Use of high resolution sonar for near-turbine fish observations (DIDSON) – We@Sea 2007-002

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Summary

In this study we investigate small scale distribution of pelagic fish within a windfarm by means of a high resolution sonar (DIDSON, Dual frequency IDentification SONar; Soundmetrics). In addition we assess the bias of small scale variations induced by the effects of wind turbines (monopiles) on distribution of the pelagic fish community in the hydro acoustic surveys carried out on the OWEZ Near Shore Wind farm (NSW).

A deployment for the use of a DIDSON sonar is presented as well as a survey technique from onboard a RIB (inflatable boat). The qualitative results from this study clearly show that the fish concentrations around the monopiles are much higher in the first 15 – 20 meters. Overall fish density was on average a factor 37 higher above the scour bed around the monopiles than in the open water habitats in between monopiles.

We calculate the possible bias in a large scale hydro acoustic survey for densities around the monopiles. Avoidance does not lead to a significant bias. A density higher than 100 times the density in the open water leads to an underestimation of 8%. For the OWEZ windfarm, the factor 37 found from the DIDSON data would lead to an underestimation of 3% of the fish density.

More insight in the spatial and temporal dynamics of occurrence of pelagic fish is needed for a complete understanding of the species-specific response of pelagic fish to wind farms and monopiles. For this, hydro acoustic surveys and DIDSON observations are complementary, focusing on different spatial and temporal scales ranging from meters to kilometres, and from tidal, daily to seasonal. Although DIDSON has more potential for species identification than other acoustic methods, additional techniques are needed to determine species composition at the monopiles at the time of the large scale acoustic surveys.

1 Introduction

1.1 Background

The Dutch government allowed the construction of a Near Shore Windfarm (NSW) demonstration project under the condition that a monitoring program on - amongst other things – the ecological impacts is carried out. Within the NSW - MEP project IMARES carried out the baseline study (T0) for pelagic fish. In this study the pelagic community was sampled twice; in April and October 2003 (Grift *et al.* 2004). The windfarm was built in 2007 and the T1 survey was carried out in order to establish the situation one year after the construction of the windfarm. The results of this survey will be reported in 2011 after the completion of a third survey (T5).

After windfarm construction, we were confronted with limitations in the execution of the T1 survey. Practical and safety considerations make it impossible to use existing survey techniques for detecting fish within the direct surrounding of wind turbines ("monopiles"). For safety reasons the research vessel cannot approach the turbines close enough to be able to observe fish. In addition, it is logistically not possible to re-locate acoustic equipment off the ship. Using the present applied acoustic technology would not reveal fish distribution on a fine scale in relation to the windmill monopiles.

In the case of relatively high or low concentrations in these areas (illustrated by Figure 1) the current survey scheme might lead to underestimations of the pelagic fish community in both the hydro acoustic and trawl surveys in the wind farm because the research vessel has to stay away at least 200m from the monopiles. It is essential to know at which spatial scale fish are redistributed, so that the quantitative abundance estimations may be corrected for systematic variations in densities within the wind farm.

There are several hypotheses why pelagic fish distributions would be affected by the presence of a windfarm. Two main hypotheses are that (1) fish increase in the windfarm because of the absence of fishery and (2) fish concentrate around the windmill monopile: the so called artificial reef effect. Fish, both demersal and pelagic, are known to concentrate around reefs. All around the world artificial reefs are constructed for reasons of increasing the fish production, restoration of lost natural environment, or to protect fish against (trawl) fishery. The reasons for attraction vary by species and include increased shelter for both predators and prey, increased food supply, an increased complexity of the physical environment leading to suitable habitats for more species. Hence it is to be expected that the monopiles have an effect on the abundance and distribution of fish in windfarms.

Here we present trials with an easy to handle high frequency sonar, with the objective to develop a technique for application in studies of future windfarms. In this way we hope to gain insight into the effects of both a variation in the number of windmills in the windfarm and the scaling of the windfarm itself on the local fish populations.

