitat selectivity

From 13 fish sufficient positions could be calculated to investigate the small scale habitat selectivity (Table 3). All fish were mainly observed between 20 and 40 m distance from a wind turbine. Almost 75% of the relative detections were encountered on the WARs, while 97% of the relative detections were within a 50 m range of the wind turbine. Only few detections were encountered further away (Fig. 3). This indicates that the Atlantic cod present in the study area were strongly aggregated at or close by the WARs, although the studied area was dominated by soft-bottom sediments and only small patches of hard substrates were available. Most of the detections were concentrated within this small region of hard substrates or the transitory area between hard and soft substrates.

Most of the tagged cod were observed at both wind turbines investigated. The tagged Atlantic cod were not faithful to one turbine and changed position; some movements in-between the turbines occurred.

3.3. Longer term monitoring period: seasonal presence

During the longer term monitoring period, four (18%) of the 22 tagged Atlantic cod were detected only the day of release. The 18 remaining fish (82%) were detected for 5 up to 348 days (Table 1). Fish were present within the study area for an extended period of time during summer and autumn and had left the study area by the end of December or were only sporadically detected (Fig. 4). Throughout the winter months (December–March) few detections were encountered within the study area. In spring five fish returned to the WARs and three of them (Fish T25, T26 and T38) were observed for a prolonged period, although most of the fish did not return anymore after winter time.

The mean number of fish present per month was highest in July 2011 (11.2 ± 1.1) and stayed fairly constant between August and November (between 7.7 ± 2.5 and 5.6 ± 1.8). During the winter months (i.e. Dec–March) only few fish were observed (between 3.2 ± 1.3 and 1 ± 0.19). In spring, a slight increase in mean monthly numbers was noted (between 1.7 ± 0.8 and 2.2 ± 0.4). Significant differences in presence were observed between the months

Table 3
Measured distance of tagged Atlantic cod from wind turbine at detected position.

	T20	T22	T24	T25	T26	T27	T28	T30	T31	T35	T36	T38	T40	Rel. surface	Rel. %	SE	Cum. %
5	3	11	12	219	4	44	62	53	42	2	40	0	0	0.1	22.3	5.2	22.3
10	37	48	36	436	15	144	181	161	257	10	155	16	0	0.4	19.7	3.4	41.9
15	167	29	26	214	52	521	176	77	215	29	448	99	1	1.0	13.8	1.9	55.7
20	150	46	24	68	80	479	141	100	184	70	1750	138	0	1.8	10.5	2.4	66.2
25	136	46	29	203	97	251	193	113	165	204	1766	77	0	2.8	8.0	2.5	74.2
30	349	104	32	481	214	179	165	44	207	101	726	55	1	4.0	5.4	1.2	79.6
35	753	173	37	407	204	199	131	30	317	42	523	46	10	5.4	5.3	1.3	84.8
40	1645	264	20	93	154	133	147	10	218	14	383	116	17	7.1	5.4	2.0	90.2
45	1110	136	9	34	130	124	113	12	186	5	173	355	29	9.0	4.6	2.0	94.8
50	164	33	10	64	58	88	31	6	100	9	103	746	6	11.1	2.1	1.2	96.8
60	171	20	22	80	59	136	19	4	177	8	101	262	44	16.0	2.3	1.6	99.2
70	50	3	19	55	18	22	10	0	36	4	40	77	14	21.8	0.5	0.4	99.7
80	6	1	38	62	14	5	1	0	23	1	27	13	5	28.4	0.2	0.1	99.9
90	3	1	1	1	5	2	0	0	10	1	19	11	1	36.0	0.0	0.0	99.9
100	0	1	1	2	2	1	0	0	2	0	8	33	0	44.4	0.0	0.0	99.9
110	3	0	1	5	1	2	1	0	6	0	9	13	0	53.8	0.0	0.0	100
120	0	1	0	10	2	0	0	0	8	0	4	0	2	64.0	0.0	0.0	100
130	4	1	1	4	0	2	0	0	4	0	3	2	3	75.1	0.0	0.0	100
140	1	0	0	6	2	1	0	0	6	0	1	1	0	87.1	0.0	0.0	100
150	1	2	0	3	0	1	0	0	3	0	0	0	0	100.0	0.0	0.0	100

Left side: number of calculated positions per distance for individual Atlantic cod; Right side: average relative percentage (±SE) of calculated positions per distance and cumulative percentage. Distance is calculated as distance between the calculated position and the centre of the closest wind turbine foundation. Transition between habitat types (i.e. hard, transitory and soft sediments) is indicated with a dashed line.

