Residence time and behaviour of sole and cod in the Offshore Wind farm Egmond aan Zee (OWEZ)

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Summary

The Offshore Wind farm Egmond aan Zee (OWEZ) located 10-18 km off the coast comprises of 36 wind turbines with steel monopile foundations. The OWEZ was taken into operation in 2007. As part of a Monitoring and Evaluation Program (NSW-MEP), this study focuses on the behaviour of fish in response to the operation of the wind farm. Wind farms can have either negative or positive effects on fish, for instance by disturbance due to noise or by acting as a refuge because fisheries are banned within the wind farm. An important feature to determine if positive effects might occur is residence time. The longer individual fish spend in the wind farm, the stronger potential benefit of wind farms can be expected. To our knowledge this is the first study on individual behaviour of fish within wind farms.

To study the potential effects of wind farms on fish behaviour, we used two approaches: tagging experiments (mark-recapture) and telemetry experiments by following individual fish with small transmitters in time. We selected two target fish species that are important for fisheries: sole *Solea vulgaris* as a target species potentially representing fish that use sand habitats and Atlantic cod *Gadus morhua* as a target species potentially representing fish that use artificial reefs such as the monopile and scour bed habitats in the wind farm.

With tagging experiments with sole, we compared return rates of fish caught, tagged and released within the wind farm to return rates of fish caught, tagged and released in a reference area outside the wind farm. If individual residence time in the wind farm is larger, then a significant lower return rate is expected for the wind farm batch over the reference area batch. And in addition, a stronger difference is expected between return rates in the period directly following the release than at longer time intervals after release. Two paired tagging experiments were performed: 300 tagged sole (150 caught tagged and released in OWEZ and 150 in a reference area) in October 2007, and 800 (400 in OWEZ and reference area) in June 2008.

With telemetry experiments with sole and cod, we assessed individual residence time and individual behavioural patterns. During early 2008, different telemetric deployment methods were tested in the wind farm and found to be robust against severe winter storm conditions. In July 2008, professional divers installed an array of detection stations on the sea floor covering 16 out of 36 monopiles. In August 2008, transmitters were implanted in 40 sole (length range sole 25-34 cm), 40 cod in September 2008, and 7 cod in January 2009 (length range cod 22-46 cm, i.e. predominantly juveniles). In June-July 2009, all 16 detection stations could be retrieved and the telemetric data was extracted. We determined the duration between first and last detection in the wind farm for each fish as a proxy for individual residence time. We also determined the fraction of the time between first and last detection (detection rate). We compared detection rates as observed from fish with transmitters with as hypothesized for different behavioural scenarios: a) if random movement within the wind farm (associated expected detection rate would then be 7 %, i.e. detection area/wind farm area); b) if random movement occurred within the area where monopiles were present (expected detection rate: 14 %, i.e. detection area/wind turbine area); c) if strong attraction to the monopile habitats occurred (expected detection rate: 44 %, i.e. 16 out of 36 wind turbines covered with detection stations); or d) if extreme site fidelity occurred (expected detection rate: 100 %, i.e. stationary at catch and release site).

For tagged sole, there was no overall significant difference in return rate between OWEZ and reference area batches. Our combined results of the tagging and telemetry for sole indicate that the majority of movements take place at spatial scales larger than the wind farm area of OWEZ. Some individuals use the wind farm area for periods up to several weeks during the growing season, which indicates that there is no large scale avoidance of the wind turbines, at least in part of the sole population. On the other hand there were no indications found for attraction to the monopile habitats either. All of the individual soles showed detection rates well below the 44 % as expected when attraction to monopile habitats had indeed occurred.

For cod, as measured by telemetry, large variation in individual behaviour was observed. About 30 % of the cod were detected for only a few days after release and appeared to use spatial scales larger than the wind farm. About 55 % of the cod with transmitters were detected for several weeks to just over two months. About 15 % of cod with transmitters was detected in the wind farm for 8-9 months (the duration of the experiment). Individual detection rate averaged 46 %. Typically, cod stayed within a detection area for prolonged periods and sometimes switched to a different detection area within a short time interval. Cod staying within the wind farm showed clear

cyclic daily patterns that changed throughout the seasons. Our results show that at least part of the juvenile cod population spends long periods within the OWEZ. No larger adult cod were caught in the wind farm. Whether this is due to a difference in behaviour between juveniles and adults or due to the 'young' age of the wind farm (just over a year at the start of the telemetry experiments) and subsequent later development or colonization of a 'resident' adult cod population within the wind farm, can not be determined at this stage. We also compared presence of cod near monopiles prior, during and after events when wind turbines were temporarily out of order and found no evidence for disturbance by the operation of wind turbines. Moreover, there appears to be strong attraction to the newly created monopile habitats. Cod behaviour as observed in OWEZ in combination with the fact that all fisheries are banned within the wind farm, make it that the wind farm acts as a refuge against fisheries for at least part of the cod population.

Acknowledgement
The Off Shore wind Farm Egmond aan Zee has a subsidy of the Ministry of Economic Affairs under the CO2 Reduction Scheme of the Netherlands.

1 Introduction

'Noordzeewind' (a Nuon and Shell Wind Energy consortium) exploits a wind farm with 36 wind turbines off the coast of Egmond aan Zee: the Offshore Wind farm Egmond aan Zee (OWEZ). This project serves to evaluate the economical, technical, ecological and social effects of offshore wind farms in general. To gather knowledge which will result from this project, a Monitoring and Evaluation Program (NSW-MEP) has been developed. Knowledge on environmental impact gained by this project will be made available to all parties involved in the realization of large-scale offshore wind farms.

The construction and operation of offshore wind farms may result in possible negative impacts on fish populations, e.g. disturbance by noise or electromagnetic fields around cables, and consequent loss and degradation of habitats. On the other hand, due to the creation of new structures, i.e. additional habitats, that might act as artificial reefs or fish aggregation devices in combination with banning fisheries and shipping within wind farms, also positive impacts on fish populations are possible (Inger et al. 2009). In the latter case, wind farms might act as marine-protected areas or refuges for some fish species. The overall effect of the potential negative and positive impacts of the construction and operation of wind farms for fish is highly dependent on individual behavioural responses of fish to wind farms. To our knowledge this is the first study on individual behaviour of fish within wind farms.

In this study we focus on exploring the potential benefits of the wind farm OWEZ, i.e. whether the wind farm can act as a refuge against fisheries for some fish species, by studying individual behaviour of fish during the operation phase of the wind farm. A key factor in this is individual residence time of fish within the wind farm. The longer individual fish spend in the wind farm, the stronger potential benefit of wind farms can be expected. Two underlying behavioural scenarios might account for long individual residence times:

1) Small-scale individual movement (smaller scale than the wind farm area), indifferent to the newly created habitats or possible disturbances
2) Strong attraction to the newly created habitats despite noise and vibrations produced by wind turbines, i.e. by means that fish is not disturbed by the levels of noise or easily habituates to it

In scenario 2, the beneficial effect of wind farm acting as refuge against fisheries is expected to be higher than in scenario 1. In case of very short residence times also two behavioural scenarios might account for this:

3) Spatial movements take place on a much larger scale than the area of the wind farm but indifferent to the wind farm compared to other habitats, i.e. no disturbance takes place
4) Avoidance of areas near wind turbines or newly created habitats

To investigate fish behaviour in wind farms, we used two approaches: tagging experiments (mark-recapture) and telemetry experiments by following individual fish with small transmitters in time. Prior to these experiments we had to select the best suited methods and target species for both the tagging and telemetry experiments. For this, we analyzed the T_0 surveys and conducted pilot studies to test and sort out logistical, safety and methodological issues.

For the tagging experiment, we compared return rates of fish tagged within the wind farm with return rates of fish tagged in a reference area outside the wind farm. If individual residence time in the wind farm is large, a significant lower return rate is expected for the wind farm batch compared to the reference area batch. And in addition, a stronger difference is expected between return rates in the period directly following the release than at longer time intervals after release. If a difference is found in return rate between experimental groups (released within the wind farm versus released in a reference area outside the wind farm), then this directly reflects a difference in fishing mortality.

For the telemetry experiments, we assessed individual residence time and potential attraction of the newly created habitats. This was done by implanting telemetric transmitters into individual fish which can be detected by receiver stations placed on the seafloor near monopiles in the wind farm. From individual detection patterns throughout the seasons, we derived which type of behaviour most likely explained our observations.

In addition to this, if sufficient individual telemetric data would be obtained, individual behaviour and presence could be related to the operation of wind turbines. If the presence of fish around the wind turbines is a trade-off between attraction to the monopile habitats and avoidance due to disturbance related to the operation of turbines, e.g. noise or vibrations, then fish should have a higher preference for habitats near a wind turbine that is temporarily out of order compared to when a wind turbine is in operation.

From the differences in return rates from fisheries (tagging), behavioural patterns and assessed individual residence times (telemetry), we discuss whether beneficial effects of the wind farm can be expected for the fish species under study.

***Photo 1**. Two of the 36 wind turbines of the Offshore Wind farm near Egmond aan Zee (OWEZ) (Erwin Winter)*

2 Materials and Methods

2.1 Study area

The Offshore Wind farm off Egmond aan Zee (OWEZ) consists of 36 wind turbines, type Vestas V90 (3 MW). The wind farm is located west of Egmond aan Zee, 10 to 18 kilometers from the shore. Water depth varies between 17-20 m. Each wind turbine stands on a steel monopile foundation driven deep into the sea bed. The sea bed around each monopile is reinforced with a bed of small stones (ca 25 meter in diameter) covered by a smaller bed of large boulders (ca. 18 m in diameter). A yellow transition piece is mounted on this foundation. Attached to this transition piece are work platforms, ladders and a berthing facility for boats. Hub height of the wind turbines is 70 m. In the wind farm area and the safety zone around it (Figure 1) fisheries and shipping are forbidden. Only vessels with permits (mainly for inspection, maintenance, construction or research) are allowed within the wind farm. The wind farm area comprises 27 km^2 (Figure 1). The construction of the wind farm started in 2006 and was completed in December 2006. The operation of the wind park started officially in April 2007.

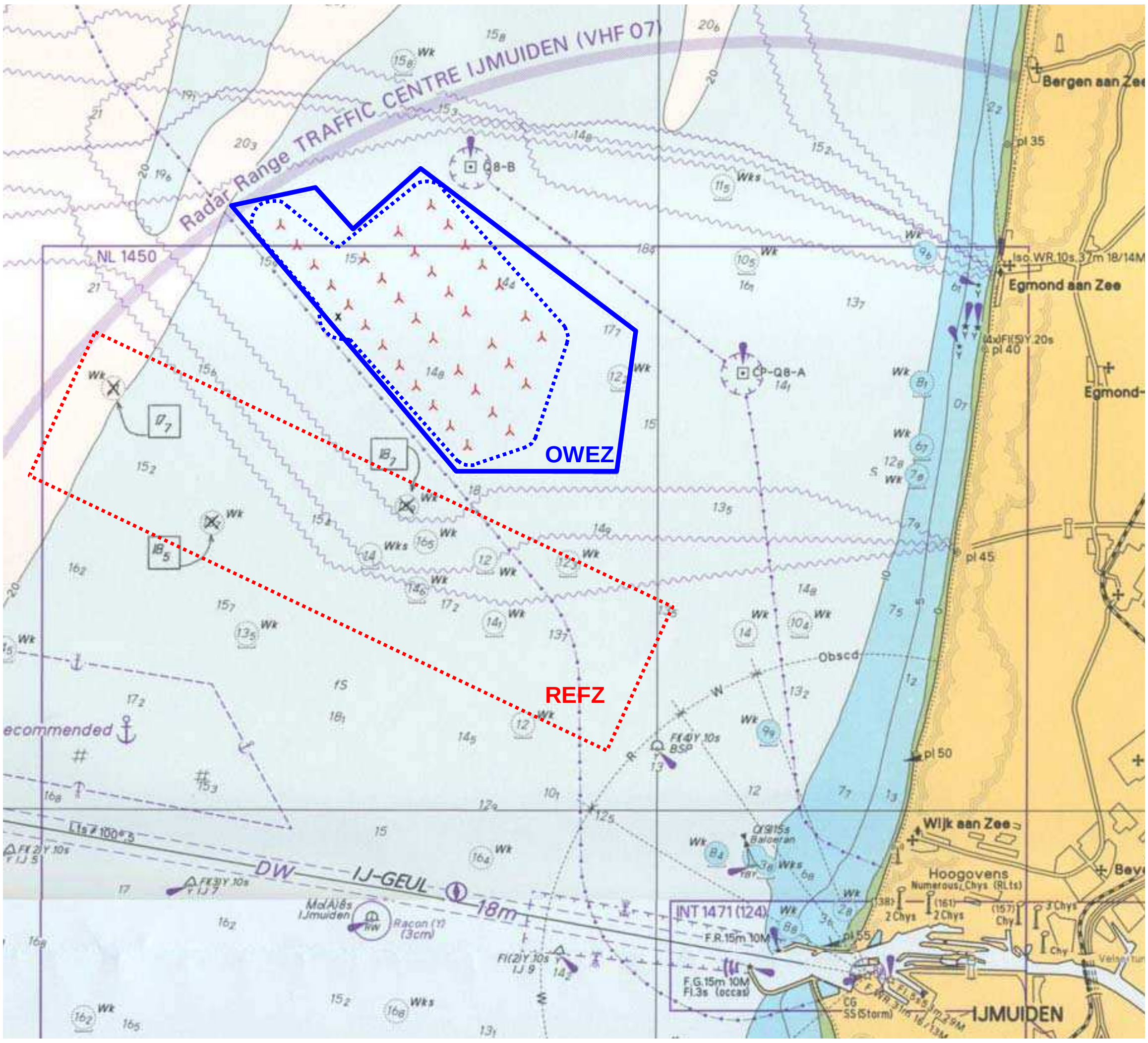

Figure 1*. Location of the Offshore Wind farm off Egmond aan Zee (OWEZ), with 36 wind turbines. Shipping and fishing within the wind farm area and the safety zone around it (marked by solid blue line) is only allowed with permits (mainly for inspection, maintenance, construction and research). The 500 m buffer zone ('wind turbine area') is indicated with the blue dotted line. The Reference area REFZ is indicated with a red dotted line.*

2.2 Tagging experiments

Prior to the set up of the conventional tagging (mark-recapture) experiments the following decisions had to be taken:

1. which species to use
2. which gears to apply to catch these species
3. which tagging method is best suited for the selected species and research questions

2.2.1 Species selection for the tagging experiment

For the choice of species used for the tagging experiment we used the following criteria:

1. The species has to be sufficiently abundant in the coastal areas around the OWEZ to enable sufficient numbers to be caught for the tagging experiment inside and outside the wind farm
2. The species has to be of commercial importance to maximize tag recapture and reporting by fishing vessels and to allow for the exploration of the effect of wind farms as a refuge against fisheries
3. The fish used for this experiment must be large enough to be suited for attaching tags and sizable for fisheries to land

First, the catch data of the T_0 trawl study (ter Hofstede, 2008) was used to identify target species that meet criteria 1-3. Plaice, dab and sole were the most common flatfish species in this study, while whiting was the most common roundfish species. Other flatfish species such as flounder, turbot and brill and roundfish species such as cod were caught in much lower numbers. Most plaice, sole, dab and whiting caught during the T_0 study were caught below minimum landings size (Table 1 and 2). Most individuals above minimum landing size were caught during the T_0 study for sole. For this species, more individuals were caught during the summer period than during winter. For dab and plaice, this holds true for some areas, but for other areas more individuals were caught during winter. Whiting however was caught in lower number compared to the flatfish species, and it was caught more in winter.

***Table 1**. Total number of fish caught above minimum landing size (sized) and below (under) of plaice, sole, dab, whiting and cod caught during the T_0 study for the wind farm (OWEZ) and three reference areas.*

		OWEZ		REFN		REFS		REFZ	
Species	**year**	**sized**	**under**	**Sized**	**under**	**sized**	**under**	**sized**	**under**
Plaice	2003	17	2877	14	12446	8	320	15	238
	2004	1	1316	0	2231	0	516	1	524
Sole	2003	32	184	99	658	36	111	5	16
	2004	0	9	2	72	0	6	0	3
Dab	2003	35	856	19	1968	4	243	32	353
	2004	34	951	33	1783	30	1525	34	713
Whiting	2003	0	23	0	26	0	0	0	13
	2004	16	442	5	50	1	4	3	5
Cod	2003	0	0	0	0	0	0	0	0
	2004	1	3	0	4	0	1	1	1

***Table 2**. Sampling effort in minutes during the T_0 study for the wind farm (OWEZ) and three reference areas.*

Year	OWEZ	REFN	REFS	REFZ
2003	315	225	70	120
2004	195	195	90	120

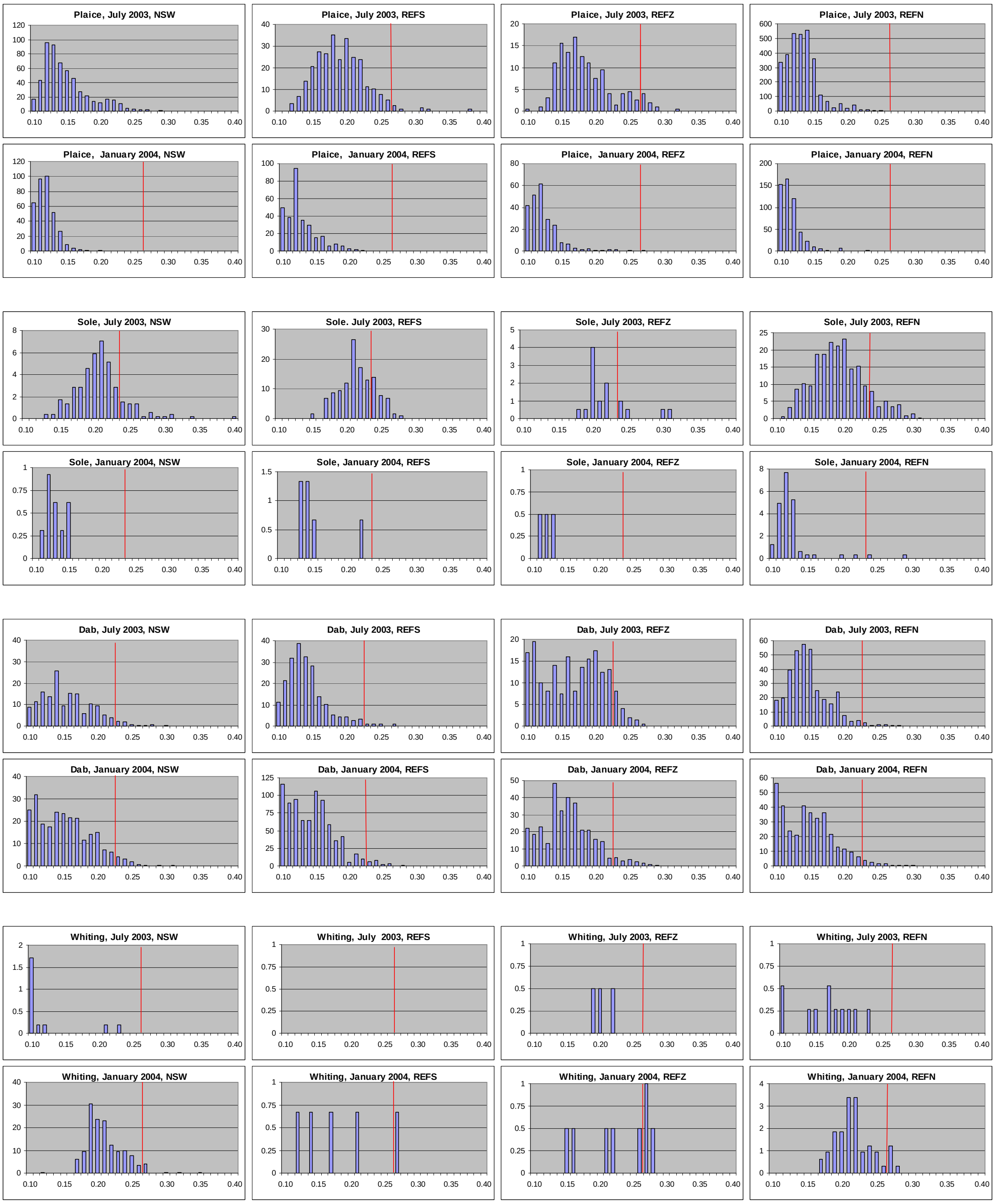

***Figure 2**. Numbers of plaice, sole, dab and whiting caught per hour per length class (in m) for the wind farm (OWEZ) and three reference areas during the July 2003 and January 2004 T_0 surveys. Red vertical line indicates minimum landing size for each species.*