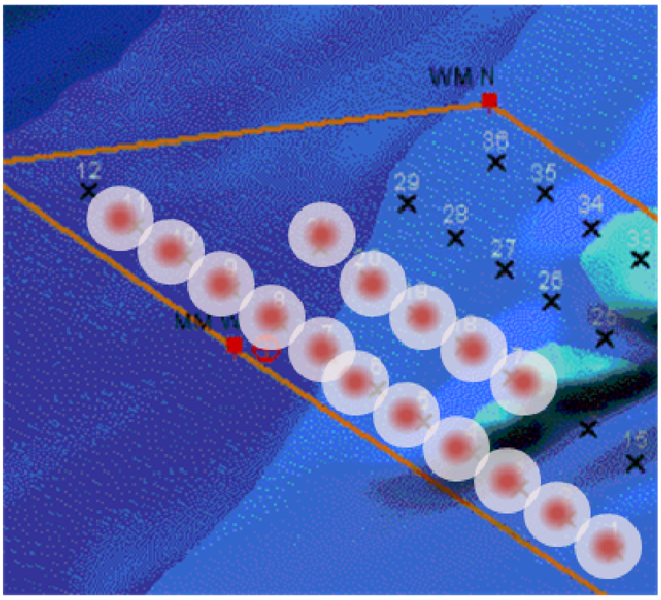


Figure 1. Schematic presentation of possible increased fish concentrations near individual monopiles in the OWEZ windfarm. The transects of acoustic surveys in 2003 and 2007 are situated amidst the rows of windmills which could lead to severe under estimation of pelagic abundance.

1.2 Objective

The objective of this study is to develop a methodology for monitoring of fish behaviour in the direct surroundings of artificial reef elements such as wind turbines, ship wrecks, pipelines and offshore platforms which are known to attract fish. More specifically, we assess the effect on the outcome of the large scale acoustic surveys executed in 2003 and 2007 and to be executed in 2011 in the Near Shore Wind farm

2 DIDSON

For this study, a high resolution DIDSON sonar was used (DIDSON: Dual frequency IDentfication SONar: http://www.soundmetrics.com/). The DIDSON uses acoustic lens technology which forms acoustic images with greater detail than found in conventional sonars. DIDSON allows to observe fish (behaviour) in turbid water. Methods for processing fish counts are available in the DIDSON software. The DIDSON is relatively easy to handle, which allows for a close, but safe approach to the turbines, by means of scuba diving or by operating it from a small boat. In addition the resolution of the echogram provided is sometimes high enough to allow species identification. The standard DIDSON operates at two frequencies (Table 1) and provides images of objects from 1 m to over 30 m in range.

Table 1. Specifications of the two frequencies

Mode	Operating Frequency	Beam width (2-way)	Number of Beams	Range
HF	1.8 MHz	0.3° H by 14 ° V	96	1-15 m
LF	1.1 MHz	0.6° H by 14° V	48	1-35 m

Photo 1. DIDSON as stand alone unit with the diving mask.

3 Developing methods in the OWEZ windfarm

3.1 Survey area

The OWEZ windfarm is situated at 10-18 kilometer at sea near Egmond aan Zee. The windfarm contains 36 windmills, each with a capacity of 3 MW. The total surface area is about 27 km2. For this project, tests were performed at three windmill poles, while the actual recordings were done at five other poles: pole number 19, 20, 26, 29 and 36 (Figure 2). The baseline survey in April and October 2003 revealed sandeel (*Ammodytes* sp), mackerel (*Scomber scombrus*) and clupeids: herring (*Clupea harengus*), sprat (*Sprattus, sprattus*), pilchard (*Sardina Pilchardus*) and anchovy (*Engraulis encrasicolus*) and horse mackerel (*Trachurus trachurus*) as the common pelagic species in the area. Sandeel and mackerel were dominant in April, mackerel and clupeids dominated in October while in June Sandeel dominates.

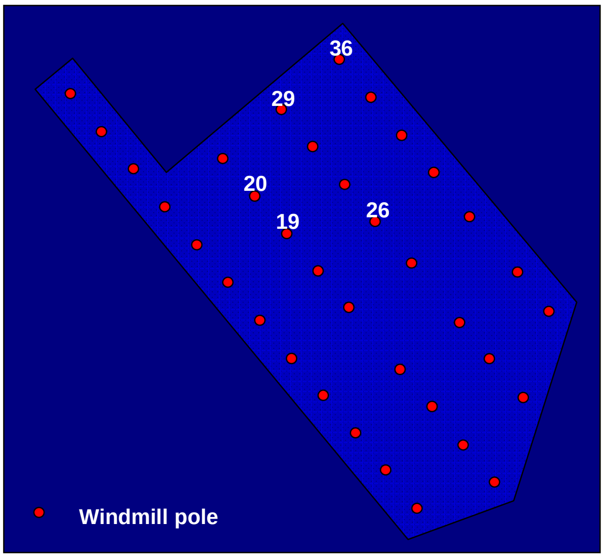


Figure 2. Overview of the windfarm with the five windmill poles that were investigated with the DIDSON.