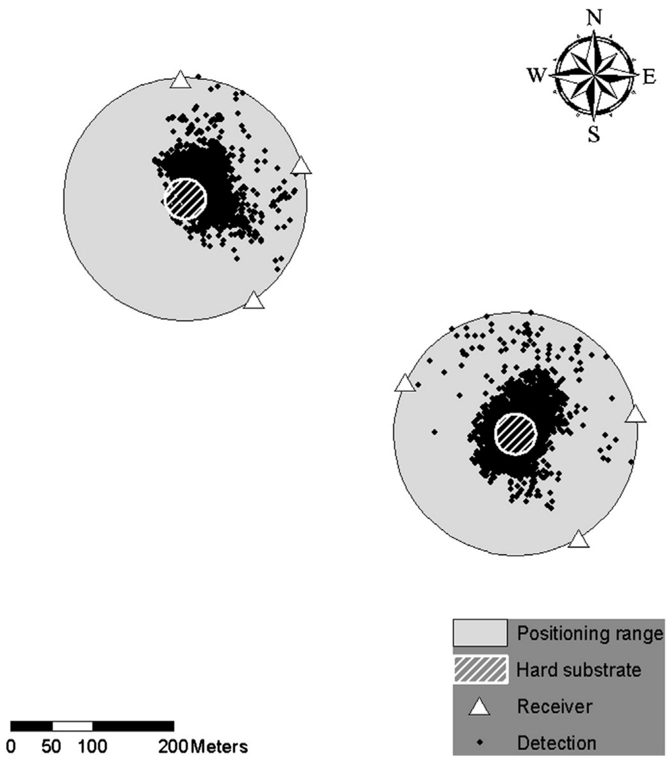

Fig. 3. Overview of the calculated positions (based on 6 receivers).

(Kruskal–Wallis, $p < 0.001$). Post-hoc tests revealed that mainly the summer and autumn samples (i.e. Jul–Nov) significantly differed with the winter and spring samples (i.e. Jan–Jun); confirming the seasonal trends in detection.

4. Discussion

Atlantic cod, as many other fish species, is liable to natural spatial and temporal patterns in movements and habitat use (Metcalfe, 2006; Neat et al., 2006; Righton et al., 2007). Environmental factors play an important role in these patterns, leading to regional differences in its behaviour (Righton et al., 2001). Spatial movement differs from sedentary groups with strong site fidelity to dispersers roaming around in large geographical areas (Robichaud and Rose, 2004). Temporal movements may differ substantially between stocks and could be related to prey availability, predation pressure and abiotic factors (e.g. light regime, prevailing currents) (Løkkeborg and Fernö, 1999; Reubens et al., 2013b; Righton et al., 2001). The present study provides important evidence concerning temporal movements and habitat use of Atlantic cod at an OWF in the BPNS.

4.1. Short term habitat use: opportunities of WARs

Reubens et al. (2013a) revealed high catch rates of Atlantic cod in summer and autumn at the WARs in the BPNS. Here, residency and site fidelity were investigated in closer detail to elaborate on the behavioural ecology of Atlantic cod at this habitat during summer and autumn. Although the monitored area in this study is very limited (2 km^2 approximately), most of the tagged fish were present within the area for many days and showed high individual detection rates. This indicates that the tagged Atlantic cod had very restricted distribution ranges and high residency during summer and autumn. Winter et al. (2010) observed similar results in an OWF in the Netherlands; with the majority of the tagged cod exhibiting small scale movements.