From the T_0 surveys it is clear that the number of species that meet the criteria is small. The majority of the fish caught in and around the wind farm area are small juveniles that are unsuitable for tagging experiments because they are well below the minimum landing size (Figure 2). Only for the flatfish species plaice, sole and dab considerable numbers of individuals larger than the size limits were caught. Of these, dab is of lesser commercial interest. This leaves mainly plaice and sole as candidate target species for the tagging experiment. For these two species earlier tagging and telemetric studies were screened to take existing knowledge on spatial behaviour into consideration:

In the EU FAIR Project PL96-2079, the migration, distribution and spatial dynamics of plaice and sole in the North sea and adjacent areas was investigated, using tagging experiments (Anonymous, 2001). Results from this study are summarized below:

Migration patterns of juvenile plaice
Juvenile plaice did not participate in the seasonal migration pattern of the adults during their first year after tagging. Juvenile plaice was found more inshore than adult plaice. The recapture distributions in the spawning season clearly show that the general direction of movement was south to southwest for juvenile plaice released in the continental nurseries of the North Sea. The direction of displacement was different for juveniles released in the English nurseries. Most of the juveniles released in the Thames, Wash and Humber nurseries were recaptured north of the release position, both in the feeding season and in the spawning season.

Migration patterns of adult plaice
Plaice spawn in offshore waters to depths of approximately 50m, mainly in the region south of the Dogger Bank. The spawning season in the North Sea is around January-March. Recaptures revealed that for all North Sea regions except Flamborough, the majority of plaice caught in the spawning season were recaptured in the same region in which they were released. After the spawning season, adult North Sea plaice released at the spawning ground characteristically moved northwards, away from the release position during the feeding season, but would return to the vicinity of the release position the following spawning season. Most adult plaice tagged at the feeding grounds in the North Sea, showed a similar seasonal migration pattern.

Migration patterns of juvenile sole
Unlike juvenile plaice, all juvenile sole released in the nurseries participated in the seasonal migration pattern of the adults in their first year after tagging. For juveniles, the distribution of recaptures in the feeding and spawning season strongly resembled the distribution patterns observed in the adult experiments. Although the migration patterns observed in the juvenile and adult experiments off the east Anglian coast were similar, inshore migration in the spawning season was not evident in the adult experiment, but was visible in the juvenile experiment.

Migration patterns of adult sole
Sole spawns in coastal waters. Spawning season of sole is in April-June, which is later than for plaice. Generally they are distributed more south than plaice. Similar to plaice, the recapture rate of sole in the spawning season was generally highest in the region of release.. Along the Danish coast and in the German Bight, the adult spawning releases clearly show a seasonal migration pattern, with offshore movement in the feeding season and inshore movement in spawning season. This inshore-offshore movement observed in the eastern North Sea was not obvious in Southern Bight, where the distribution of recaptures was very similar, both in the spawning and feeding season. The dispersion of sole released on the continental side of the Southern Bight was low, both in the feeding season and the spawning season. In contrast to plaice, the sole recaptures showed no clear migration pattern during the feeding season. Most of the sole released in the western and eastern Southern Bight remained there. The majority of sole released in the Frisian Front and German Bight regions were recaptured in these two regions.

Conclusion on species selection for the tagging experiment
From above it was decided to use sole > 20 cm for the tagging experiment:

- Flatfish are much more common in the surveys than roundfish species
- Sole is a commercially important species for fisheries
- Adults are also relatively common in inshore areas at least during the feeding season
- Sole disperse at smaller scales than plaice, and may benefit more from restricted areas where fishing is banned such as the OWEZ wind farm
- For sole the minimum landing size is 24 cm. Particularly small sole (known as ‘slips’) are favoured by restaurants, and thus, fishermen will pay more attention to small sole which is equal or just above minimum landing size. Because the fish will grow during the experiment, it was decided to tag sole from 20 cm or larger.

2.2.2 Selection of catch methods for the tagging experiment

The best available method for collecting sufficient numbers of demersal fish species living near or in the sea bottom, such as sole, which temporarily buries itself into the sediment, appears to be using beam trawls. The haul duration need to be short (e.g. 15 min) to attain undamaged fish suitable for tagging. Past experiences with tagging sole caught in trawls with short haul duration showed good return rates (Anonymous, 2001, see further in 2.2.3).

2.2.3 Selection of tagging method

The EU FAIR Project (Anonymous, 2001) showed that for sole the return rate of conventional disc tags was 16% for the Dutch tagging experiment, while for the UK this was 23% (Table 3). For plaice the return rate was higher (NL 29%, UK 32%). The tagging methods with disc-tags used in this EU FAIR Project proved to be suitable for the target species (sole and plaice) and study area (the Southern North Sea). Therefore, this tagging method was selected for this project. An additional advantage is that the results obtained in our experiments could then also be compared with the results from the FAIR project.

***Table 3**. Tagged and recaptured plaice and sole available in a database in December 1997, used for the FAIR project from the former RIVO (now IMARES) and CEFAS (in Lowestoft, UK).*

	Plaice			**Sole**		
	Tagged	**Recapture**	**Return rate**	**Tagged**	**Recapture**	**Return rate**
RIVO/IMARES	148.794	43.264	29%	57.721	9.278	16%
CEFAS	41.292	13.217	32%	28.909	6.684	23%

2.2.4 Set up and procedures of the tagging experiments with sole

The set-up for the tagging experiment with sole consisted of a pair-wise comparison between the return rates of sole tagged within and outside the wind farm (Figure 3). If individual residence time of sole in the wind farm is large, then a significant lower return rate is expected for the wind farm batch over the reference area batch. Furthermore, if sole stays in the wind farm for prolonged times, a stronger difference is expected between return rates in the period directly following the release because tagged sole can only be caught by commercial fisheries outside the wind farm. Thus, the mark-recapture experiments detect if there is a difference in fishing mortality for both experimental groups. Not all tagged sole recaptured by fishermen will be detected and reported, which will result in an underestimation of the true fisheries mortality. However, it is expected that that the rate of underreporting does not differ between both experimental groups, since disc tags originating from both groups cannot be distinguished in the field.

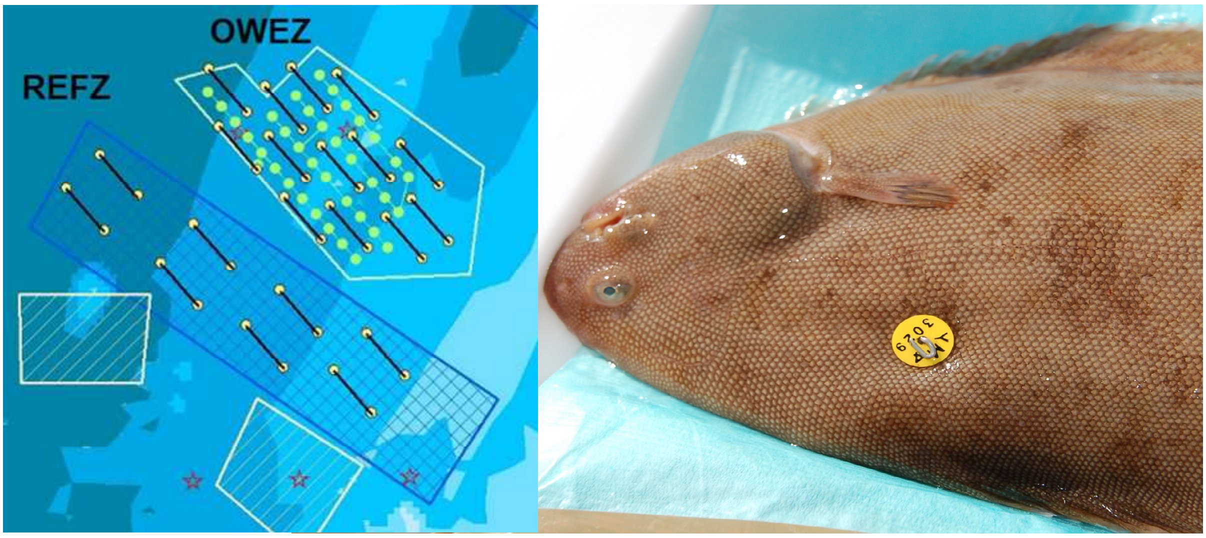

Figure 3. *Basic set-up of the tagging experiment (left) with disc tags (right). Batches of sole were caught and released inside (OWEZ) and outside (REFZ) the wind farm to test differences in tag return rates by fisheries for both groups. The black lines represent the trawl hauls (see table 4).*

To carry out the tagging experiments, the beam trawler GO58 was hired to catch sole with short hauls at fixed haul tracks for which fishing permits were given (Table 4). Two 6-metre long beams were used, from which a triangular purse-shaped net was towed over the seabed (Photo 2). The haul duration was 15 minutes with an average speed of 3.5 knots (~6.5 km h^{-1}) similar to earlier tagging experiments with sole within the EU-FAIR project (Anonymous 2001).

Photo 2. *The beam trawler GO58 (left, Erwin Winter) and the 6-m beam trawl (right, Olvin van Keeken) that was used for the tagging experiments with sole.*

The first batches were foreseen for June 2007, but due to adverse weather, only tagging of sole within the wind farm (n=634) could be carried out. It was then decided to perform two additional tagging experiments: On 25 and 26 October 2007, in total 300 sole were tagged; 150 in the wind farm, and 150 in the reference area. On 15 and 17 June 2008, in total 800 sole were tagged; 400 in the wind farm and 400 in the reference area. The start and end position of the hauls can be found in Table 4. All tagged sole were released in the vicinity of the catch track. Each sole was anaesthetized with 0.5 ml/l 2-phenoxy-ethanol, weighted, measured and a disc tag was inserted on the flank. Thereafter, sole were held in a large water tank with flowing sea water to recover from the anesthesia and released after ‘normal’ swimming behaviour resumed.

__Table 4__. The start and end positions of the trawling hauls for the tagging experiments in 2007-2008.

station	lat_s	lon_s	lat_h	lon_h
OWEZ01	52.6107	4.3797	52.6258	4.3603
OWEZ02	52.5772	4.4237	52.5892	4.4083
OWEZ03	52.6292	4.3712	52.6162	4.3990
OWEZ04	52.6103	4.3937	52.5977	4.4178
OWEZ05	52.5818	4.4377	52.5937	4.4238
OWEZ06	52.6183	4.4067	52.6293	4.3895
OWEZ07	52.5983	4.4343	52.6100	4.4185
OWEZ08	52.5790	4.4600	52.5918	4.4443
OWEZ09	52.6322	4.4097	52.6195	4.4243
OWEZ10	52.6060	4.4457	52.6180	4.4275
OWEZ11	52.5818	4.4757	52.5943	4.4615
OWEZ12	52.6195	4.4438	52.6308	4.4260
OWEZ13	52.6073	4.4615	52.6193	4.4447
REFZ01	52.5977	4.3013	52.5852	4.3188
REFZ02	52.5670	4.3507	52.5802	4.3333
REFZ03	52.5480	4.3992	52.5567	4.3810
REFZ04	52.5720	4.3710	52.5875	4.3563
REFZ05	52.5350	4.4347	52.5430	4.4120
REFZ06	52.6000	4.3343	52.6060	4.3047
REFZ07	52.5685	4.3945	52.5563	4.4100
REFZ08	52.5480	4.4428	52.5333	4.4603

2.2.5 Data treatment and analysis of the tagging experiments

All tags returned to IMARES up to December 2009 were used in the analyses. For each returned disc tag, if possible, catch date, catch position and measurements on the recaptured sole were collected, although not all these parameters were available for each returned tag. For all recaptures with known catch dates, the cumulative number of recaptures was plotted to determine differences in timing of returns between groups. All recaptured sole with known catch position were plotted to explore potential differences in the spatial distribution of recaptures between periods and groups. To test for statistical differences in return rate between groups and periods, we used the 2x2 G-test of independence ($p < 0.05$, df=1) and William's correction factor (Sokal & Rohlf, 1995). This G-test of Independence tests the goodness of fit of observed frequencies against the expected frequencies under the null-hypothesis that the return frequency of the OWEZ group does not differ from the return frequencies of the reference group.

2.3 Telemetry experiments

To study individual behaviour of fish during long periods in response to the wind farm and newly created habitats near the wind turbines, telemetry is the best available research method. Prior to the set up of the telemetry experiments the following decisions had to be made:

1. which species to be used for telemetry (see criteria for species selection in 2.2.1)
2. which gears are suitable to catch these species
3. what methodology will be best suited for telemetric research with the selected species
4. which deployment of telemetric equipment and set-up of the array is best suited given logistic, environmental and safety constraints within the wind farm

2.3.1 Species selection for the telemetry experiments

Based on surveys within T_0 and literature and the above mentioned criteria:

1a. The species have to be sufficiently abundant in the coastal areas
1b. The species have to be of commercial importance to ensure reporting of caught tags
1c. The fish used for this experiment must be above a certain size limit

In this telemetric study we explore potential benefits of the wind farm OWEZ. In other words, can the wind farm act as a refuge against fisheries for some fish species. A key factor in this is individual residence time of fish within the wind farm. The longer individual fish spend in the wind farm, the stronger potential benefit of wind farms can be expected. Two underlying behavioural scenarios might account for long individual residence times:

1) Individual movements on small spatial scales (smaller than the scale of the wind farm area), but indifferent to the newly created habitats or possible disturbances
2) Strong attraction to the newly created habitats despite noise and vibrations produced by wind turbines, i.e. by means that fish is not disturbed by the levels of noise or easily habituates to it

In scenario 2), the beneficial effect of wind farm acting as refuge against fisheries are expected to be higher on the population level than in scenario 1). Based on species-specific knowledge on habitat and spatial use, ideally species representing each of the two potential behavioural scenario are selected. However, since knowledge on how fish use wind farms is largely lacking, no a priory certainty for this could be obtained.

Sole *Solea vulgaris* was selected as the target species for telemetry being a potential candidate using the sand habitats in the wind farm for prolonged periods (scenario 2). Moreover, since this species was also selected as a target species for the T_1 tagging experiments (2.2.1) this enables to cross check findings from the tagging experiments with the telemetry results. Both methods yield different perspectives on the behaviour and exposure to fisheries that combined might strengthen each other.

Cod *Gadus morhua* was selected as the preferred target species for telemetry being a potential candidate to use the newly created habitats within the wind farm: i.e. the monopiles and artificial stone habitats directly around each monopile. Cod is known to show high site fidelity for at least part of the population and part of the year (Righton et al. 2001, Lindholm et al. 2007) and shows attraction to artificial reefs such as ship wrecks.

2.3.2 Selection of catching methods for the telemetry experiments

For sole, the best available method for catching this demersal fish species living near or in the sea bottom, is using beam trawls (see 2.2.2).

For cod, the catch method mostly used in other telemetry experiments to get undamaged live individuals from rocky habitats is by line and rod (Righton et al. 2001, Righton et al. 2006, Nichol & Chilton 2006, Lindholm et al. 2007). However, due to safety regulations within the wind farm this was assessed as a less desirable method due to the potential loss of hooks and lines around the monopiles. Lost hooks and lines could be a potential danger for divers working on the monopiles.

Therefore, as an alternative, baited traps were selected as the preferred method to catch cod for the telemetry experiments (Figure 4). Experiences with baited traps to catch cod in Norway and pacific cod in Alaska appeared promising (Nichol & Chilton 2006). The traps are baited to attract fish and lure them to enter the trap. Depending on the buoyancy attached to the top of the trap and weights attached to the bottom of the trap, these traps can fish at all depths. The traps were installed to passively fish for hours and retrieved later. If, unexpectedly, these traps fail to catch cod in sufficient numbers and sizes, but do catch other round fish of commercial interest and potential attraction behaviour to artificial reef like habitats such as whiting or sea bass, one of these species might be selected for the telemetric experiments instead. On forehand, it is difficult to predict the catch composition of the baited traps in the newly created habitats in the wind farm.