3.2 Field work

Field work has conducted in the windfarm itself, on board the MV Zeeland. Observations with the DIDSON were carried out by using different platforms: from the MV Zeeland (photo 2), a RIB (Rigid Inflatable Boat) and diver-held (photo 3).

Photo 2. MV Zeeland

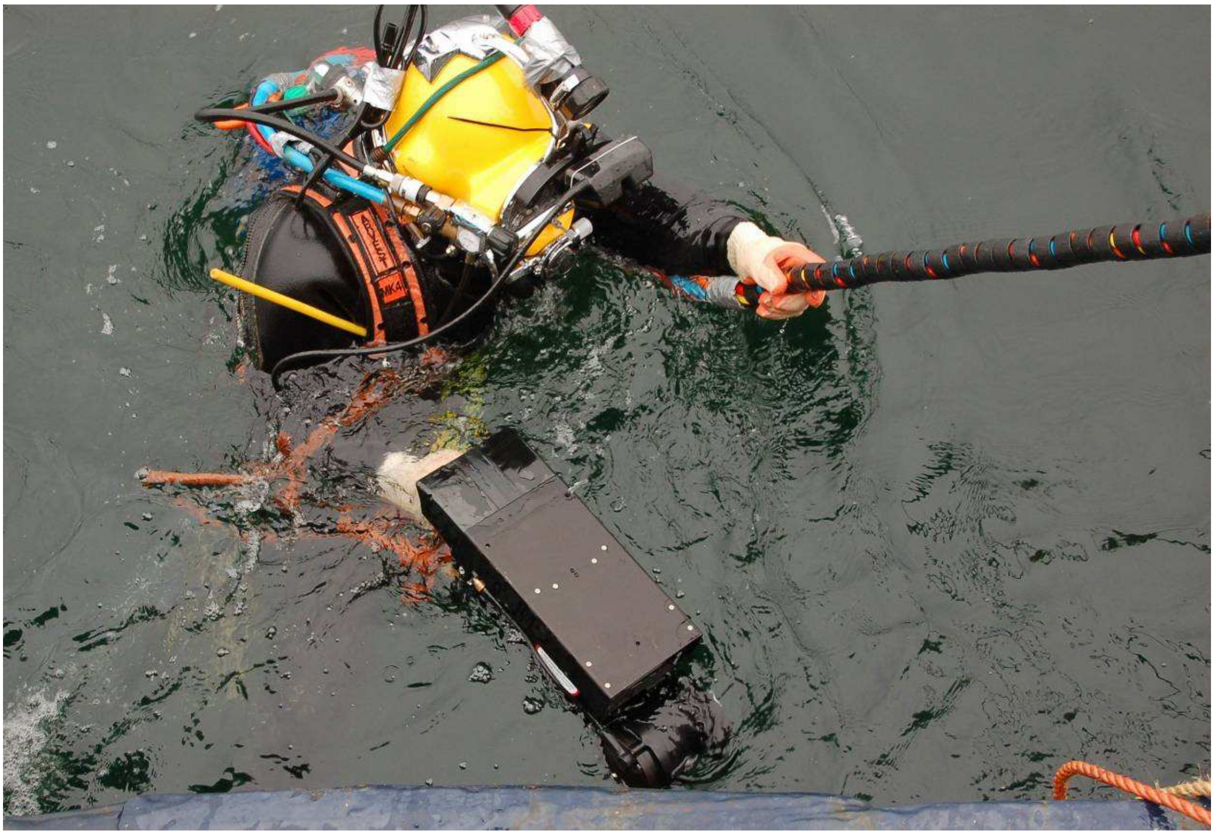


Photo 3. Diver with DIDSON

3.2.1 Screening different methods of applying the DIDSON sonar

Deployment

A special device was constructed in order to operate the sonar from a RIB (Photo 4).

Photo 4. Deployment device to operate the DIDSON at the transects from an inflatable boat.