Atlantic cod makes extensive migrations between feeding (i.e. in summer and autumn) and spawning grounds (i.e. in winter time) (Turner et al., 2002), but during the feeding season they may reduce their foraging movements to less than one km (Righton et al., 2001; Turner et al., 2002). The results from this study suggest that Atlantic cod uses the WARs as feeding ground. Atlantic cod is an opportunistic feeder and their diet is known to be largely determined by availability of prey (Daan, 1973). A wealth of prey species is present at the OWFs in the BPNS and the predominant prey of Atlantic cod caught near these wind turbines (Reubens et al., 2013b) are known to occur in very high densities at the WARs (Kerckhof et al., 2010). As food is plentiful and readily available, the feeding efficiency increases near the WARs and the need for extended movements related to feeding is strongly reduced.

Other mechanisms that may stimulate site fidelity and residency near WARs are the increased protection against predators and currents (Reubens et al., 2013b; Wilhelmsson et al., 2006). At the WARs, the scour protection forms a habitat with a high complexity. The stone mattress of boulders and rocks creates an ideal shelter with many holes and crevices. In addition, there is always one side around the concrete foundations in the lee of the currents.

4.2. Habitat selectivity

The VPS study revealed that Atlantic cod are strongly attracted towards the WARs. About 97% of the calculated positions (relative measure) were within a 50 m range from a wind turbine (note that the hard substrates extent to approximately 25 m from the wind turbine) (Table 3). Trawl data confirmed that the catch rates of

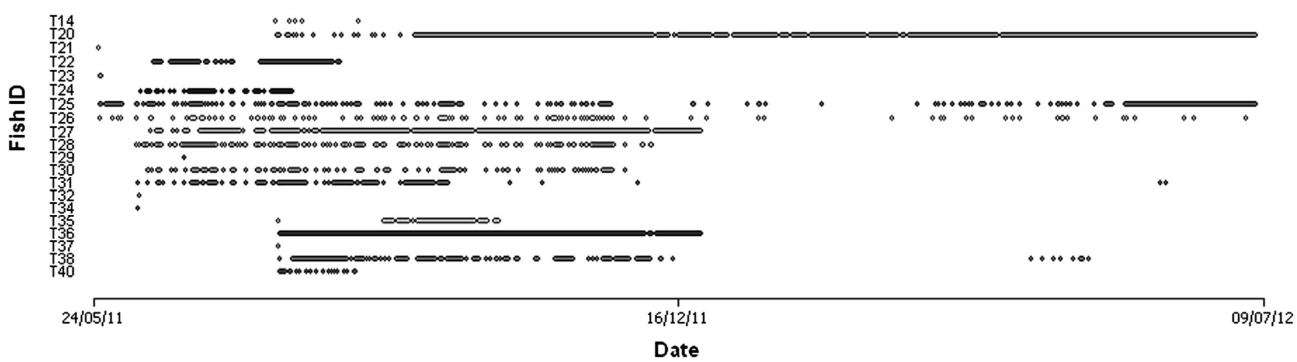

Fig. 4. Overview of detections of all tagged Atlantic cod; from 24th of May 2011 until 9th of July 2012 (based on information of 2 receivers). Each line represents the detections of one fish.

Atlantic cod on soft-bottom sediments inside OWFs were very low ($<$0.1 ind/km^2) (Vandendriessche et al., 2012), while CPUE data from line fishing showed enhanced densities of Atlantic cod near the WAR ($>$4 ind h^{-1} fm^{-1} in autumn) (Reubens et al., 2013a). Although no direct comparison between both fishing methods is possible, it is considered circumstantial evidence, underpinning the findings of this study.

Numerous studies have shown the potential of artificial reefs to attract and aggregate fish species (Jørgensen et al., 2002; Langhamer and Wilhelmsson, 2009; Leitao et al., 2009; Reubens et al., 2013a, 2011) and this aggregation effect may extent from several metres (Stanley and Wilson, 1997) to more than 100 m off an artificial reef (Soldal et al., 2002).