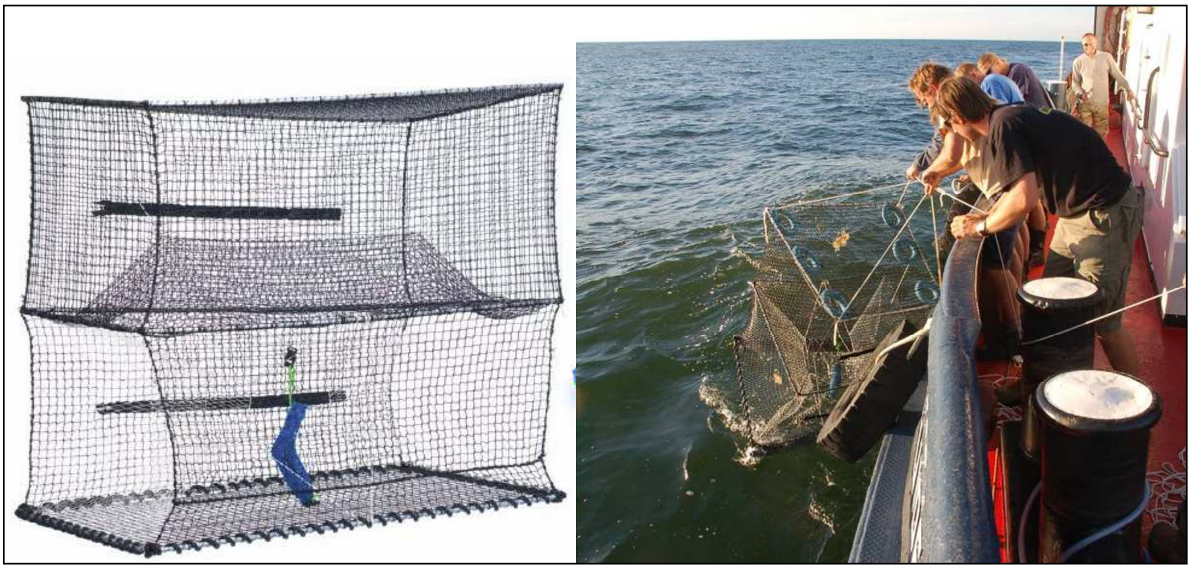

***Figure 4**. Baited life traps selected for catching cod directly around the wind turbines: bait will be placed in the blue socket. Weights will be attached to the bottom of the trap and buoyancy will be added to the top of the trap.*

2.3.3 Selection of telemetric method

Because of the relatively large water depths (17-20 m) and the saltwater environment, radio-telemetry and transponder-telemetry are unsuitable. Acoustic telemetry is best suited for the environmental conditions and purposes of the T_1 telemetry study (Jepsen et al. 2002). Based on experiences from foreign research institutes and comparison between different manufacturers, the VEMCO VR2-method was selected to be best suited for our study. This method is based on VR2-receivers that are placed within the wind farm. The detection range depends upon the used type of transmitters ranging from 100-500 m per receiver. These receivers act as data loggers detecting the presence of transmitters within its detection range throughout the duration of the experiment and need to be retrieved after the experiment has been ended. Battery life of the receivers is approximately 15 months. The exact configuration of the array of receivers was determined after the outcome of field tests and pilot studies in the wind farm with different deployment methods. Given the size of sole and round fish in previous surveys in the wind farm area, the small sized V7-2L transmitter was selected. When programmed to transmit a signal at random intervals between 150-300 s, minimum battery life of the transmitters is guaranteed by VEMCO for 269 days.

2.3.4 Pilot studies to test receiver deployment

All proposed options for using anchors, weights and ropes in combination with buoys or attachment to the platform on the monopile were not approved due to safety regulations. On forehand these methods were considered to be the best available given experiences in other studies in Norway, New Zealand and USA. In stead, alternative attachment methods were discussed with NoordzeeWind and external experts. It was decided that the only available option was using professional divers to attach the receivers on either the J-tube or with a anchored pole (‘suction anchor’) just outside the stone bed on the bottom around the monopiles (Figure 5). Attaching the receiver to the J-tube has the benefit of being more easy and costing less diving time, but the disadvantage is that it probably created a ‘dead angle’ in the detection area due to the ‘shadow’ of the monopile.

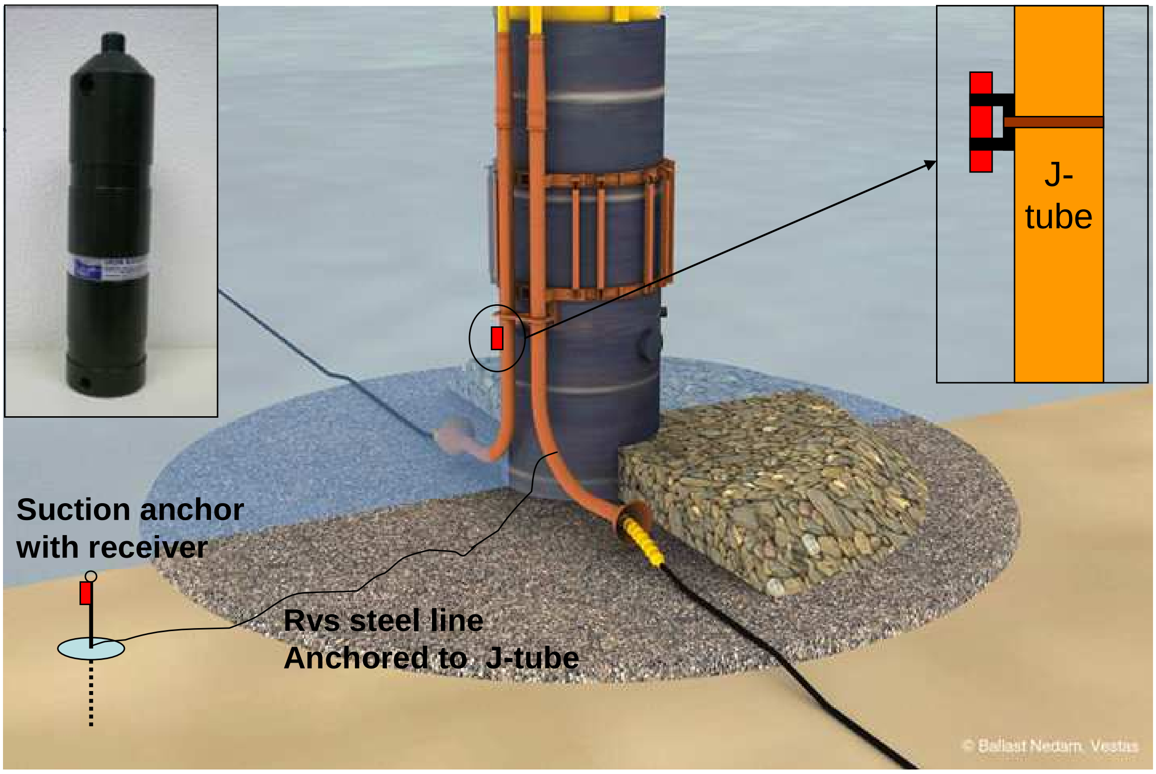

Figure 5. *Two different attachment methods for VEMCO VR2 receivers (top left) near the wind turbines: 1) attached to the J-tube, 2) by using an anchored pole ('suction anchor') just outside the stone bed. A stainless steel cable will be used to secure the 'suction anchor' to the windmill pole to make it easier to find for divers.*

The field test / pilot study was carried out at 2 wind turbines and aimed to test:

a. the performance of the receivers (measure detection range, 'dead angles'),
b. the practicality of each attachment method,
c. the robustness of the deployment method against the currents and field conditions,
d. how much time and effort is needed to install and retrieve a receiver in relation to tidal cycles (needed for planning the full array),

This field test was carried out during February-April 2008 with the vessel Pollux and a five men diving crew from Wals Diving & Marine Service (photo 3). On 18 February 2008, one receiver mounted on a suction anchor and one mounted on the J-tube was installed by professional divers at the monopiles WT13 and WT34 during slack tide. The suction anchor was a 3.5 m stainless steel pole that was driven into the seabed for 2 m by using a lance inserted in the pole blowing compressed air. At 2 m a stainless steel plate was made on the suction anchor resting on the seabed to minimize the effects of erosion around the pole. The VR2 receiver was mounted on the 1.5 m pole standing up from the seabed, about 10-15 m outside the stone scour bed surrounding the monopole. A stainless steel cable resting on the sea floor connected the suction anchor to the J-tube to enable easier finding of the suction anchor during retrieval of the receiver. The connection between the stainless steel and J-tube was made of nylon rope to prevent unwanted side-effects due to the electro-magnetic field surrounding the J-tube. The receiver on the J-tube itself was mounted on a holding clam using tie ribs and a stainless steel metal band. On 19 February, test measurements were carried out from the vessel Pollux and in cooperation with Wals Diving & Marine Service using a Rigid Inflatable Boat (RIB) with test V7 transmitters and test receivers to test range and coverage of the receivers.

On 11 April 2008 the receivers were retrieved by using the vessel Pollux and a five men diving crew from Wals Diving & Marine Service. All four receivers functioned very well during the entire test period and the deployment method appeared to be robust enough to withstand two severe storms that took place during the test period. Tests with a submerged transmitter sailed with a RIB in circles (from 30 to 150 m) around the windmill pole yielded 25% more detections for the receiver placed on the suction anchor than for the receiver attached to the J-tube due to a larger 'dead angle' for the latter. It was therefore decided that for the final experiment the array would be build with receivers attached to suction anchors placed just outside the stone scour bed. The test receiver was detected over maximum distances using V7 test transmitters varying between 200-300 m in different trials.

Photo 3. *The tug vessel Pollux (left, Erwin Winter) and diver climbing on board after retrieving receivers (right, Erwin Winter)*

2.3.5 Pilot study with baited traps for cod and testing a release device

The practical handling of the baited traps were tested in a basin and thereafter in the field. The handling, placing and robustness of the traps in the field conditions were tested during the retrieval of the test receivers in April 2008. During the installation of the array of detection stations in July 2008, several trials with baited cages were carried out (Table 5). Because the first 3 trials produces only few cod, and the cages might potentially be pushed flat by the tidal currents, a different setting of the cage with tubes to keep the cages fixed in an open position was tested in addition. However, also these trials produced only few cod. There was no difference between the fixed and original setting. Cages set for up to 19.5 hours all caught zero cod, whereas cages set for 29 hours caught 3-6 cod per cage. Next to cod, only few Bull-rout *Myoxocephalus scorpius* and Pouting *Trisopterus luscus* were caught. Neither of the two species met the criteria set for selecting target species for the telemetry experiments.

Table 5. *Test trials with baited cages in an original setting and in a fixed setting with tubes so that tidal currents could not change the shape of the cage.*

Windmill	Type cage	Date setting	Time	Date hauling	Time	Hours fished	n cod
WT27	original	06/07/2008	12:00	06/07/2008	16:30	4.5	0
WT19	original	24/07/2008	13:00	25/07/2008	18:00	29.0	6
WT17	original	25/07/2008	20:00	26/07/2008	07:00	11.0	0
WT17	fixed	25/07/2008	20:00	26/07/2008	07:00	11.0	0
WT24	original	26/07/2008	08:30	27/07/2008	13:30	29.0	3
WT24	fixed	26/07/2008	08:30	27/07/2008	13:30	29.0	4
WT2	original	27/07/2008	15:00	28/07/2008	10:30	19.5	0
WT2	fixed	27/07/2008	15:00	28/07/2008	10:30	19.5	0

The disappointing results with the baited cages could mean two things: 1) the baited cages were suitable to catch cod, but only very few were present around the monopiles or 2) there were more than sufficient numbers of cod present around the monopiles but the catch efficiency of the baited traps for cod was low. To distinguish between these two scenarios, it was decided to use rod and line with pilkers to try to catch cod directly above the scour bed around the monopile, since the diving team was standby during the trials to remove eventual hook and lines that got stuck to rocks. It turned out that with 3 rods in only a few hours 20-40 cod could be caught above the scour bed at a given monopile. Thus, the catch efficiency of the baited cages proved to be small. Together with NoordzeeWind it was then decided that catching cod with rod and line was selected as the catch method to be used under the condition that a diving team was standby to remove hooks and lines that got stuck to the scour bed around the monopile. An extra advantage of catching cod by rod and line over baited cages, was that the time between catch, treatment and release would be much smaller, reducing potential stress and disturbance.

To prevent tagged fish from drifting with the water current after release, we developed a release 'tube' that enabled us to release the tagged fish near the seafloor where they were caught. The fish were placed in the tube and both entrances were closed. Then the device was lowered to the seafloor where the lids on both ends were opened. The open tube is then hauled up in such a way that it positions at an angle, forcing the fish to easily 'slip' out of the device near the seafloor. This device was tested during July 2009 field work (photo 4).

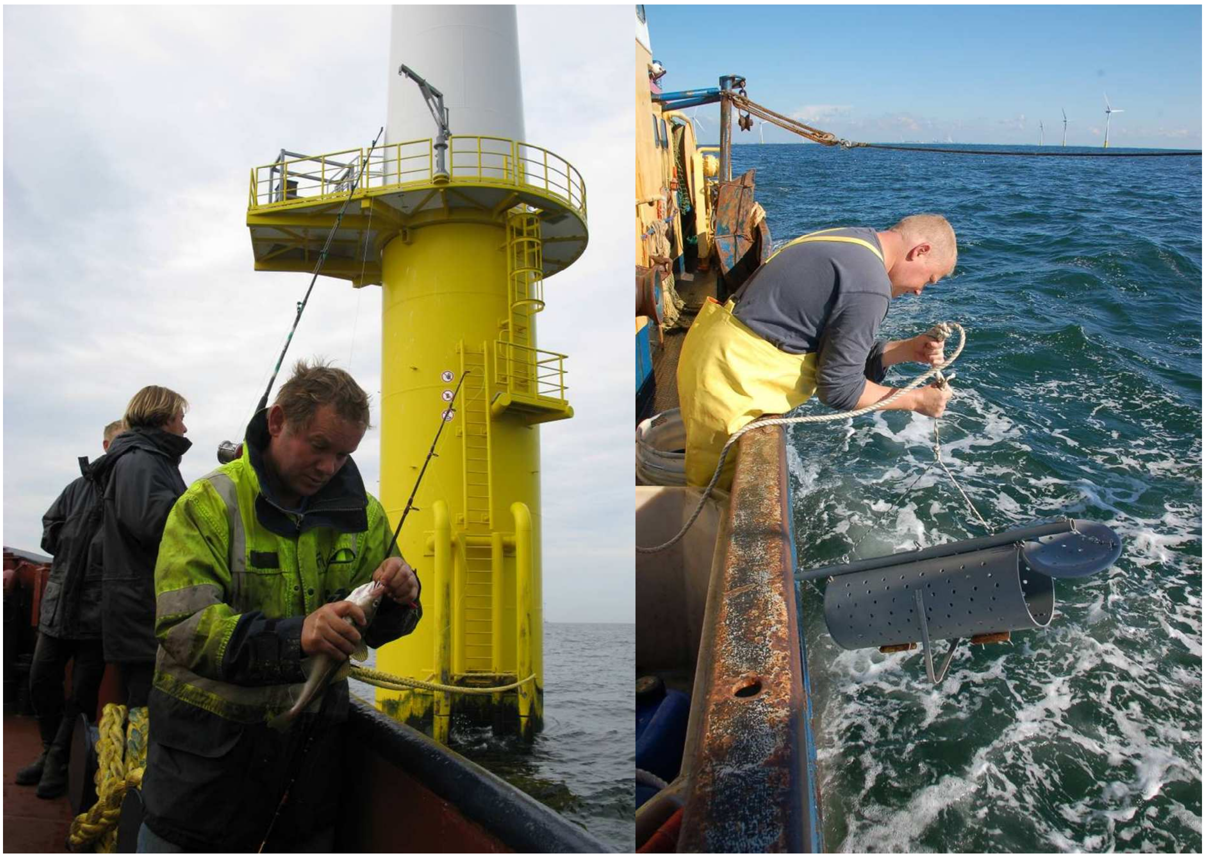

Photo 4. *Catching cod above the scour bed with rod and line (left, Joep de Leeuw) and the release device we developed being hauled aboard after fish was released near the sea floor (right, Erwin Winter)*

2.3.6 Experimental set-up, placing and retrieval of the detection stations

Experimental set-up of the array of detection stations

For logistical reasons (only two detection stations per day can be placed during slack tide by a diving crew), for safety regulations (no buoys or lines were admitted within the park), and for weather conditions needed to carry out the diving work (maximum allowable wave height well below 1 m), it was not feasible to cover each monopile with a detection station, nor to place detection stations in areas in between monopiles. It was therefore decided to cover 16 out of 36 monopiles with detection stations, for which 8 working days with favourable weather conditions would be required, which was assessed to be possible to complete within a time frame of maximum two months. For the set-up of the array of detection stations, the wind farm was divided in two sections; one area in the North where at all 9 monopiles detection stations were placed, and 7 were placed at random among the 27 monopiles in the remaining part of the wind farm (Figure 6). This allows two levels of analyses, small scale movements can be detected within the 3x3 monopile square and large scale movements within the wind farm can be followed using all detection stations.

In addition, two arrays of 8 test transmitters were placed at regular intervals in between two sets of monopiles to measure detection range in situ during the telemetry experiment. Together with NoordzeeWind and Vestas and based on the cable-map and foreseen works in the coming year it was decided that the planned placing of two arrays of test transmitters was best along the line WT1-WT12 (because no works on the power cable were foreseen here for the coming year) and between WT26-WT27 (because no power cable is present here). It was therefore decided to make two adjustments to the initial setup that followed by the initial random appointment: WT26 in stead of WT33; and WT3 in stead of WT6. This made it possible to place the arrays of test transmitters in between WT2-WT34 and WT26-WT27.

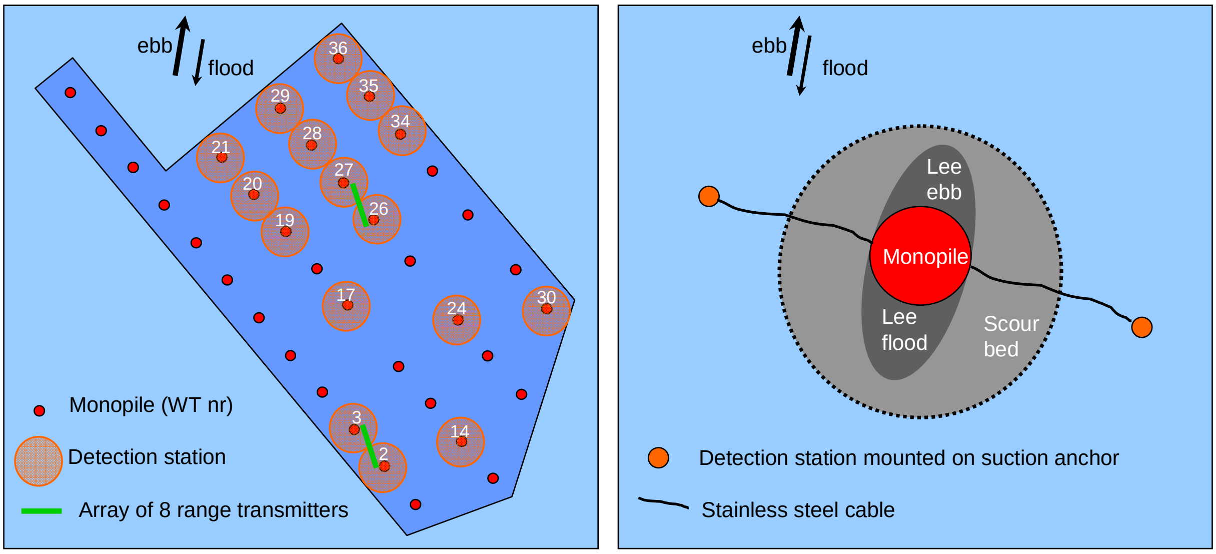

***Figure 6**. Experimental set-up of the array of detections stations and continuous range measurements by arrays of test transmitters (left). Each receiver was placed in an angle of 90° to the direction of the tidal currents. This will maximize the chance of detecting fish with transmitters in case they were 'resting' in the lower water velocities on the lee side of the monopile during either ebb or flood currents (right, showing the 2 potential positions of receiver placement that we favoured). A cable connecting the J-tube to the suction anchor was used to make finding the detection station by divers more easy*

Placing of the detection stations (July 2008)
With the vessel Pollux and a 5 men diving crew from Wals Diving, we placed 16 acoustic receivers in the OWEZ in July 2008. These receivers were mounted on suction anchors placed in the seabed just next to the scour bed. The placing took 9 days in total. 6 receivers were placed between 3 and 6 July 2008, when due to adverse weather conditions the work had to be stopped. The remaining 16 receivers could be placed between 24 and 28 July (see Table 6 for details on timing and placing). Battery life of the receivers was guaranteed for at least 12 months after the installment (usually around 15 months).