Photo 5. Action RIB

Beam angle and distance settings
Different types of image are obtained if the DIDSON is held at different angles. The DIDSON was tested at three different tilts ranging from a horizontal to a vertical position, to determine the best angle for analysis (Figure 3). Note that the viewpoint of the images obtained from the DIDSON are always perpendicular to the direction the DIDSON is held.

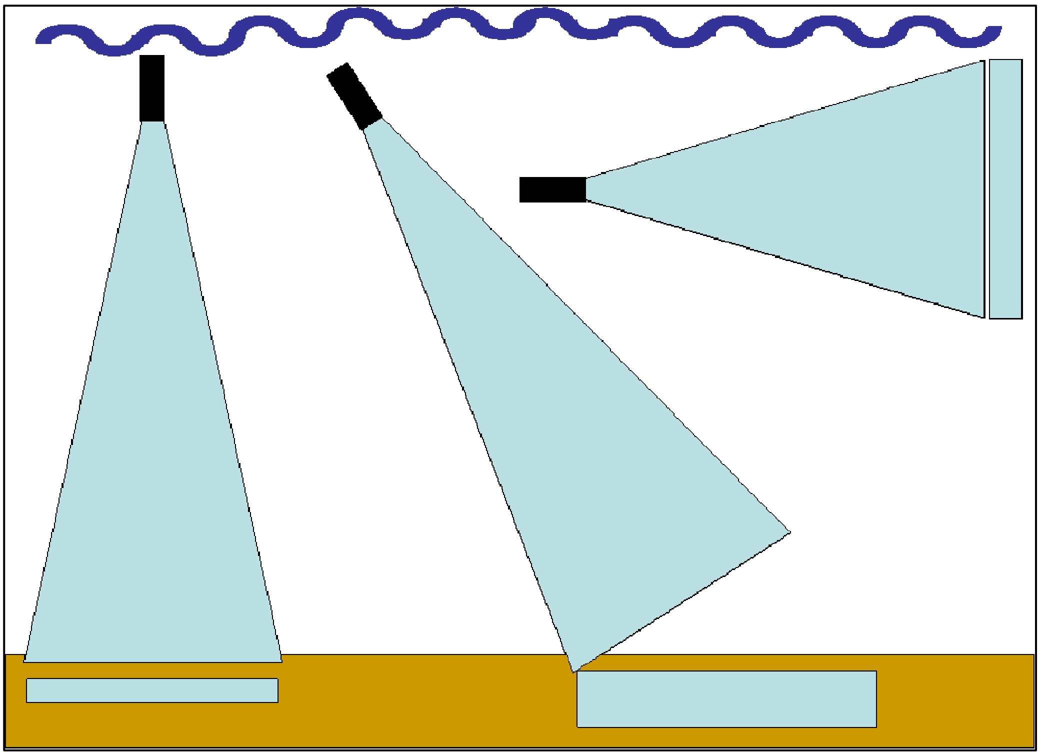


Figure 3. Directions of the DIDSON. Left=vertical, middle=diagonal, right=horizontal.

When the DIDSON is held in a vertical position (sending the beams from surface to bottom), the images are shown in a perpendicular angle. This results in images which give the impression that the viewer is in the water looking horizontally at the fish and the structure (Figure 4). Because of the narrow width of the beams, the images lack depth.