4.3. Longer term habitat use – seasonal movement patterns: from feeding to spawning ground?

This study has been performed on a small spatial scale within an OWF. Movement behaviour of Atlantic cod was investigated around two WARs from a wind farm with 54 turbines. If tagged fish were no longer detected, this only signified they were not present in the study area, but could still be present inside the OWF. However, we are convinced that the two WARs investigated are representative for the entire OWF, and this for several reasons: 1) Different sampling techniques demonstrate similar results as the present study. Both line fishing and visual observations with divers revealed seasonality in catch rates at the WARs Reubens et al. (2013a and unpublished data). During summer and autumn high catches of Atlantic cod were observed, while in winter catch rates/abundances were strongly reduced. 2) Recapture rates from an earlier tagging experiment at the WARs demonstrated that tagged Atlantic cod moved away from the WARs in winter. Recreational fishermen returned 5 of the 19 (26%) tagged fish. Most were caught in coastal areas, indicating spatial redistribution (J. Reubens: unpublished data). 3) The majority of the wind turbines (48 out of 54) in this wind farm investigated are jacket foundations without scour protection, while the study area was at turbines with gravity-based foundations. Preliminary results indicate that the jacket foundations are less attractive to Atlantic cod compared to the gravity-based foundations (J. Reubens: unpublished data).

Atlantic cod exhibited a clear seasonal pattern in presence. Fish were present at the WARs for an extended period of time during the summer. In autumn the numbers decreased and in winter time almost all fish had left the study area. Although some fish returned to the WARs, most were no longer encountered. Comparable results were found in an OWF in the Netherlands (Winter et al., 2010). Many of the tagged cod had left the OWF by winter, although some stayed throughout the winter season.

As mentioned before, Atlantic cod makes extensive migrations from feeding (i.e. in summer and autumn) to spawning grounds (i.e. in winter time) (Turner et al., 2002). To our knowledge however, there are no known spawning locations in the Belgian part of the North Sea and Righton et al. (2007) showed that Atlantic cod from the Southern Bight of the North Sea has some spawning areas along the coasts of the United Kingdom and the Netherlands. Thus, the seasonal pattern in presence at the WARs might be related to spawning migrations.

Only few of the tagged cod returned to the WARs in spring 2012. Fish may no longer be interested any more to this type of substrate due to changes in their life history behaviour. Predator–prey relationships alter with age, related to prey size preferences (Daan, 1973). Younger Atlantic cod mainly forage on smaller crustaceans (e.g. amphipods, small crabs) which are readily available at the WARs. Older individuals change to a fish dominated diet (Daan, 1973). In addition, older fish are less vulnerable to predation themselves as cannibalism and predation by other fish species does not longer occur. As a result, older Atlantic cod are less dependent of protective habitat.

For younger ages, predation dominates Atlantic cod mortality, while fishery takes over at older ages (Link et al., 2009). This might be the second reason for the low return rate after winter time. Inside the Belgian offshore wind farms no fishery activities are allowed, enhancing the survival rate of cod present in these areas. Once they left the areas, they are more vulnerable to fisheries (both commercial and recreational). Julliard et al. (2001) revealed that fisheries mortality of the 0-group Atlantic cod is negligible, but that it is high for older fish. More than 60% of the 2 to 4- year-old Atlantic cod in the North Sea are caught annually by fisheries (ICES, 2013). This indicates that fisheries mortality may influence fish survival considerably and may hence have artificially reduced the probability of fish to return to the wind farm after winter migration.

It can be concluded that Atlantic cod demonstrates strong residency and high individual detection rates during summer and autumn at the WARs investigated, which is probably related to the use of this habitat as feeding ground. Within the OWF, Atlantic cod shows distinct habitat selectivity behaviour and is strongly attracted towards the artificial hard substrates. In addition a seasonal pattern in presence at the WARs is observed. The high residency during summer and autumn alternates with a period of very low presence during winter time.

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