*Deployment of 2 arrays of 8 transmitters for in situ range-testing***.**
In between WT2-WT3 and WT26-WT27, 8 transmitters per array were lowered on the seabed during 19-20 September 2009. Each transmitter was attached to a 1 m rope connecting a 5-10 kg weight and 15 cm popup-float and were placed using a RIB with the Pollux standby nearby. Positioning was done by means of hand-GPS.

The weight with the short 1 m rope and small 15 cm diameter popup float was set overboard to sink down to the seabed. These transmitters enable continuous measurement of the detection range throughout the telemetry experiment. The small weights with popup float did not need to be recovered and could be left on the seabed after completion of the experiment.

Table 6. *Timing of the placing of 16 recievers in the OWEZ during July 2008 per windmill, serial number of receiver placed, direction of the placing relative to the windmill pole (at 20-28 m from the J-tube) and estimated digital lat-long position of each receiver.*

Placing of Vemco VR2 recievers in the OWEZ, July 2008						Receiver position	
Day	**Date**	**Time**	**Pole nr**	**Reciever**	**Placing**	**Latitude N**	**Longitude E**
1	03/07/2008	14:30	WT34	102054	NW	52.62278	4.43094
2	04/07/2008	15:00	WT35	102053	NW	52.62722	4.42481
2	04/07/2008	21:45	WT36	102052	NW	52.63162	4.41868
3	05/07/2008	16:00	WT29	102056	SE	52.62560	4.40807
4	06/07/2008	10:30	WT28	102058	SE	52.62123	4.41430
4	06/07/2008	16:45	WT27	102060	SE	52.61681	4.42044
5	24/07/2008	12:00	WT21	102057	SE	52.61983	4.39682
5	24/07/2008	18:00	WT20	102059	SE	52.61543	4.40298
6	25/07/2008	13:15	WT26	102055	SE	52.61256	4.42578
6	25/07/2008	19:15	WT19	102061	SE	52.61098	4.40912
7	26/07/2008	7:30	WT17	102062	SE	52.60215	4.42137
7	26/07/2008	13:15	WT30	103669	NW	52.60211	4.45957
8	27/07/2008	8:30	WT3	102063	NW	52.58740	4.42245
8	27/07/2008	14:15	WT24	103670	SE	52.60056	4.44292
9	28/07/2008	9:30	WT14	103671	SE	52.58622	4.44345
9	28/07/2008	15:15	WT2	103672	SE	52.58331	4.42774

Table 7. *Positions of the 2x 8 transmitter arrays in between WT2-WT3 (total distance between poles 579m), and WT26-WT27 (total distance between poles 595m).*

Distance to receiver WT3 (m)	Distance to receiver WT2 (m)	Position N	Position E	Tag
50	529	52.58706	4.42292	16280
100	479	52.58670	4.42335	16281
150	429	52.58635	4.42383	16282
200	379	52.58600	4.42428	16283
250	329	52.58563	4.42473	16284
300	279	52.58527	4.42519	16285
350	229	52.58494	4.42565	16286
400	179	52.58458	4.42611	16287

Distance to receiver WT26 (m)	Distance to receiver WT27 (m)	Position N	Position E	Tag
50	545	52.61292	4.42534	16288
100	495	52.61327	4.42490	16289
150	445	52.61363	4.42444	16290
200	395	52.61398	4.42399	16291
250	345	52.61434	4.42354	16292
300	295	52.61470	4.42309	16293
350	245	52.61505	4.42265	16294
400	195	52.61541	4.42220	16295

Retrieval of the detection stations (summer 2009)
Initially, it was foreseen to retrieve the detection stations before severe winter storms occurred and follow fish behaviour only during the feeding season, because on forehand the risk of losing some of the detection stations and therefore the datasets they contained was considered too high. However, as a result of the successful pilot during February-April 2008 when several severe storms did not result in the loss of any detection station, NoordzeeWind decided that the full length of the battery life of detection stations (1 year) could be used. Thus, the retrieval of the detection stations was rescheduled for June-August 2009 instead of autumn 2008, allowing us to study fish behaviour in the windfarm for a prolonged period during different seasons.

During 25 June - 2 July 2009 weather conditions were favourable on eight consecutive working days and allowed us to retrieve the detection stations and suction anchors by using the tug vessel Zeeland and a five men diving team from Wals Diving & Marine Service. Most of the stainless steel cables were torn apart in the scour bed indicating severe forces there (perhaps by rolling or moving stones during severe storms), or disappeared due to erosion of the connection, which somewhat delayed finding the suction anchors with receivers. Nevertheless all 16 receivers were retrieved in good working order after being present on the sea floor for nearly a year. All receivers contained detection data which combined with the fact that they were are still active when retrieved suggests that no data have been lost. On board, all the data was directly retrieved from the receivers with VUE software from VEMCO.

The data for the test transmitters for determining detection range in situ showed that some transmitters were lost during the course of the year, possible by being moved due to waves during severe storms, as indicated by the timing of the loss that coincided with strong wind periods in October-November 2008. The measurements during the first week following placement of the arrays was considered to be the best reliable range test. For each of the four receivers we determined detection efficiency in relation to the distance from the receiver. Each transmitter had a transmit interval randomly varying from 300-600 s with an average interval between transmits of 450 s. For the first week total number of detections for each transmitter and receiver was divided by total number of transmits to determine detection efficiency. For 3 receivers, detection efficiency showed a similar distribution where 80% detection efficiency was reached at 180-200 m distance (Figure 7). One receiver (WT26) showed a somewhat lower detection efficiency than the other 3.

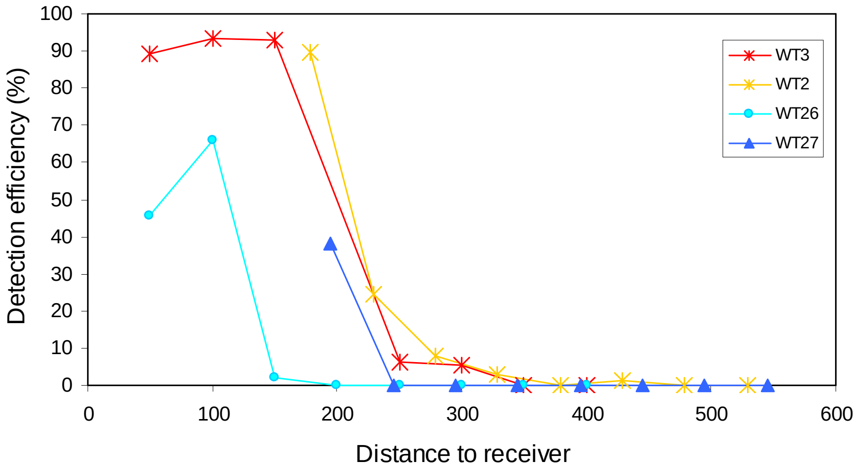

Figure 7. *Detection efficiency of the 2 arrays of 8 transmitters in between WT2-WT3 and WT26-WT27.*

2.3.7 Catch, implanting transmitters and release of sole and cod

On 15 August 2008, sole were caught within the wind farm with the beam trawler GO58 (see 2.2.4 for details on catch tracks, gears and method). In total 40 sole were anaesthetized with 0.5 ml/l 2-phenoxy-ethanol, weighted, measured, surgically implanted with a V7 VEMCO transmitter into the body cavity by making a small incision < 7 mm and placing a suture to close the wound. A disc tag was inserted on the flank. Thereafter, the tagged sole were held in a large water tank with flowing sea water to recover from the anesthesia and after 'normal' swimming behaviour resumed, they were released with the release device near the sea floor at four different sites (Figure 8).

On 19 and 20 September 2008, 40 cod were caught by rod and line, and implanted with transmitters using the same telemetric method and surgical procedure as for sole. Because disc-tags can not be used for round fish, we used Floy tags inserted just below the dorsal fin to enable recognition in case cod implanted with transmitters were recapture by fishermen. Cod were caught, tagged and released at 4 different sites (Figure 8). They were reeled in very slowly to minimize barotrauma (Lindholm et al. 2007). Only cod without any signs of barotrauma were used for the telemetry experiment.

***Photo 5**. Surgical implantation of transmitters into the body cavity of an anaesthetized sole (left, André Dulkes) and sole after implantation of a transmitter and deployment of a disc tag (right, Erwin Winter).*

Because no *a priory* knowledge on the use of wind farms by cod was available, the possibility exists that all cod released in summer 2008 emigrated from the wind farm during the growing season and that no data would be collected on behaviour of cod in the wind farm for other seasons. Moreover, cod present in the windfarm during the growing season might be other individuals than cod present during the wintering season, and potentially have different behaviour or residence times in different seasons. Therefore, NoordzeeWind made extra funding available to catch, implant with transmitters and release an additional 40 cod during winter 2009, to increase the chance to study cod behaviour during different seasons. However, despite intensive rod fishing from the Pollux with a diving team from Wals Diving & Marine Service standby on 9 - 10 January 2009, only 7 cod suitable for implanting a transmitter were caught at 2 sites (Figure 8).

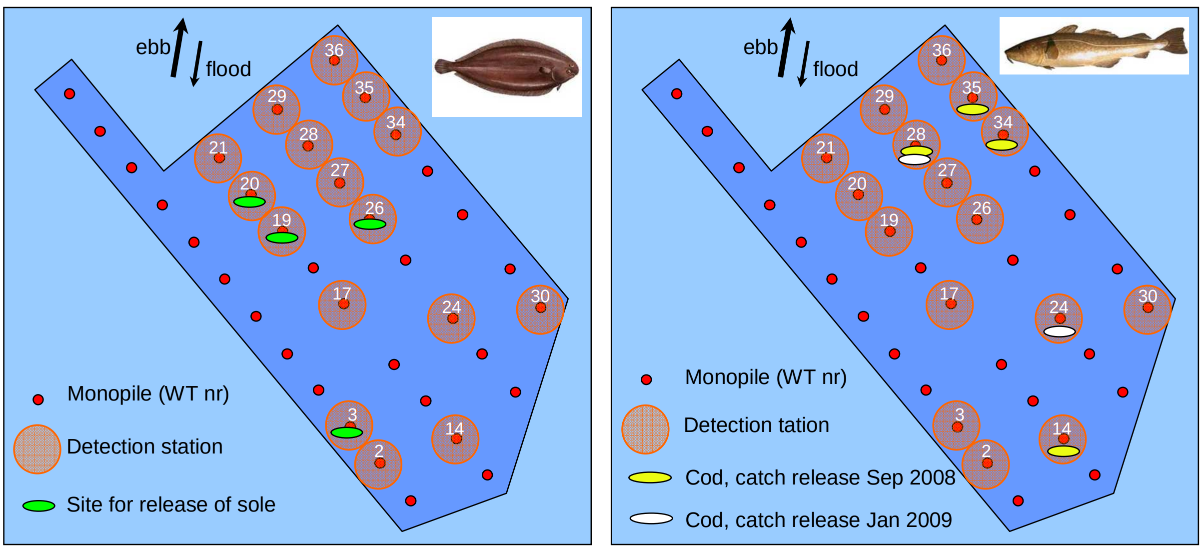

***Figure 8**. Catch and release sites for the telemetry experiments as used for 40 sole on 15 August 2008, for 40 cod on 19-20 September 2008 and for 7 cod on 9-10 January 2009.*

2.3.8 Data treatment and analysis of the telemetric experiments

Detections

The V7 transmitters were programmed to transmit a unique identification code at random intervals ranging from 150 to 300 s. This random interval reduces the chance that two signals of two simultaneously present fish collide and produce a 'ghost'-ID number.

As a proxy for individual residence time we used 'time at-large' (the time period from the first detection to the last detection) for each fish implanted with a transmitter (Lindholm et al. 2007). To calculate individual detection rates, we assigned each detection to 1 hour bins (e.g. from 00:00:00 to 00:59:59 to bin 1), according to Lindholm et al. (2007). Individual detection rate was defined as the number of hour bins that a fish was detected as a fraction of the total time at-large within the wind farm. Because detection efficiency at close range is not 100 % (Figure 7), and fish might temporarily be obscured by rocks or in the 'shadow' of a monopole, using hour bins as a base for detection rates is presumably more accurate. We plotted individual detection rate during individual time at-large, and calculated average detection rate for different groups. These were compared to expected detection rates of four different hypothesized behavioural scenarios (Figure 9).

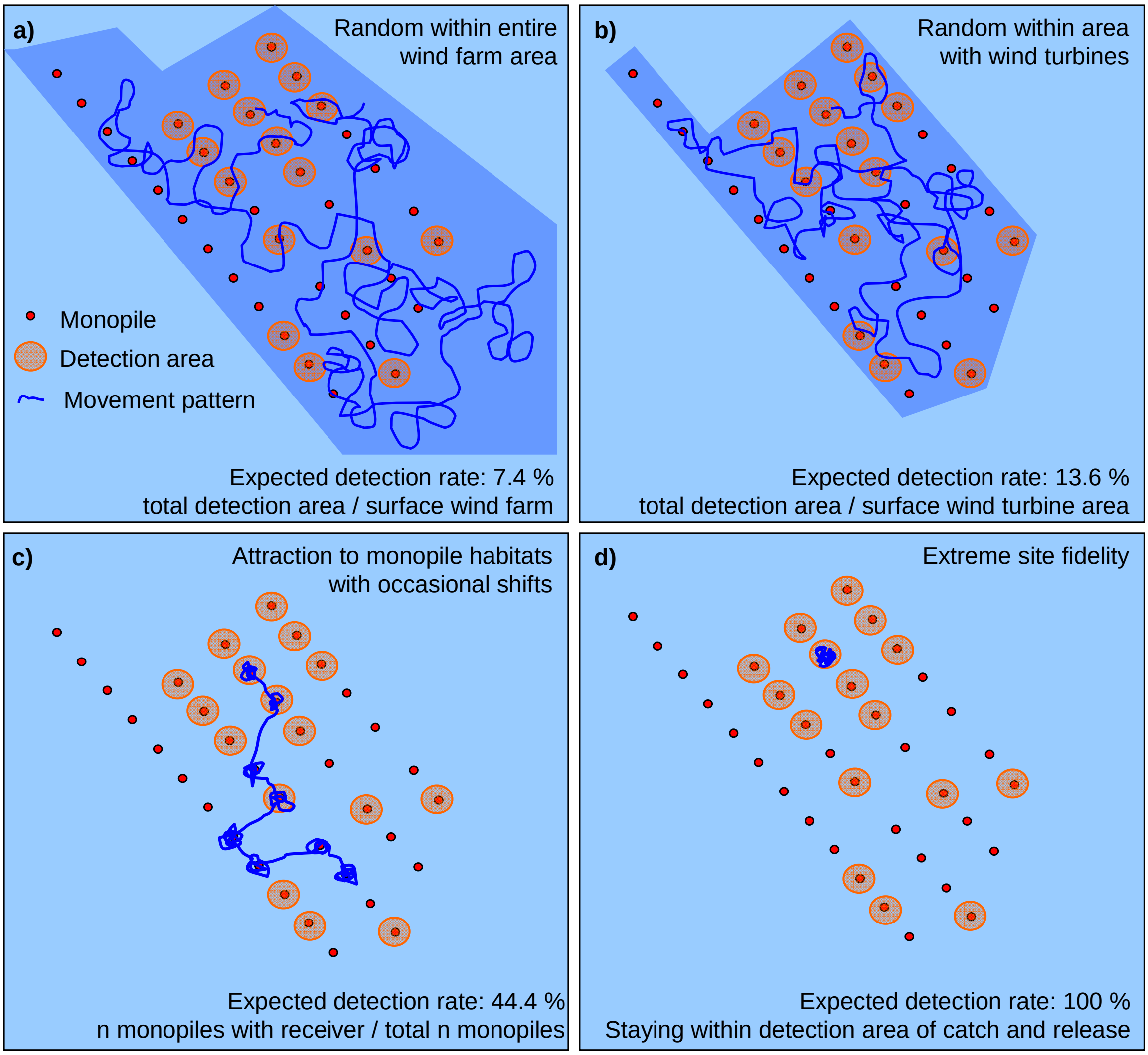

Figure 9*. Examples of movement patterns for four different hypothesized behavioural scenarios and the detection rate that is expected to be observed if the underlying behaviour pattern is in accordance with a hypothesized pattern. For scenarios a, b and c the number of detection stations per individual fish with a transmitter is expected to be > 1, whereas for scenario d this is limited to 1.*

Relation between behaviour and wind turbine operation
Vestas provided us with data series on wind turbine operation in 10 minute intervals during the entire course of the telemetry experiment. The rocky structure around the wind turbines may form an attractive feature for cod, however the different sounds and vibrations produced by the wind turbine may scare off individuals. If the datasets are extensive enough, we could investigate this effect by comparing the detections prior, during and after events where the wind turbines were not in operation, i.e. *out of order*.

For each wind turbine, information is available on the revolutions of the generator per minute (rpm) as an average value for every 10 minutes. During operation, the generator speed is around 1600 rpm. To link this data with the hourly detections, we first calculate the maximum rpm for each hour. Next a wind turbine was characterized as out of order if the rpm <1000 and at least the majority of wind turbines (>18 out of 36) were operating (>1000 rpm). Next we defined the start and end and duration (*d* hours) of each out of order event, only considering the events lasting at least 24 hours and extracted the detections within *d* hours prior to the start of the event, during the event and *d* hours after the event.

Now it is possible to estimate for each out of order event and individual fish the number of detections prior, during and after the event. To this data, a Generalized Linear Model is fitted, which models the number of detections (assumed to be quasi-Poisson distributed) as a function of the factor indicating whether it was prior, during or after an event. The log of the duration was treated as an offset.

3 Results

3.1 Tagging experiments with sole

In June 2007 a batch of sole was caught, tagged and released only in the OWEZ. In October 2007 and in June 2008, in total four batches of sole were tagged and released. In each period, one batch was caught, tagged and released in the OWEZ and an equal sized batch in the reference area south west from the wind farm. The latter two paired groups were used to test if there was a difference in return rate from fisheries between each of the groups. If individual residence time in the OWEZ of sole is long, then a significantly lower return rate from fisheries was expected for the batches caught, tagged and released in the OWEZ compared to the reference area.