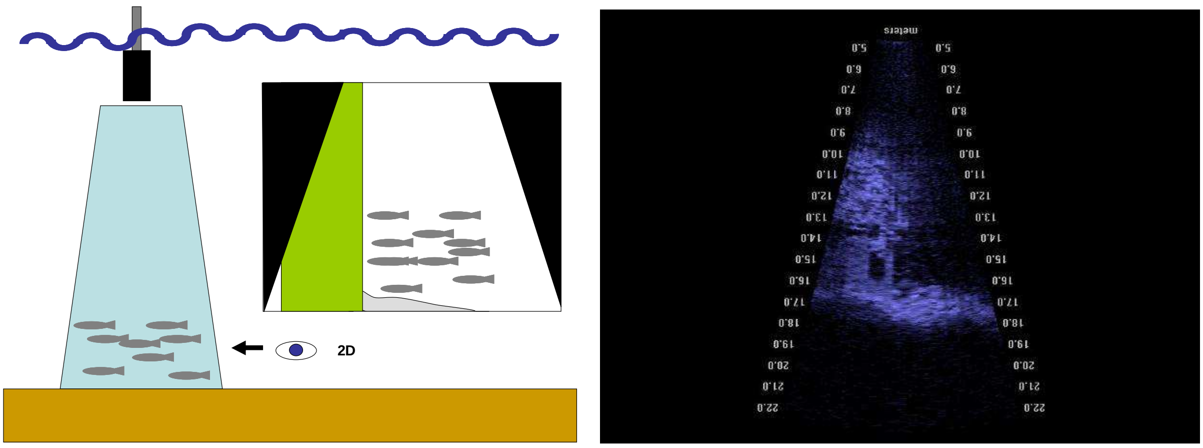


Figure 4. Images when the DIDSON (black box on the left) is held in a vertical position. Left figure: the eye indicates the direction how the images have to be interpreted. The box on the right shows how images of fish near a windmill pole (green bar) will look like. Right figure: DIDSON image with windmill pole on the left.

When the DIDSON is held in a diagonal position, sending beams diagonal to the bottom, it looks like the viewer is high in the water , looking down towards the bottom. Because the beams cover a wider area, the images have more depth (Figure 5).

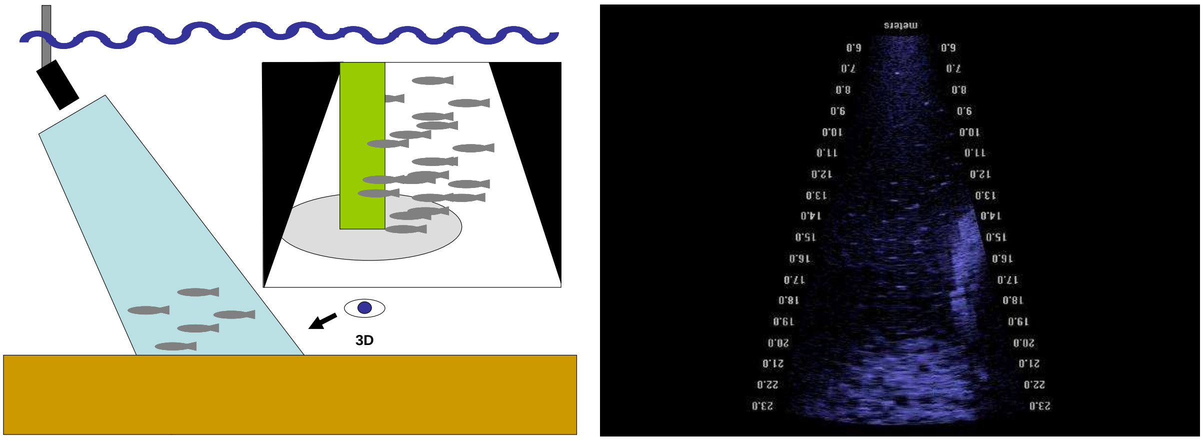


Figure 5. Images when the DIDSON is held in a diagonal position. Left figure: the eye indicated the direction how the images have to be interpreted. The box on the right shows how images of fish near a windmill pole (yellow bar) will look like. Right figure: DIDSON image with windmill pole on the right.

When the DIDSON is held in a horizontal position the beams are sent into the open water. This results in images for which it looks like the viewer is hovering above the water and looking vertically into the water. The images are more or less 2-dimensional (Figure 6).