Return rates of each of the batches varied between 8.8 – 16.7 % (Figure 10). For comparison, the return rate of the 40 sole implanted with transmitters and tagged with discs within the telemetry experiment was 15 %.

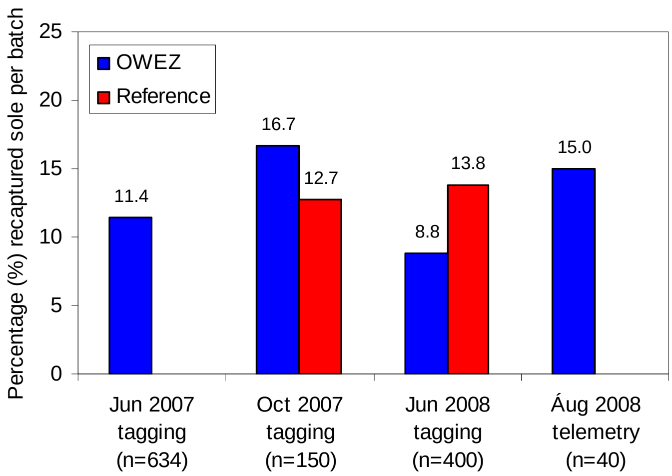

Figure 10. *Recapture rates by fisheries for each of the batches of tagged sole.*

Table 8. *Overview of the number of returned tagged sole from fisheries ('recaptured') and number of sole that were tagged but not returned by fisheries ('not recaptured') for each of the batches: OWEZ and Reference Area in June 2007, October 2008 and combined for both periods. Differences between groups were tested by a 2x2 G test of independence.*

	OWEZ	Reference	*totals*	2x2 G-test of independence	
Batch oct 2007					
recaptured	25	19	*44*	Observed G=	0.96
not recaptured	125	131	*256*	William's correction=	1.01
totals	*150*	*150*	*300*	p-value=	0.33
Batch jun 2008					
recaptured	35	55	*90*	Observed G=	5.05
not recaptured	365	345	*710*	William's correction=	1.01
totals	*400*	*400*	*800*	p-value=	**0.03**
Both batches combined					
recaptured	60	74	*134*	Observed G=	1.67
not recaptured	490	476	*966*	William's correction=	1.00
totals	*550*	*550*	*1100*	p-value=	0.20

There appeared to be no consistent difference between return rate of batches caught, tagged and released within the OWEZ and in the reference area south from the OWEZ. To test this, a 2x2 G-test of independence was carried out for each of the two paired batches and for these two batches combined (Table 8). Only in the batch of June 2008 a significantly lower return rate for OWEZ was found. In the batch of October 2007 and when both batches of October 2007 and June 2008 were combined, no significant difference in return rate was found.

If individual sole is present within the wind farm for long times, i.e. large individual residence time occurs, then the return rate of the OWEZ group is expected to be low during the first period following the release of tagged sole compared to the return rate of the reference groups. However, the cumulative return rate in time for each of the periods (October 2007 and June 2008) and groups (OWEZ and Reference) show no indication that this is the case. In fact, for the only period where a significant difference between OWEZ and Reference was found (June 2008) return rates of both groups did not start to diverge until after 10 months after release (Figure 11). If the significant difference in return rates between both batches released in June 2008 is caused by a longer residence time of sole within the wind farm, it was expected that the difference appeared mainly in the first period following release. However, the contrary is the case with a very similar return rate for the first 10 months before the return rates of the Reference group increase compared to the OWEZ group. Because of this and, moreover, it was not consistent for both experiments it is unlikely that the found significant difference in one experiment is due to long individual residence time in the wind farm.

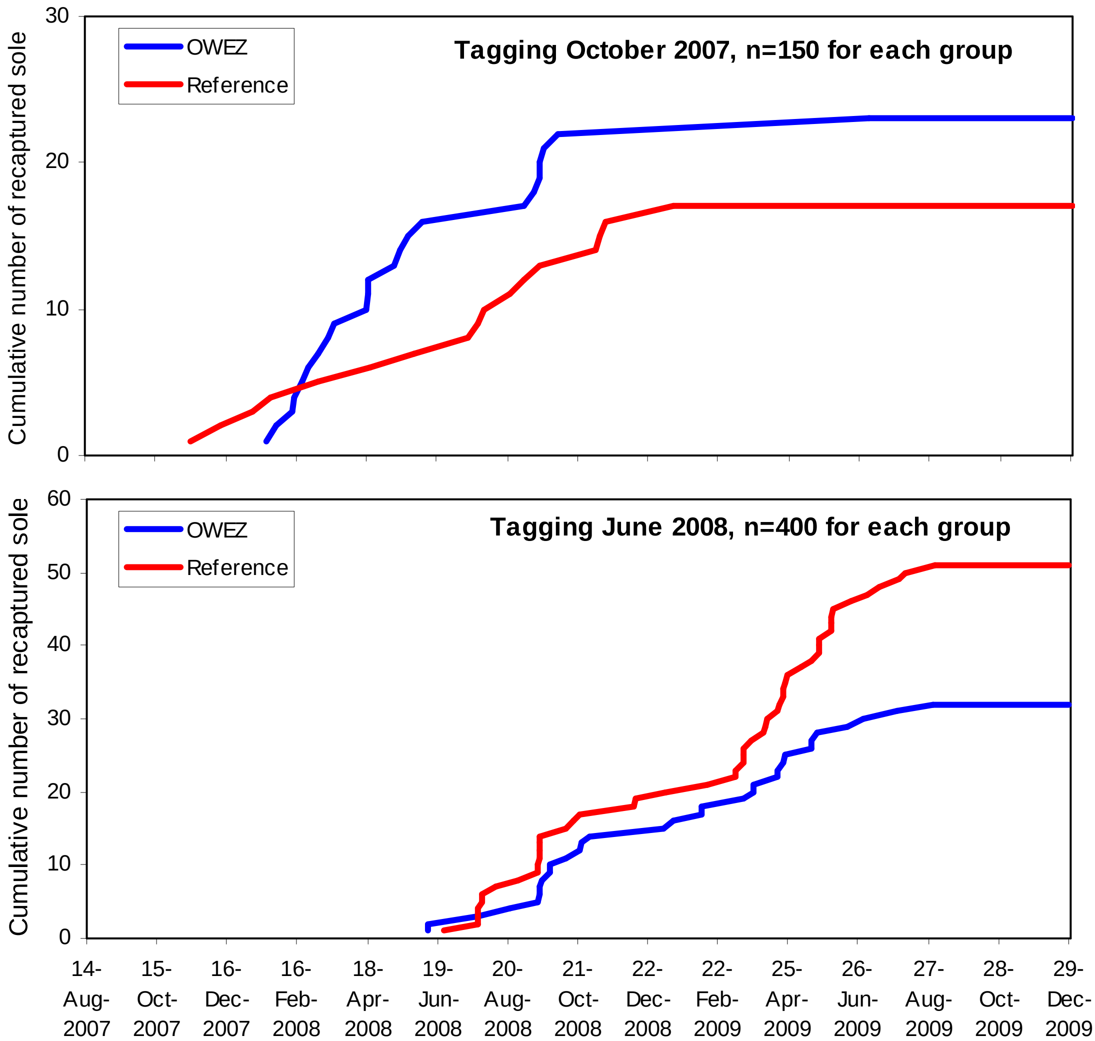

Figure 11. *Cumulative number of recaptured tagged sole that were returned by fisheries in time after release for both groups (OWEZ and Reference) for each of the periods (October 2007 and June 2008).*

All tagged sole that were returned by fisheries for which the position of catch was known, were caught in the Southern North Sea within a zone of up to 200 km from the Dutch coast line (Figure 12). There appears to be no difference in spatial distribution between groups (OWEZ and Reference) and periods. For the batch caught, tagged and released within the wind farm OWEZ in June 2007, 9 tags were found on the bottom in a cormorant colony in the dunes near Castricum. These tagged sole must have been caught by cormorants and either fed to their young and subsequently regurgitated or by the breeding or roosting adults themselves. Despite several intensive searches in the following two years, no more tags were found in the colony. Since cormorants are present in the colony for only part of the year and roost on various places, chances of finding regurgitated tags from sole predated by cormorants outside the breeding period are probably extremely low.

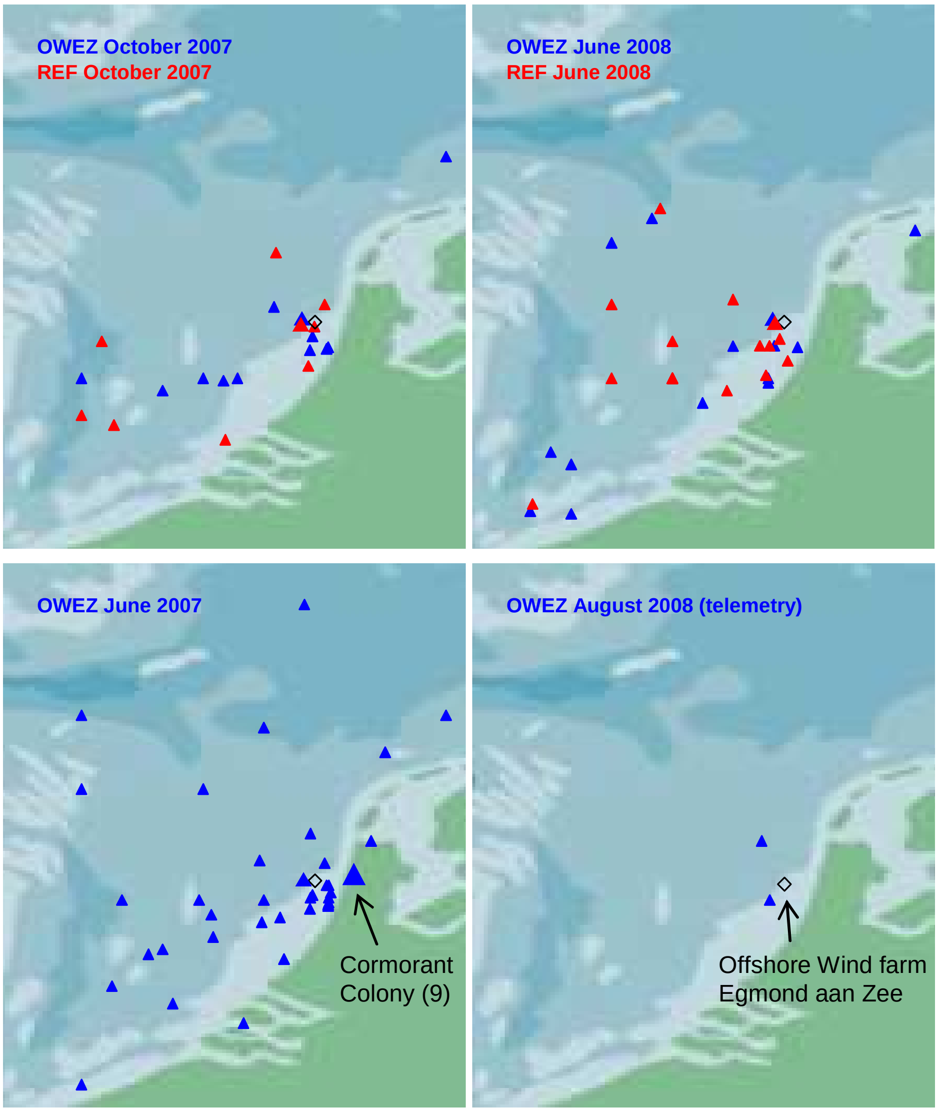

Figure 12. *Spatial distribution of the tagged sole that were returned by fisheries and where the position of recapture was reported for the different periods and groups (OWEZ and Reference). Next to returns from fisheries, 9 tags of the OWEZ June 2007 batch were recovered in a cormorant colony in the dunes near Castricum.*

3.2 Telemetry experiment on individual behaviour of sole in OWEZ

In total 40 soles were implanted with an acoustic V7 transmitter and released near the catch site in an area covered by one of the detection stations deployed in the wind farm. Of these, 55% (22) were not detected after the day of release. All implanted transmitters were tested and worked properly before release. Only 30 % were detected for more than one week, and 22% for more than one month (Figure 13). Detection patterns show that only some individuals spend periods ranging from one to six weeks within the vicinity of a single detection station (Figure 14).

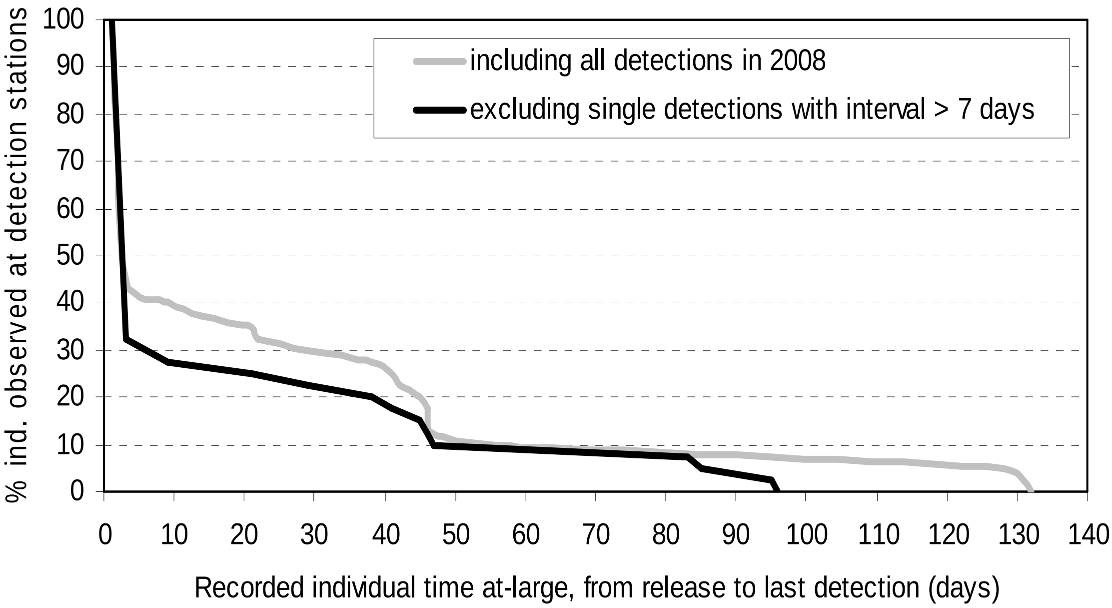

Figure 13. *Percentage of individual sole with transmitters that were detected within the wind farm through time, based on individual time at-large, i.e. the time between the first and last detection within the wind farm, for each sole.*

Most sole were detected within the wind farm for relatively short periods varying between hours to a few months and intervals between detections are large for most individuals. Detections ceased in de course of October to November. Three soles were detected once in spring 2009 after a long period of not being detected (Figure 14). In total, 6 tagged soles with transmitters were returned by fisheries, of which 5 were detected within the wind farm for only the first days after release. This suggests that the majority of the 55% that was never detected after the first days emigrated outside the wind farm shortly after release. The two recaptured soles with a known position are given in Figure 12.

We compared the observed proportion of hour bins that individuals were detected during their time at-large, i.e. between the first and last detection, with expected proportions of various behavioural scenarios. These scenarios range form random movement on various scales, strong attraction to the newly created habitats directly around monopiles to extreme site fidelity on a small spatial scale, < 200 m which is the average detection range (Table 9). The average observed detection rate of sole with transmitters (13.2 % of hours bins detected during time at-large) is close to the expected detection rate of the behavioural scenario with random movement within the area with wind turbines and detection stations (b; 13.6 %, Table 9). Individual variation in observed detection rate while in the wind farm (min. 0.7- max. 38.3 %) shows that none of the individuals exceeded the expected detection rate of 44.4 % for the behavioural scenario with strong attraction to the monopile habitats (Figure 15). On average each sole with a transmitter that was detected in the wind farm for more than one day was detected at 3.2 detection stations.

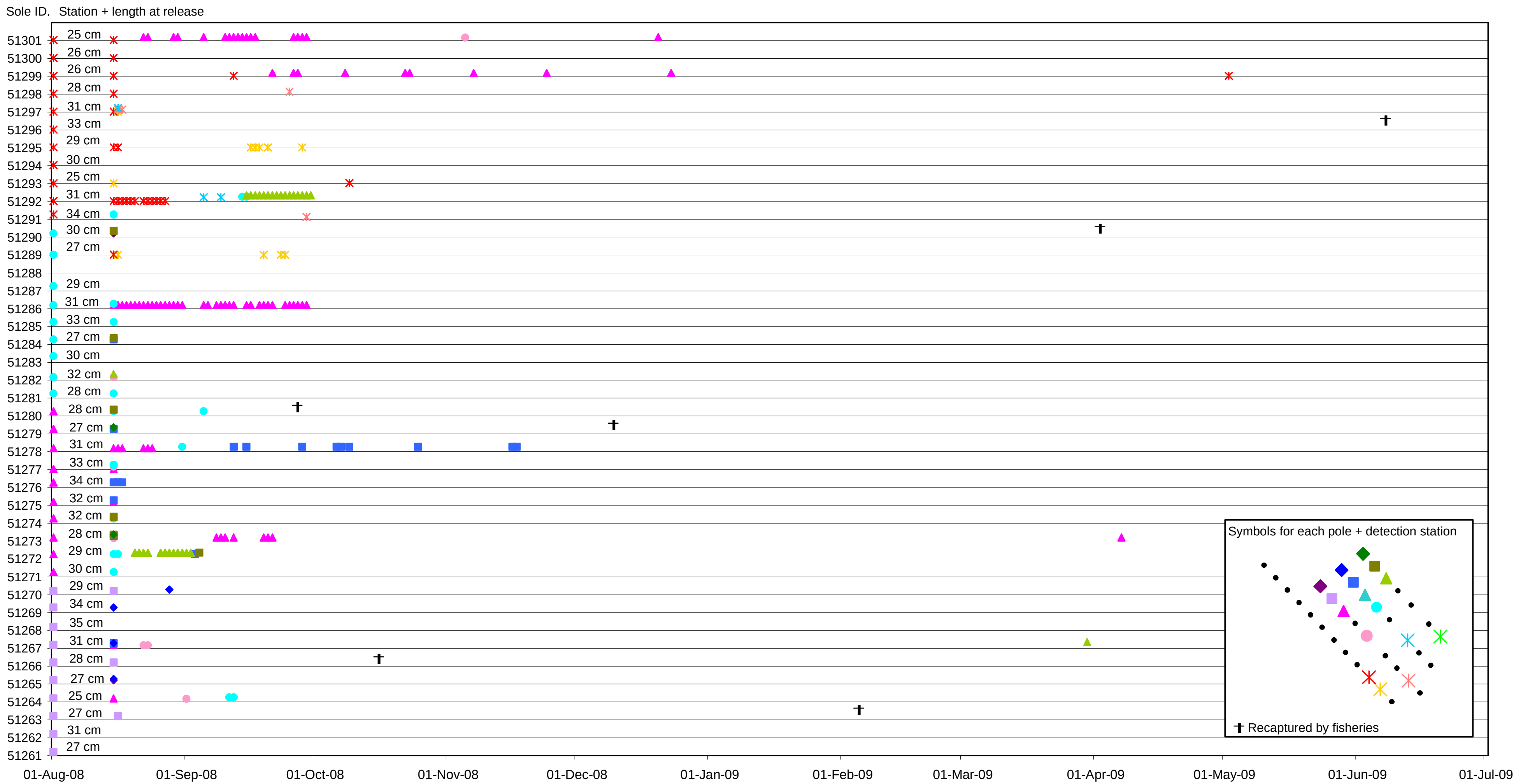

Figure 14. *Overview of 40 soles that were caught, implanted with a transmitter and released in the wind farm on 15 August 2008. For each sole, transmitter ID, detection station where released, total length, and detection pattern through time is given. Detections at a particular detection station is denoted with a different symbol (see map in legend) and recaptures by fisheries are noted with a cross.*

Table 9. *Comparison of expected detection rates, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), and number of detection station where detected for different behavioural scenario's with the observed detection rates for sole that were present in the wind farm for more than one day following release.*

Hypothesized behaviour and expected detection rates	Detection rate % (n receivers/ind)
a) Random movement within entire wind farm area:	7.4 % (>1)
Expected rate = surface area covered by receivers / surface area wind farm	
b) Random movement within area with wind turbines (and detection stations):	13.6 % (>1)
Expected rate = surface area covered by receivers / surface area with turbines	
c) Strongly attracted to monopile habitats with occasional 'monopile hopping':	44.4 % (>1)
Expected rate = n monopiles covered by receivers (16) / n monopiles (36)	
d) Extreme site fidelity, i.e. all sole are continuously recorded at the site of release:	100 % (1)
Expected rate = 100 % and number of receiver where recorded is 1	
Observed detection rate*	
Sole released in August 2008	13.2 % (3.2)

* sole that were never detected after the day of release were excluded from this analysis

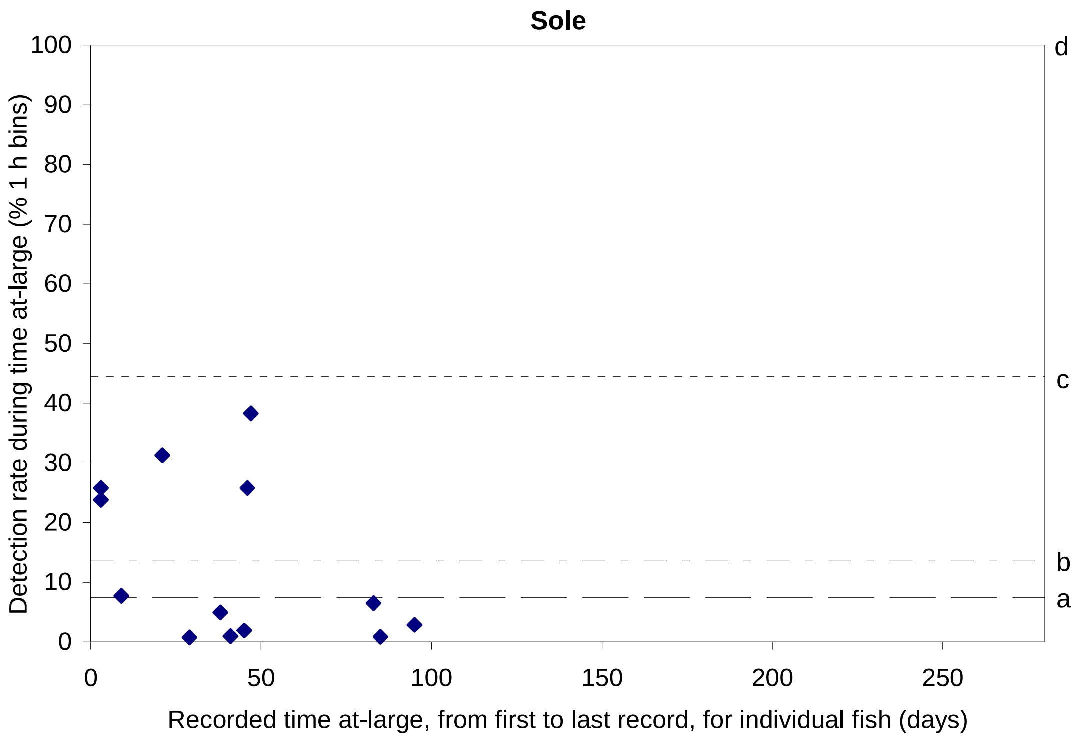

Figure 15*. Observed detection rate, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), for individual sole with transmitters. The lines represent the expected detection rates from different behavioural scenario's, see Table 9.*

3.3 Telemetry experiments on cod

3.3.1 Individual residence time and behaviour of cod in OWEZ

In September 2008, in total 40 cod were caught, implanted with an acoustic transmitter and released near monopiles in the wind farm. In January 2009, an additional 7 cod were implanted with a transmitter (Figure 17). Of the September group 11 cod (28 %) were not detected after the first day of release, while of the January group, 1 cod was not detected after the day of release (14 %). Individual variation in detection patterns was large varying from being detected within the wind farm during just days to individuals being detected for periods of over 9 months and with individuals present for months near a single detection station to individuals being detected at 10 different detection stations. In total, 3 cod with acoustic transmitters were returned from fisheries (Figure 17).

For the September group, ca 30% was detected for only up to a few days, ca 50 % was detected for 3 weeks to 2 months and ca. 20 % was detected for more than 2 months up to 9 months (Figure 16). A relatively large proportion of cod ceased to be detected after the end of the growing season in October-November. For the January group, more than 50% (4 out of 7) were detected for over 4 months.

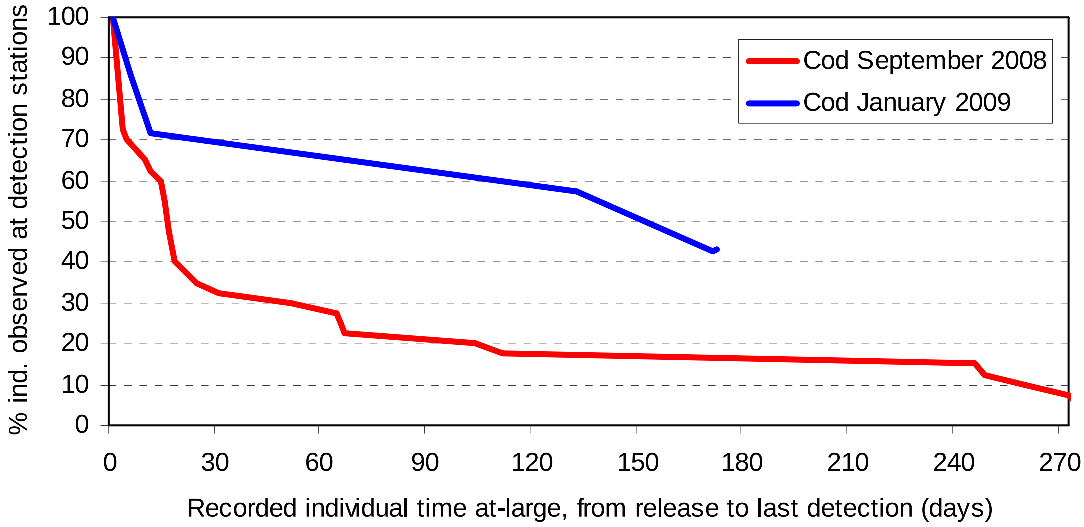

Figure 16. *Percentage of individual cod with transmitters that were detected within the wind farm through time, based on individual time at-large, i.e. the time between the first and last detection within the wind farm, for each cod in the two different batches released in September 2008 (n=40) and January 2009 (n=7).*

We also compared the observed proportion of hour bins that individual cod were detected during their time at-large, i.e. between the first and last detection, with expected proportions of various behavioural scenarios. The average observed detection rate of cod with transmitters (46.1 % of hours bins detected during time at-large for the September 2008 group and 41.3 % for the January group) is close to the expected detection rate of the behavioural scenario with strong attraction to monopile habitats (c; 44.4 %, Table 10). Variation between groups caught, tagged and released in different parts of the wind farm show very similar percentages for the September 2008 group. The average number of detection stations that were visited was 3.3 for the September 2008 group and 1.8 for the January 2009 group.

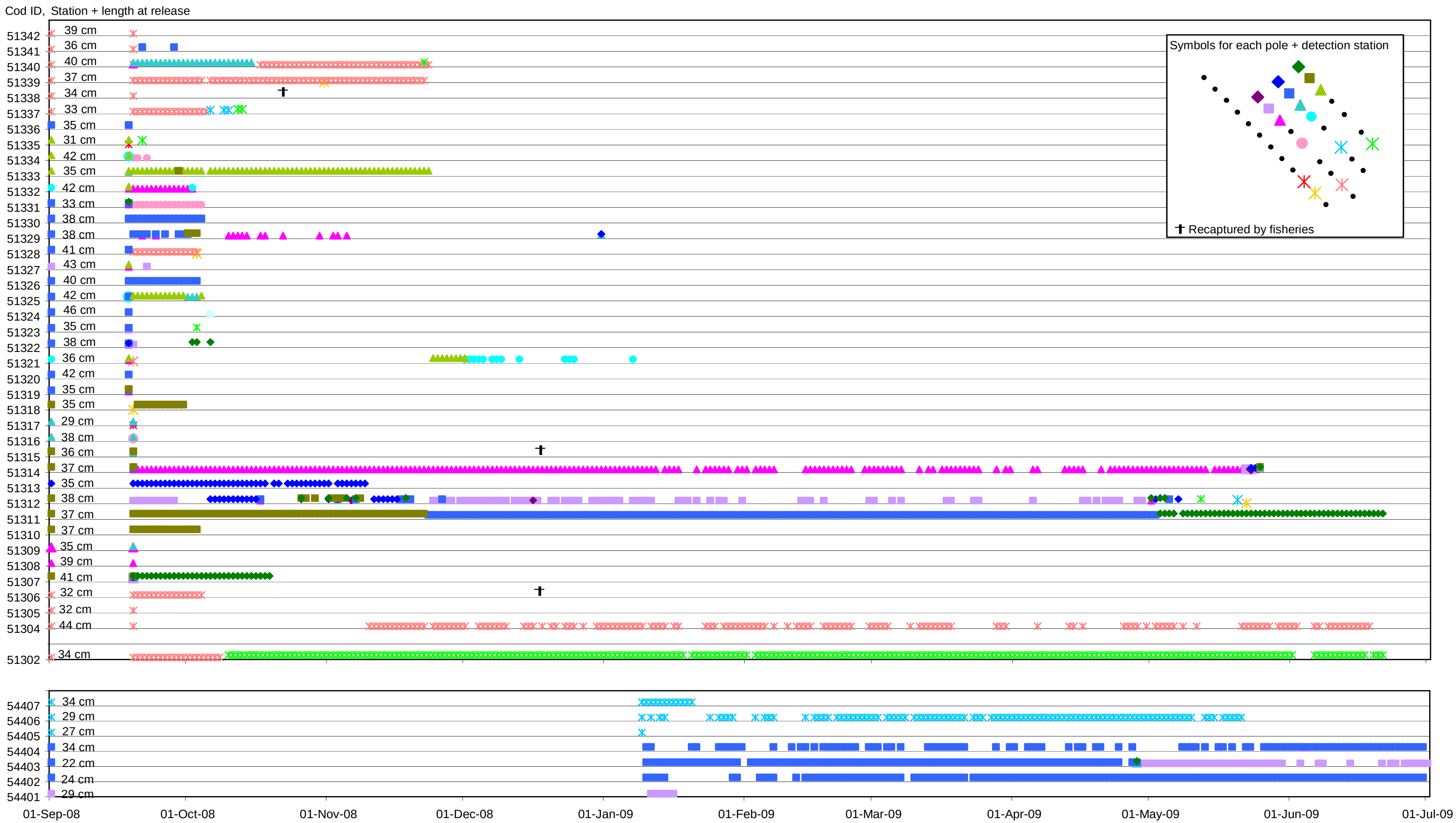

Figure 17. *Overview of 40 cod that were caught, implanted with a transmitter and released in the wind farm on 18/19 September 2008 (top panel) and 7 cod on 9/10 January 2009.. For each cod, transmitter ID, detection station where released, total length, and detection pattern through time is given. Detections at a particular detection station is denoted with a different symbol (see map in legend) and recaptures by fisheries are noted with a cross.*

Table 10. *Comparison of expected detection rates, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), and number of detection station where detected for different behavioural scenario's with the observed detection rates for cod that were present in the wind farm for more than one day following release.*

Hypothesized behaviour and expected detection rates	Detection rate % (n receivers/ind)
a) Random movement within entire wind farm area:	7.4 % (>1)
Expected rate = surface area covered by recievers / surface area wind farm	
b) Random movement within area with wind turbines (and detection stations):	13.6 % (>1)
Expected rate = surface area covered by recievers / surface area with turbines	
c) Strongly attracted to monopole habitats with occasional 'monopile hopping':	44.4 % (>1)
Expected rate = n monopiles covered by receivers (16) / n monopiles (36)	
d) Extreme site fidelity, i.e. all cod are continuously recorded at the site of release:	100 % (1)
Expected rate = 100 % and number of receiver where recorded is 1	
Observed detection rates*	
September 2008 batch	
- Cod released in centre of square where all monopiles were covered by receivers	45.2 % (3.4)
- Cod released at border of square where all monopiles were covered by receivers	46.2 % (4.0)
- Cod released in the wind farm part where 7 out of 27 monopiles were covered	46.5 % (2.1)
All cod released in September 2008 combined	46.1 % (3.3)
January 2009 batch	
- Cod released in centre of square where all monopiles were covered by receivers	48.6 % (2.0)
- Cod released in the wind farm part where 7 out of 27 monopiles were covered	26.6 % (1.5)
All cod released in January 2009 combined	41.3 % (1.8)

* cod that were never detected after the day of release were excluded from this analysis

However, individual variation in observed detection rate for cod with transmitters while in the wind farm was very large (min. 0.5 % to max. 97.8 %, Figure 18). Some individuals showed high site fidelity spending most of their (often large) residence time within the range of a single detection station. Cod present in the wind farm spend considerably more time within the reach of detection stations than can be expected from a random use of the wind farm. For this, both extreme site fidelity (not necessarily to monopile habitats, but to habitats within the reach of detection stations) or strong attraction to monopile habitats can be underlying explanations.

Individuals that were detected for prolonged periods within the wind farm occasionally shifted to an area covered by another detection station (Figure 17). This behaviour might reflect 'monopile hopping' as hypothesized for behavioural scenario c (Table 10). When plotting the last detection date of each period that an individual was detected at a single detection station, most occurred during autumn (October-November), and during spring (April-May) and hardly not during winter Figure 19). These 'departures' of cod after prolonged presence within an area covered by a single detection station might reflect a shift to another area covered by a detections station, a shift to an area within the wind farm not covered by a detection station or an emigration out of the wind farm.

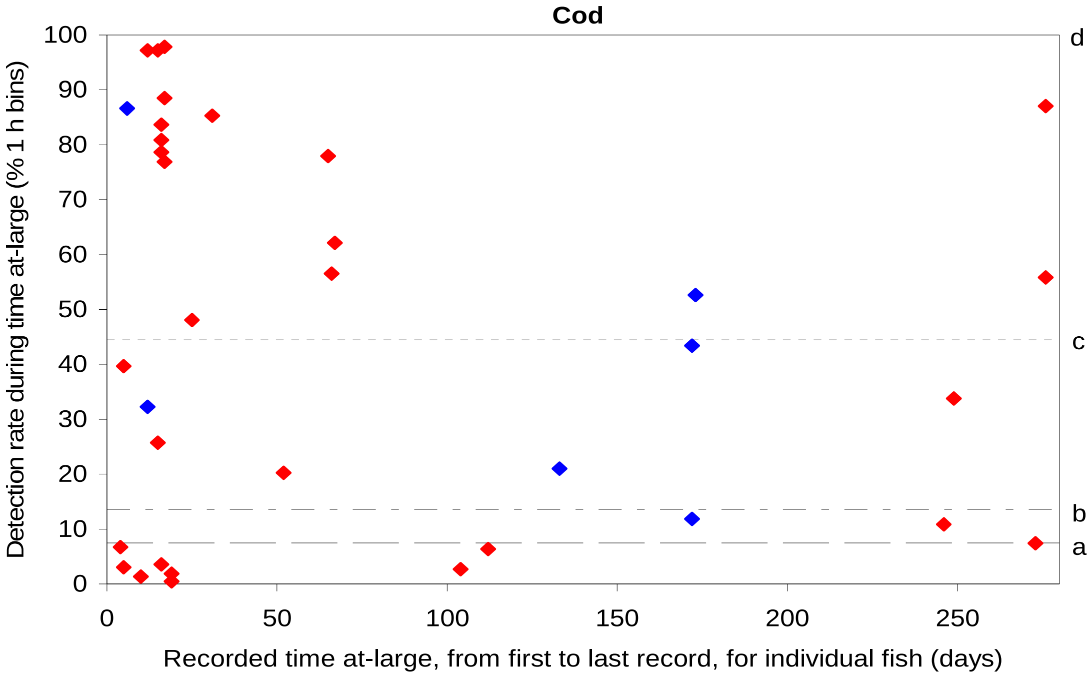

***Figure. 18**. Observed detection rate, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), for individual cod with transmitters of the September 2008 batch (red) and January batch (blue). The lines represent the expected detection rates from different behavioural scenario's, see Table 10.*

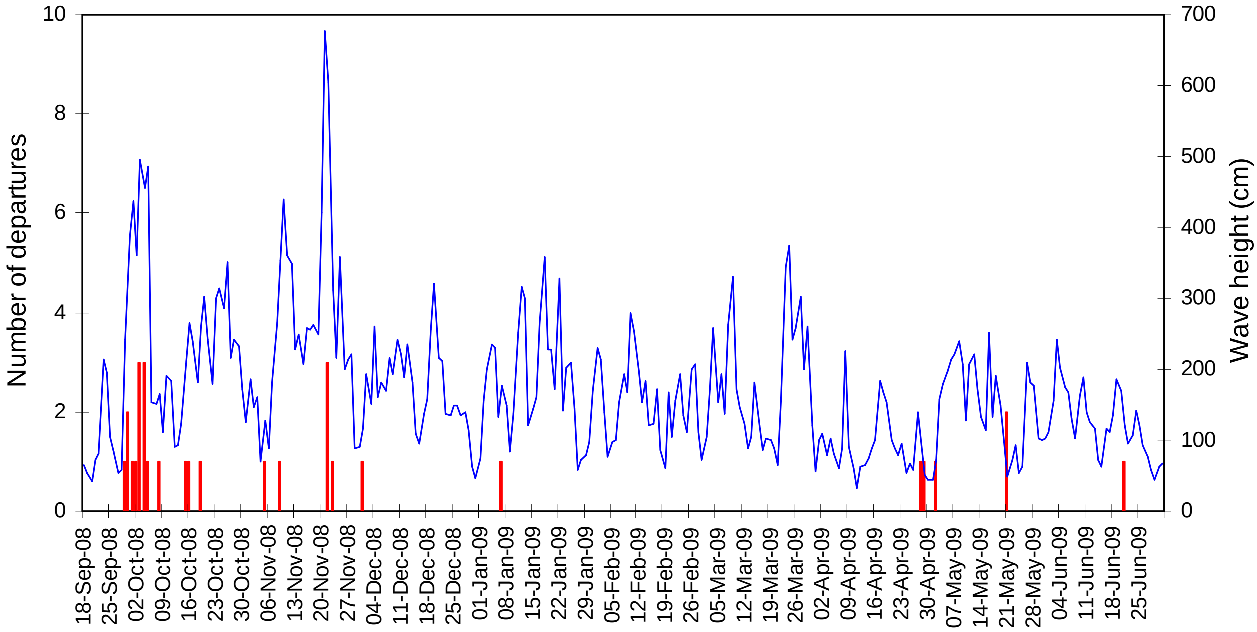

***Figure 19.** Number of 'departure' dates of cod with transmitters from an area covered by a single detection station after being detected there for more than one week (red bars), compared to the wave height (blue line)*

When comparing these departure dates to wave height, relatively many departures during autumn coincide with the two periods when severe storms occurred causing the highest waves during the entire experiment period.