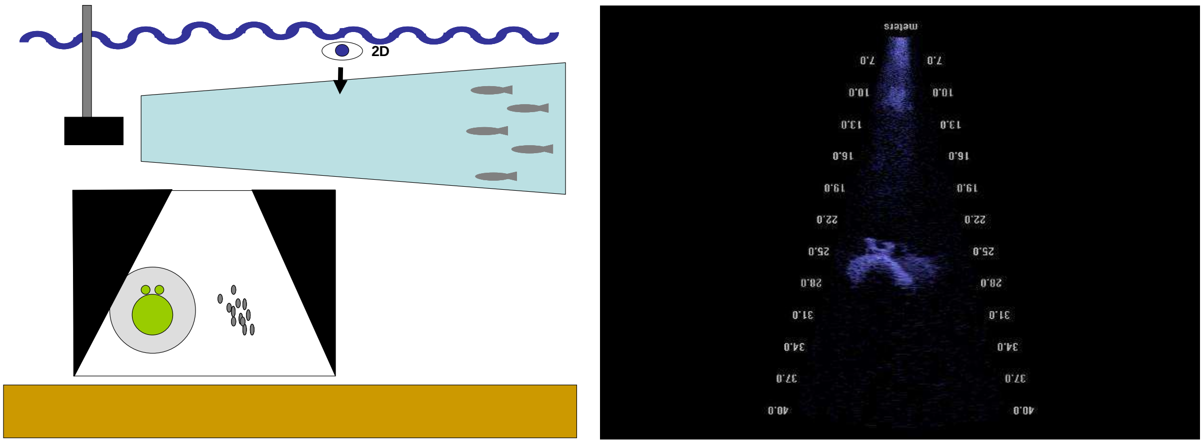


Figure 6. Images when the DIDSON is held in a horizontal position. Left figure: the eye indicated the direction how the images have to be interpreted. The box below shows how images of fish near a windmill pole (green circle with two J-tubes) will look like. Right figure: DIDSON image with windmill pole and J-tubes.

The vertical holding position of the DIDSON was thought to be most suitable for assessing the abundance of fish near the windmill pole. When most fish are near the windmill pole, the horizontal and in lesser degree the diagonal direction will result in fish overlapping within the image, thereby having greater uncertainty in the estimates of fish abundance than when holding the DIDSON in the vertical direction. In the vertical position the image is more or less 2 dimensional, therefore the chance of fish overlapping in the image resulting in an underestimate of the number of fish in the images is much less compared to holding the DIDSON in the diagonal position, when fish in a 3 dimensional view can overlap (fish swimming behind another fish, and as a result not visible).

Stationary vs transects

Application of the DIDSON from a small inflatable boat was better when sailing slowly: even in very quiet water the movement of the boat, and consequently the DIDSON resulted in the object popping up and out of the beam, making proper analysis of targets very difficult or impossible. When sailing slowly, the boat and the DIDSON are much more stable. See clips at http://www.didson.wur.nl/windmolenpark.

3.2.2 Target identification

Species identification
We explored to which degree species identification was possible. In some occasions it was possible to recognize species from the echogram by means of shape, fin position and behaviour. Additional information was available from diver and angling observations.

3.2.3 Concluding remarks

It is possible to count number of fish on small range (within 30m) and estimate the size within 10 cm classes. Experience from field practice at sea shows that operating the DIDSON from a moving platform is only possible in vry good environmental conditions. Even under these conditions it is normally not possible to recognize the species. Experience from fixed platform shows that the power to identify species increases if the sonar is not moving.

4 Detecting fish around monopiles in the windfarm

4.1 Selected method

The DIDSON was mounted on a rubber boat with an outboard engine in the vertical position. A track along the windmill pole and open water was selected and this track was divided into 7 transects:

1) Half a circle around the windmill pole with a 5-10 m distance from the pole;
2) Transition zone between scour bed and sandy bottom;
3) Open water along the ship to the end of the anchor line;
4) Open water, 50 m perpendicular to the anchor line;
5) Open water, back to windmill pole;
6) Transition zone between scour bed and sandy bottom;
7) Back half a circle around the windmill pole with a 5-10 m distance from the pole.

The DIDSON recorded continuously along each of these transects. For the analysis of the data, three different substrate areas were selected from these transects (Figure 7):

1) the scour bed next to the windmill pole (2 transects; 1, 7);
2) transition zone between scour bed and sandy bottom (2 transects; 2, 6);
3) open water (3 tracks; 3, 4, 5).