To explore individual use of the wind farm by cod in more detail, we plotted each detection during the course of the day for the entire period for nine cod that spent prolonged periods within the wind farm. For the September 2008 group, 5 cod were detected more or less continuously for about 8-9 months in the wind farm, and for the January 2009 group 4 cod were detected for about 4-6 months (until the end of the recording period), see Figure 20, 21 and 22.

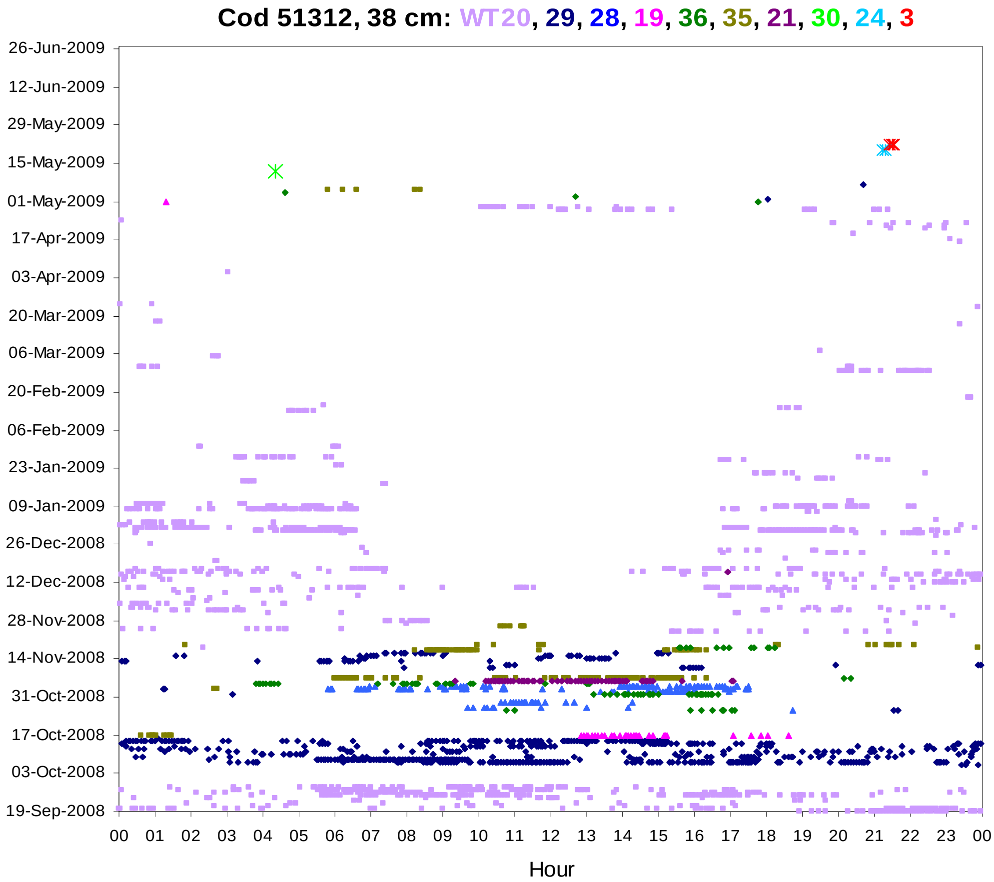

Figure 20. *Diurnal detection pattern of cod with ID 51312 during the course of the entire telemetry experiment. Each symbol represents a different detection station (see legend in Figure 17). The 10 detection stations where this cod was detected are given in the caption.*

Of all the cod in the experiments, the cod with ID 51312 was observed at the highest number of detection stations. After an initial period of 3 weeks being detected at the station near Wind Turbine 20, it shifted to the detection area near WT29 (Figure 20). During October-November it was detected at various detection stations with more detections during the day than at night. After the end of November it was only periodically detected near WT20 and more so at night than during the day. During May it showed up at different detection stations within the dense North core of detection stations before it was last detected at WT 24 and then WT3 in the Southern part of the wind farm.

Four other cod from the September 2008 group, showed higher site fidelity than cod ID 51312, with prolonged presence at only one or few sequential detection stations (Figure 21). In all of these cod, clear changes in diurnal detection patterns were observed (Figure 21). Varying from continuous presence (especially during autumn), to mostly at night (especially during winter and early spring) to mostly during the day (especially during late spring and early summer). Even though the degree of 'station hopping' and percentage of the time being present within the detection range of a station varied between these cod, the basic pattern is very similar. High site fidelity to a single station during prolonged periods, with only short time intervals in between 'hopping' to a next station and diurnal patterns that clearly change in the course of the seasons in a similar way.

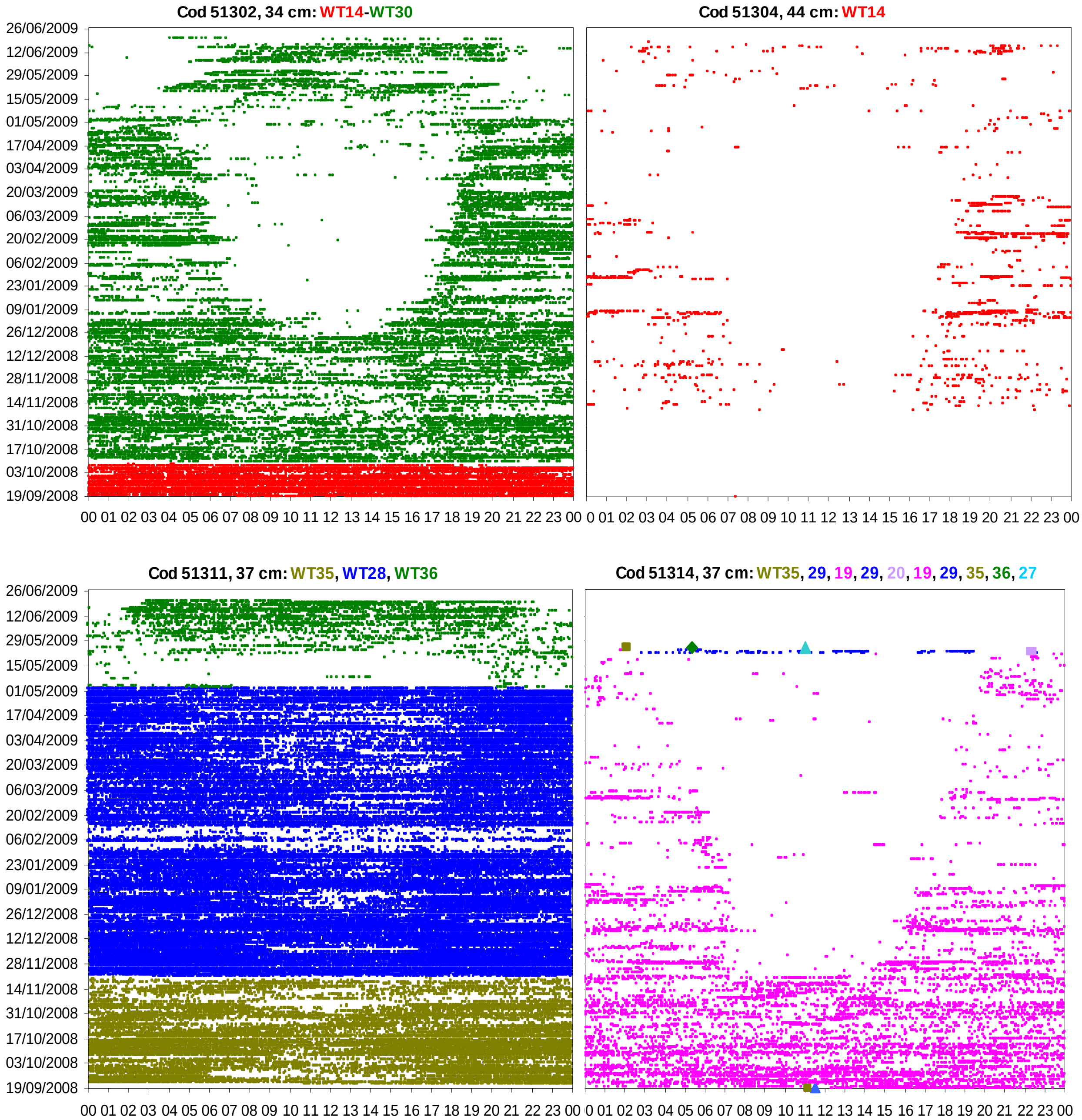

__Figure 21.__ Diurnal detection pattern of four different cod of the September 2008 group during the course of the entire telemetry experiment. Each symbol represents a different detection station (see legend in Figure 17). The order of detection stations where these cod was detected are given in each caption.

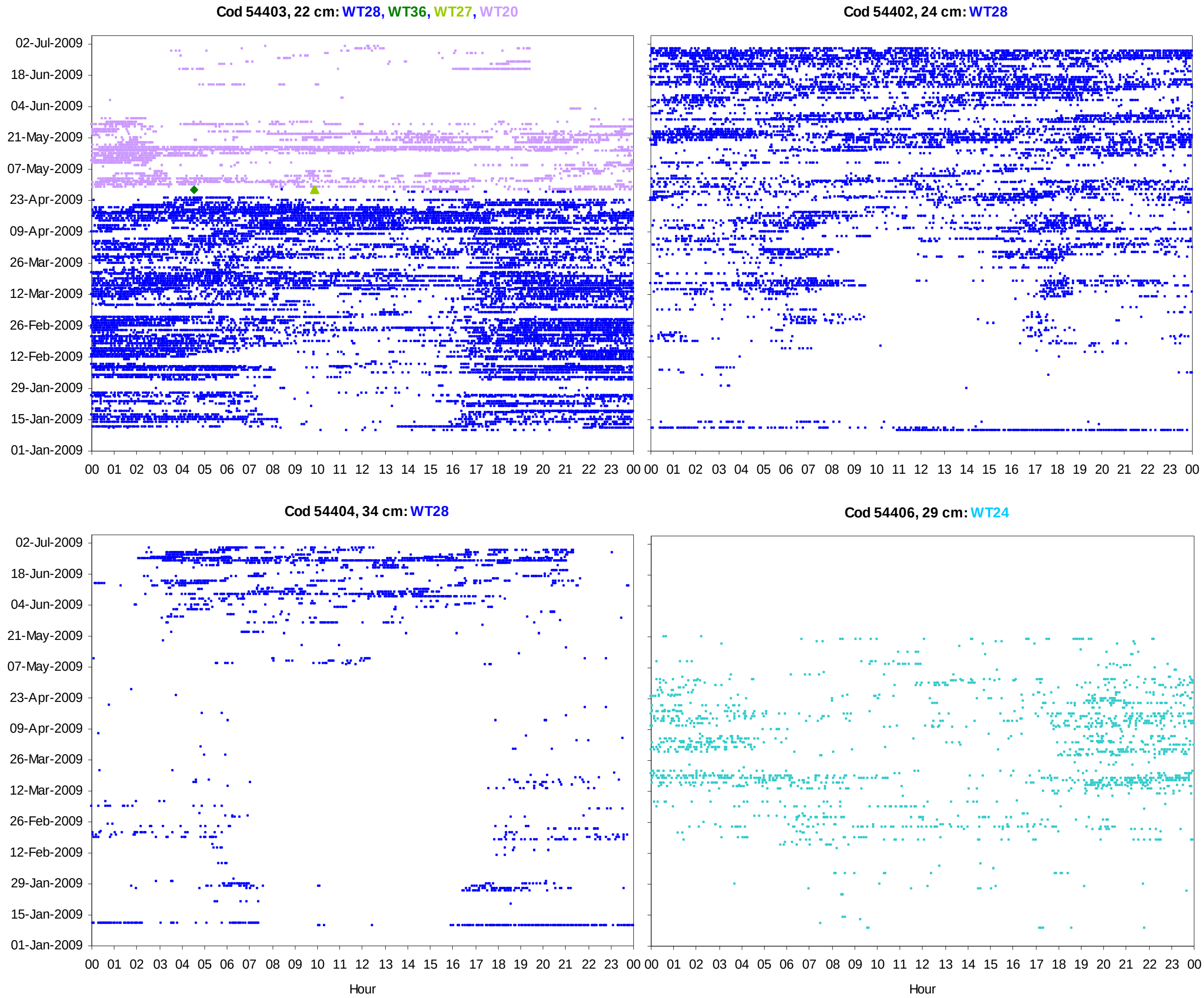

Figure 22. *Diurnal detection pattern of four different cod of the September 2008 group during the course of the entire telemetry experiment. Each symbol represents a different detection station (see legend in Figure 17). The order of detection stations where these cod was detected are given in each caption.*

The 4 cod of the January group with long residence times, show similar though less clear patterns (Figure 22) than the September 2008 group, with a shift in diurnal pattern from detected mostly at night during winter to early spring (in all four) to mostly during the day in late spring (in two). The diagonal patterns in these relatively small cod compared to the September batch coincide with tidal cycles. Three of these cod were detected only at a single detection station, whereas one (ID 54403) shifted to another detection area within a short time interval in which also two other neighbouring stations were briefly visited.

3.3.2 Individual behaviour of cod in relation to wind turbine operation

Individual cod were present in the wind farm for prolonged periods and large detection series for different cod were available. Therefore it was possible to explore a potential preference for habitats near wind turbines that were temporarily out of order and therefore producing no potentially disturbing noise or vibrations. We studied this by using turbine operation data provided by the exploiting parties of the wind farm. For those wind turbines containing a receiver station, we compared for each cod the number of hourly detections during an out-of-order event of wind turbines against the number of detections during the period directly preceding and following such an event. It was hypothesized that if cod would dislike the noise and vibrations produced by wind turbines, they would show a preference for wind turbines that were out of order. We expected, this would then lead to a higher detection rate during such an out-of-order event. Figure 23 shows for each individual for each out-of-order event (for which at least more than one detection was made prior, during or after the event), the number of detections during periods when a turbine was temporarily out of order in comparison to an equal period in operation prior and after such a out of order event. Sometimes, the number of hour bins selected prior or after the event was shorter because the out-of-order event occurred at the beginning or end of the telemetry experiment.

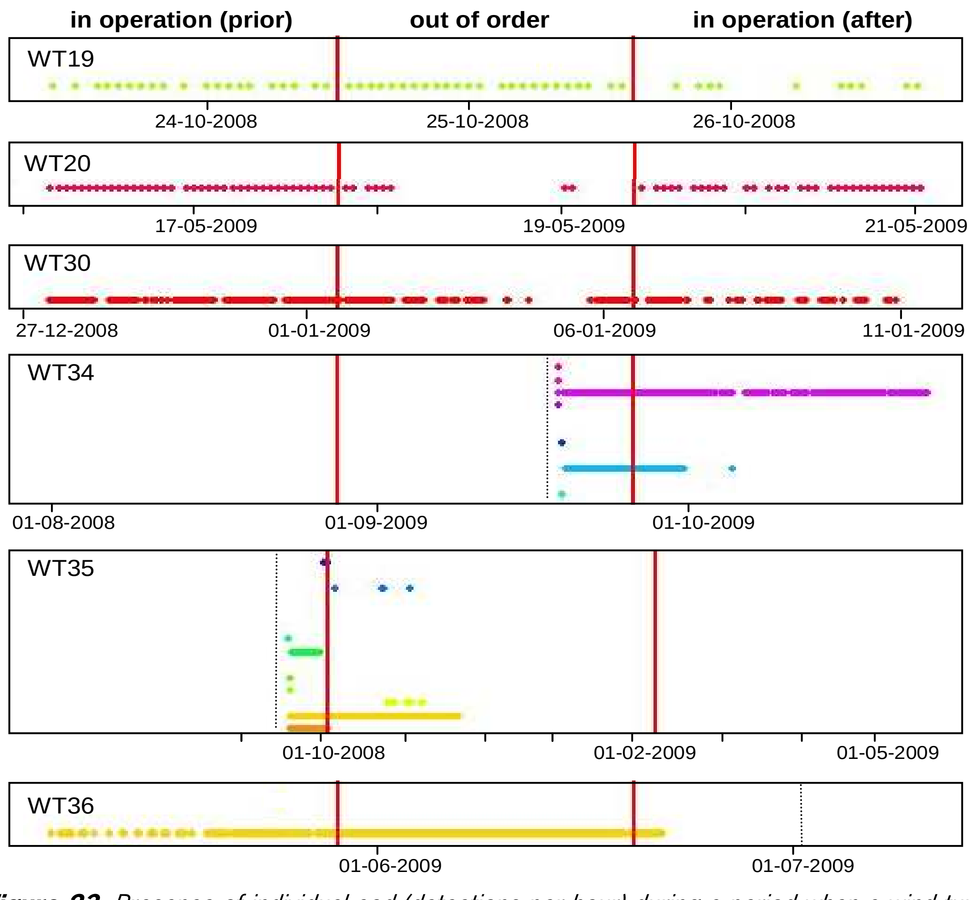

***Figure 23**. Presence of individual cod (detections per hour) during a period when a wind turbine was temporarily out of order compared to presence during equal periods prior and after such an event (the three periods are separated by vertical red lines). If a wind turbine in operation causes disturbance by noise or vibrations, higher presence would be expected during out of order events. Each series of detections represents an individual cod with a transmitter. Each panel represents a different out of order event. The start or end of the telemetry experiments is given by a vertical dotted line. Note that the time scale varies per panel.*

At first inspection, there is no consistent higher presence during out of order events. Nor are there indications that cod first appear at a wind turbine site during out of order event and subsequently leave when the wind turbine is taken in operation again. At WT35 three cod are present during operation and leave the wind turbine area when the out of order event starts in early October 2008, and one cod appears directly after the out of order event started. Because a severe storm with very high waves occurred on 2-3 October 2009 (see Figure 19), it is more likely that the departure of three cod, arrival of one cod and the start of the out of order event are all related to the occurrence of this storm than that three cod prefer a wind turbine in operation and one prefers an area with a non-operating wind turbine.