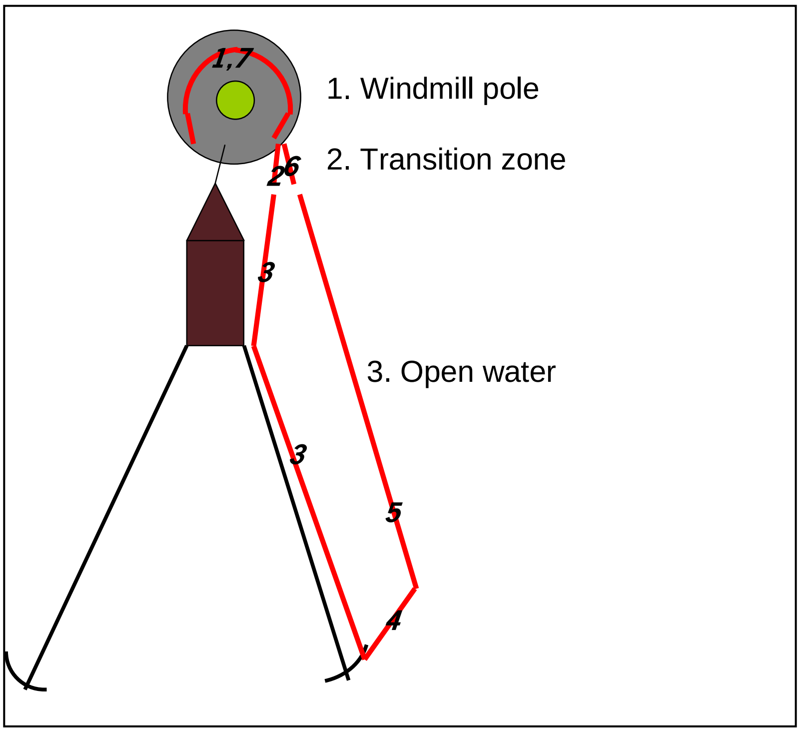


Figure 7. Overview of the three substrate areas and the transects. The boat is attached to the windmill pole and held in place with two anchors.

4.2 Data analysis

Fish were counted manually per frame using the software “DIDSON V5.21”, which was also used to realize the recordings. This software also includes an automatic fish detection tool. This could not be used because the pictures recorded were not stable enough to get satisfying results. For a clearer picture and therefore an easier counting of fish the background-subtraction function was used. This tool removes the static portion of the acoustic image, showing only objects in motion (Figure 8).

Fish density was recorded by counting the number of fish by frame. Since it was found that the numbers of fish within the immediate vicinity of the monopiles (area 1, “Windmill pole”) was much higher that in open water, different methods have been applied for the three different areas. The number of fish at the windmill pole were counted in one per fifty frames. In the transition zone, three frames were counted. In open water the frame with the highest number of fishes was taken into account. This method minimizes the loss of information due to frames with zero fish.

The fish counts were converted to density by dividing them by the volume of water in the sonar beam. For the near-monopile and transitory zone this involved calculating the volume from the beam dimensions, bottom depth, and the angle of the beam to the bottom for each frame. For the open water, the volume of the total inspected transect was estimated using the length of the transect, beam dimensions, and average water depth. It should be noted that these volumes are crude estimates, since the actual volume is also affected by variations in bottom depth, and the wave action on the boat from which observations were made.

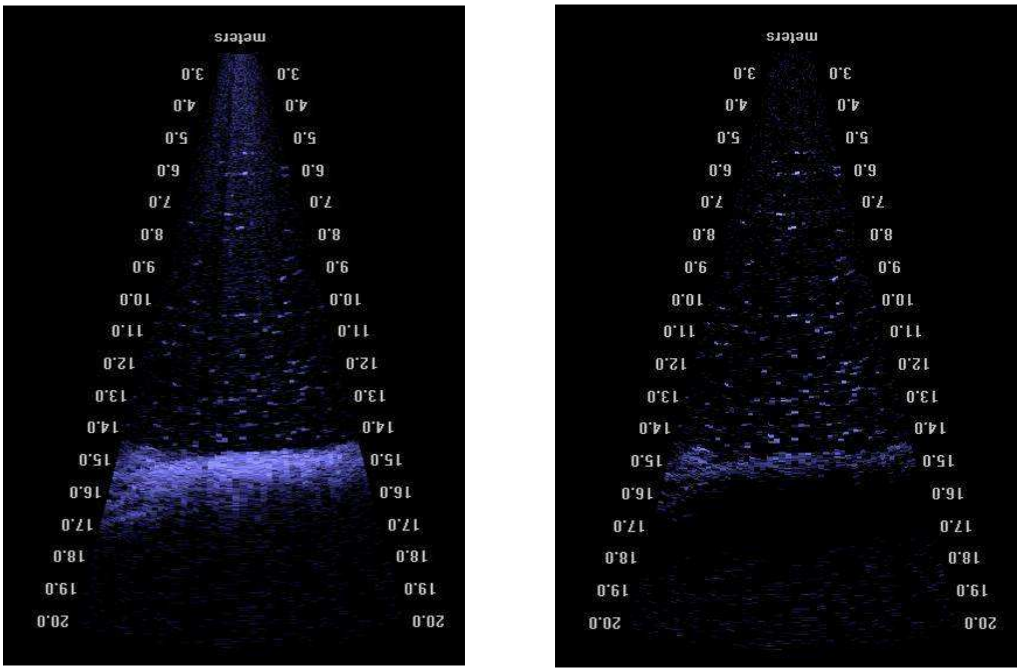
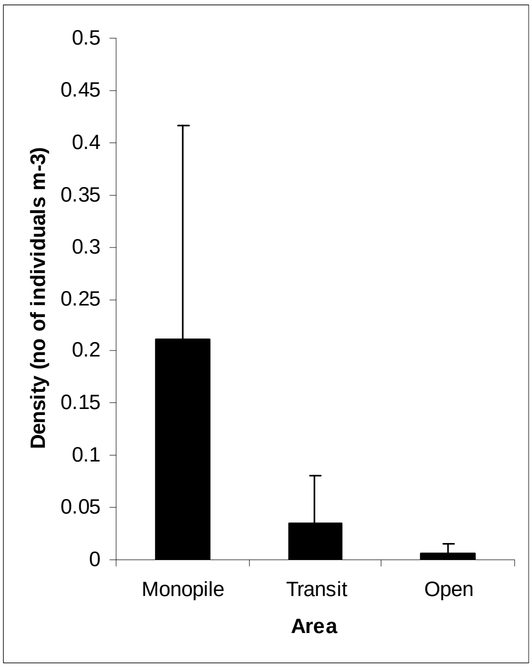