If we statistically test for a potential difference (using a Generalized Linear Model, assuming a quasi-Poisson distribution to account for temporal correlation in the data and treating the period prior, during and after the out-of-order event as a factor), the difference is not significant (p-value prior = 0.67, p-value after = 0.86, see model 1, table 11). Also when we group the detections prior and after the event, the data shows that there were more detections during the event, but again the difference was not significant (model 2, table 11).

Table 11. *Testing for number of detections prior, during and after per out-of-order event for each cod significantly differs by using four models with different assumptions for the dispersion parameter. If a preference for habitats near out-of-order wind-turbines over habitats near wind turbines when in operation exists, then a significantly higher detection rate is expected during the vent than prior or after.*

model 1

Coefficients:

	Estimate	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	-2.6612	0.8379	-3.176	0.00196 **
factor() prior	-0.6605	1.5588	-0.424	0.67263
factor() after	-0.2791	1.5767	-0.177	0.85986

Significant. codes: ***<0.001 **<0.01 *<0.05 .<0.1

(Dispersion parameter for quasi-Poisson family taken to be 1817.703)

model 2

Coefficients:

	Estimate	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	-2.6612	0.8220	-3.238	0.00161 **
factor() prior & after	-0.4908	1.2330	-0.398	0.69137

Significant. codes: ***<0.001 **<0.01 *<0.05 .<0.1

(Dispersion parameter for quasi-Poisson n family taken to be 1749.358)

4 Discussion and conclusions

Studying fish behaviour in wind farms
There is a growing interest in producing renewable energy with offshore wind farms (Inger et al. 2009). Impact studies of offshore wind farms on fish, however, are still scarce and primarily focus on comparing fish abundance before and after construction in the impact area (wind farm) and reference areas by means of traditional surveys, hydroacoustic techniques and visual observations by scuba divers (Hoffmann et al. 2000, Hvidt et al. 2005, Wilhelmsson et al. 2006, ter Hofstede 2008). To our knowledge, our present study is the first worldwide that studied individual behaviour of fish in relation to the operation of offshore wind farms *in situ*. We directly measured individual behaviour of two species, sole *Solea vulgaris* and Atlantic cod *Gadus morhua*, throughout the seasons by means of tagging and telemetry experiments.

Offshore wind farms are placed in areas that are subject to strong currents and high waves. These environments are challenging for deployment of telemetric equipment for long durations. This study in the OWEZ showed that the selected methods of deployment were robust against the high tidal currents and severe weather conditions that occur during the seasons. No detection stations were lost, nor any malfunctioning was detected during the course of the experiments. Thus, the applied telemetric method, deployment and set-up has been demonstrated to be a suitable to measure fish behaviour in offshore wind farms.

Deriving behavioural patterns from the tagging and telemetry data
The tagging data directly measured return rate by fisheries, which is a minimum estimate for fisheries mortality suffered by each of the experimental groups. Comparison of return rate between groups as an index for fisheries mortality is feasible because the underreporting rate of recaptured tagged fish are likely to be identical for the different groups, since fishermen can make no distinction between tagged individuals originating from different groups. And therefore, differences in return rate between experimental groups must be related to the behaviour patterns underlying the tagging data. When describing spatial movement patterns, however, tagging data only indicate where and when a tagged individual was released and where and when it was recaptured. It reveals little of the exact underlying individual behavioural patterns in between these two observations in time (Bolle et al. 2005). For this, telemetric research is more suitable.

The telemetry experiments yielded much more spatial observations per individual fish through time than tagging, i.e. up to 50.000 detections for a single cod during 9 months. For the telemetric data, when a transmitter is detected it is known that it is present within the detection range of the specific receiver. Theoretically, a detected individual can be either alive or dead, be it on the sea floor or inside a predator. In case it is predated, the transmitter is mostly either regurgitated or excreted and will end up on the seafloor within short time intervals. In case a transmitter would rest on the sea floor within a detection area (if at all possible given the strong tidal currents), the detection pattern should be characterized by a continuous presence at only one detection station. However, the telemetry data shows prolonged detections of individuals observed at more than one receiver. In the telemetric dataset, we found no indications that detections were obtained from individuals that died, e.g. due to predation.

When an individual is *not* detected, several underlying explanations for this are possible:
1) the individual moved outside the wind farm OWEZ,
2) the individual was present within the wind farm but outside the detection range of each of the receivers,
3) the individual was present within the detection range of a receiver, but its signal was blocked by an obstruction between the transmitter and the receiver, such as a large boulder, the monopile or, in case of sole, by temporarily being buried deeply into the sand, which is part of their natural repertoire of behaviours.
4) the individual either died, was predated or illegally fished away while being present inside a detection range.
5) the transmitter is present within the detection range but it flawed and ceased to transmit earlier than guaranteed by the manufacturer,
6) the detection was a result of colliding signals of two other transmitters emitting at the exact same time producing a 'ghost' detection.

The current set-up of the telemetry experiments does not allow to determine which explanation is true when not detected. 1, 2 and 3 can always be true if no other conclusive evidence is available. However, some explanations can be excluded based on observed detection patterns, e.g. 4) and 5), if detections occur at a later time. Or 6) in case of series of detections with intervals of only minutes, since two consecutive collisions are extremely unlikely to occur due to the random interval varying from 150-300 s at which each transmitter signals. The VEMCO VR2 technology and V7 transmitters are widely used and thoroughly tested and this shows that 5) can probably be ruled out. In fact, transmitters often perform much longer than guaranteed by VEMCO (Lindholm et al. 2007) In case of 6) these are mostly characterized by single detections with often results in a tag-ID that was not used within the experiments. Single detections while other transmitters are detected directly prior of after these occur, should be considered with caution.

Therefore, behavioural patterns as derived from data series of detections are interpretations with different degrees of likelihood to be true. We attempted to distinguish between different behavioural patterns by hypothesizing for certain types of behaviour what detection data would result from this (e.g. Table 9 and 10, Figure 15 and 18). By using hour bins as the base for detection rate calculations in stead of all detections, analyses are less sensible to be biased by explanation 3).

Using individual time at-large, i.e. duration between first and last detection, as a proxy for individual residence time within the wind farm can lead to bias. It is an overestimation in case individuals spent part of their time between first and last detection outside the wind farm (a combination of explanation 2 alternated with explanation 1). Whereas it is an underestimation in case an individual spent additional time in the wind farm after its last detection (explanation 2). Furthermore, it is difficult to distinguish between explanation 1, 2 and 3 for individuals after their last detection.

Behaviour of sole in relation to the wind farm OWEZ

The results of the tagging and telemetry experiments indicate that sole use the southern North Sea at different scales throughout the seasons. However, no prolonged small scale use of the wind farm area was observed. There was no consistent difference in return rates within the tagging experiment for the group tagged and released within the wind farm compared to the reference group tagged and released outside the wind farm. This result is confirmed with the telemetry data where 55 % of the individual sole were not detected for more than one day following release, suggesting emigration of sole outside the wind farm within short time intervals for a substantial part of the sole tagged. This is supported by the observation that 5 of the 6 soles with transmitters that were recaptured by fisheries were detected in the wind farm for less than a few days.

No evidence was found for attraction to the monopile habitats. In fact, the observed telemetry data best matched a random use of the area with wind turbines during the period that soles with transmitters were detected (Table 9). The telemetry data does not exclude the possibility that extreme site fidelity for the sand habitats where they were caught occurs because the sole might have returned to these sand habitats in between the monopile habitats outside the detection range of the detection stations (150-250 m). However, if this strong site fidelity and large residence time was indeed the true underlying behaviour then a significantly much lower return rate for the wind farm group than for the reference group should have been observed in the tagging experiment, which was not the case.

Therefore, our combined results indicate that the majority of sole movements take place at spatial scales larger than the wind farm area of OWEZ. Some individuals use the wind farm area for periods up to several weeks during the growing season, which indicates that there is no large scale avoidance of the wind turbines, at least in part of the sole population. On the other hand there were no indications found for attraction to the monopile habitats either. All of the individual soles showed detection rates well below the 44 % as expected when attraction to monopile habitats had indeed occurred.

Behaviour of cod in relation to the wind farm OWEZ

Individual patterns of cod using the wind farm as derived from the telemetric experiments were highly variable, both between individuals and seasons. Some individuals were recorded in the wind farm for only a few days, while others spent the entire study period of over 9 months in the vicinity of one or more detection stations. A continuum of behaviours appears apparent ranging from very mobile to very resident. Rapid movements at a wind farm scale with detections at many stations in short time intervals were observed in only a few cod and only for short periods, e.g. directly following release and close to the last detection of some individuals (e.g. ID 51314 and 51312). However, even in these cases usually a 'logical' track of neighboring detection stations was followed. The majority of individuals, show diurnal patterns in detections at one receiver station, suggesting small scale (< 1km) diurnal movement.

About 30 % of the cod implanted with transmitters were only detected for less than a few days. The fact that all of the three recaptured cod with transmitters by fisheries originate from this group, suggests that these cod spent only little time in the wind farm and likely represent more mobile individuals using spatial scales larger than the wind farm area during the growing season.

About 55 % of the cod implanted with transmitters were detected from several weeks to just over two months. Individual detection rates of this group varies strongly (Figure18). About half of this group shows high detection rates > 70% during their time at-large, often with prolonged presence in a single detection area (Figure 17). Two severe storms that occurred early October and late November 2008 appeared to be associated with shifts in area used (Figure 17 and 19). Some individuals moved to another detection area, some 'reappeared' after not being detected, and a considerable part was not detected anymore (Figure 17). It is most likely that part of this group emigrated outside the wind farm, e.g. as part of large-scale seasonal movements to wintering habitats, and that part of this group remained within the wind farm for longer durations but in habitats that were not covered by detections stations, e.g. near 20 out of the 36 monopiles that were not covered by detection stations. In addition to these two behavioural scenarios (see explanation 1 and 2 above), part of this group might have died while present in the wind farm and therefore not detected anymore thereafter.

About 15 % of the cod implanted with transmitters remained in the wind farm for prolonged periods up to over 9 months, the total duration of the experiment. Most of these individuals spent prolonged periods in single detection areas with occasional shifts to other detection areas. Because it is likely that part of the 55 % group remained in the wind farm at locations not covered by detection stations, the actual percentage of cod that stayed in the wind farm during several seasons, is most likely higher than 15 %.

Unfortunately, the batch caught and released in January 2009 consisted of only 7 in stead of 40 cod, despite intensive fishing on two consecutive days. Considering the diurnal patterns as shown in Figure 20 and 21, when most individuals were only detected during the night, in retrospect and with the results of the research available fishing with rod and line above the scour beds around monopiles during the day time might indeed not have been the best way of collecting cod in early January. The proportion of residence was high in this group, with 4 out of 7 remaining detected until late spring and 3 out of 7 until the end of the experiment. All of these but one remained detected within a single detection area, whereas the one shifted from one prolonged presence in one detection area to a prolonged presence in another detection area.

For cod staying in the wind farm for prolonged periods, average detection rates are much higher than expected from random movement scenarios (Table 10 and Figure 18). Even though the detection range extends to 150-250m around the monopile covered by a receiver which leaves the theoretical possibility open that sand habitats in the vicinity of wind turbines are favoured rather than the scour bed and monopile habitats, it is hard to think of a reason why these sand habitats would be favoured over other sand habitats within the wind farm that are not covered by detection stations. The observed seasonal and diurnal patterns of cod present in the wind farm for prolonged periods suggest that the monopile habitats attract at least part of the cod population. This is further supported by:

1. the very low catches of cod in the trawl surveys within the wind farm during the summer (when no diurnal absence outside the detection areas is observed) and the much higher numbers of cod caught during the T1 winter survey (when cod appear to have left the area directly around a monopile during the day), compared to T1 summer and T0 (ter Hofstede 2008)
2. the observations with a DIDSON acoustic high resolution camera show that stationary aggregations of fish were found directly above the scour bed and around the monopiles in July 2009. Angling on these aggregations showed that they consisted of mainly cod and horse mackerel., In contrast, the sand habitats around the monopiles showed very low numbers of fish (Couperus et al. 2010).

Whether the monopile constructions act as attraction devices, i.e. only temporarily changing the distribution of cod without changing the population level, or whether they provide good quality habitats providing better survival or foraging and therefore enhance overall cod population, can not be concluded from our data.

We found no significant evidence for disturbance or avoidance of cod in relation to the operation of the wind turbines. Of course, by sampling only cod in the presence of monopiles we might have selected for individuals that are less susceptible to disturbance by wind turbine noise or vibrations. However, at least part of the cod population shows no signs of disturbance or avoidance of the wind turbines during the operation phase.

The length distribution of the cod caught within the telemetry experiments in the wind farm varied from 24-47 cm. Most of these must have been juvenile cod (Yoneda & Wright, 2004). No larger adult cod were observed so far. For this, three explanations might be put forward; 1) adult cod behave differently than juveniles and tend to avoid the wind farm, or at least show less attraction; 2) Due to the 'young' age of the wind farm (just over a year at the start of the telemetry experiment), colonization of the newly created monopile habitats was mostly performed by dispersing juvenile cod. In time, they may survive and grow to resident larger individuals; 3) there is no adult cod present in the coastal zone where the OWEZ lies.

Individual behaviour in cod varied considerably from moving out of the wind farm shortly after catch and release, to moving out in autumn after spending several weeks to months in the win farm to high degrees of residency, even up to the level of long-term stays around single monopiles. Whether these differences are related to the sex of cod could not be determined, i.e. whether males show different behaviour than females. Most of the cod used in this study were sexually immature. Because we used live cod that were implanted with transmitters, we were unable to determine the maturity or sex of each individual fish, which requires internal inspection of the gonads. Little is known on differences in behaviour between male and female cod, only during the spawning period some information on differences in behaviour is available (Robichaud & Rose, 2003). Whether cod uses the wind farm for spawning is at present unknown. Given it's presence year-round, it is likely that the wind farm is used for foraging and refuge, but because most, if not all, of the individuals were immature cod, it's significance for spawning can not be determined.

Comparison of cod behaviour in the wind farm to behaviour in 'natural' conditions
In recent years, telemetric studies on cod in many different locations, has increased the insight in cod behaviour enormously. All of these studies find large variation in behavioural patterns between different areas, between individuals within the same area and within individual for different seasons (Righton et al. 2001, Neat et al. 2006, Lindholm et al. 2007, Hobson et al. 2007, Bergstad et al. 2008). The reasons for these high variations in spatial scale between and within different cod stocks are yet poorly understood (Neat et al. 2006).

Lindholm et al. (2007) studied how cod use localized deep boulder reefs in the western Gulf of Main using the same acoustic telemetric methods as we did, and found a similar distribution of more 'transient' individuals being detected only briefly after release to very 'resident' individuals spending the entire study period (three months) on a single boulder reef at scales less than 400 m. In the study by Lindholm et al. (2007), cod were followed for three months during May-February, but no clear diurnal patterns were observed.

Also Bergstad et al. (2008) used acoustic telemetry and found large individual differences in behaviour of cod using fjord and coastal waters in southern Norway ranging from highly resident on small spatial scales to more mobile individuals using larger areas.

Next to studies on cod using acoustic transmitters and detection stations similar to our study, also Data Storage Tags are often used. These tags provide continuous individual tracks of water depths and temperatures that were used by the tagged cod between the period of release and recapture (Righton et al. 2001, Neat et al. 2006, Hobson et al. 2007). Spatial patterns are not directly measured in these studies but reconstructed using geolocation modeling (e.g. Pedersen et al. 2008) and are less accurate at small spatial scales. Vertical movements however, are detected with high precision. Also here strong differences between stocks, within stocks and within individuals throughout time were observed. Neat et al. (2005) studying cod in the coastal waters of the Shetland Islands in the northern North Sea found a complete reversal of diel pattern in water column use in spring, very similar to the reversal in diel patterns we observed in spatial use during spring (Figure 20 and 21).

Comparison of the variations of behaviour in cod as observed within the wind farm shows that these are very comparable to the variations in behaviour as found in other areas and around natural reefs.

Can the wind farm OWEZ act as a refuge against fisheries for sole and cod?
For both sole and cod, no reverse effects of wind turbine operation in the wind farm were detected. The results for sole indicate that the spatial scale of the current wind farm OWEZ is presumably too small to act as a refuge against fisheries. For cod, however, at least part of the population appears to be attracted to the monopole habitats and spent prolonged periods within the wind farm. Some individuals can be considered residents, being present in the wind farm throughout the different seasons. Thus, if fishing remains effectively banned from the wind farm, it can act as a refuge against fisheries for cod. Although at this moment, it remains unclear whether this is only the case for juvenile cod or in time also for adult cod. To what the degree the cod population benefits from the OWEZ depends on the usage of adult cod and the size of the 'resident' population being present within the wind farm relative to the total population. No knowledge on this is available at present.

The telemetric method used proved robust enough to study behaviour within the wind farm. Recent developments in the possibility of using VR2 receivers for 3D research with high accuracy and in combination with other novel techniques such as DIDSON, enables a more detailed study of the behaviour and response of fish to wind turbines *in situ* in the near future.

Evaluation of the choice for sole and cod as target species
This study was limited to cod, selected as a species that potentially uses the newly created habitats associated with the turbine monopiles, and sole, selected as a species that potentially uses the sandy habitats in between monopiles. The choice for these two commercially important species proved fruitful, i.e. the species were caught in sufficient numbers to determine their behaviour in relation to the offshore wind turbines and all the research questions could be addressed. Moreover, cod produced large telemetry datasets that enabled us to determine whether the operation of wind turbines affected their behaviour.

5 Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 March 2010. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

IMARES Report C038/10
Project Number: 4392500902 (MEP NSW T1 Tagging) & 4392500901 (MEP NSW T1 Fish behaviour)

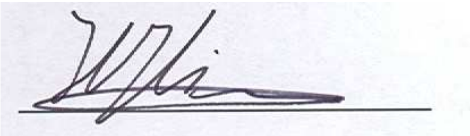
The scientific quality of this report has been peer reviewed by a colleague scientist and the director science of IMARES.

Approved: dr. M. Dickey-Collas
Senior Scientific Researcher

Signature: in absence signed by drs J. Asjes:

Date: 9 April 2010

Approved: prof. dr. H.J. Lindeboom
Management Team, Director Science



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