Figure 8: Frame without (left) and with background subtraction (right).

4.3 Results

4.3.1 Fish density

The average fish density per volume water was found to be on average a factor 37 higher in the direct vicinity of the monopiles compared to the open water around it (Figure 9). The variance within each area among monopiles was found to be rather high for all areas, with the standard deviation approximately the same order of magnitude as the mean. In spite of the large variance, we found that the pattern of strongly elevated density near the monopile compared to the open water was clearly present in every replicate. In the transitory zone separating the direct vicinity of the monopile from the open water, we found an intermediate fish density in all but one replicate, where the transit zone showed relatively low fish density, while the open water fish density was exceptionally high. The high density in the open water in this replicate was the result of a single very large school crossing the sonar beam (Video: “School vis in het open water” http://www.didson.wur.nl/windmolenpark).



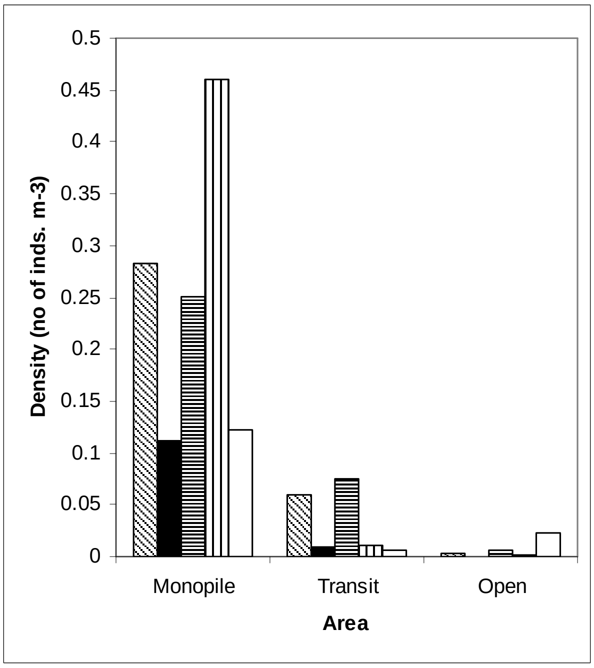


Figure 9: Left panel: Density of fish in different proximity zones to the monopiles (mean+SD). Right panel: Results breakdown per monopile. (Rocks=near monopile, Transit=transitory zone, Open=open water).

4.3.2 Role of the transitory zone

We hypothesized that the transitory zone between the open water and the near-monopile area functioned as a spillover-area, where fish density becomes high only when there is strong crowding in the direct vicinity of the monopile.

Support for this idea from our observations is ambiguous (Video: "Overgang van zand naar steen rond windmolenpaal" http://www.didson.wur.nl/windmolenpark). While there seems to be a general trend that density in the transitory zone is higher when the density around the monopile is higher, one replicate shows a strong deviation from this pattern. More research is needed to assess the function of the transitory zone.

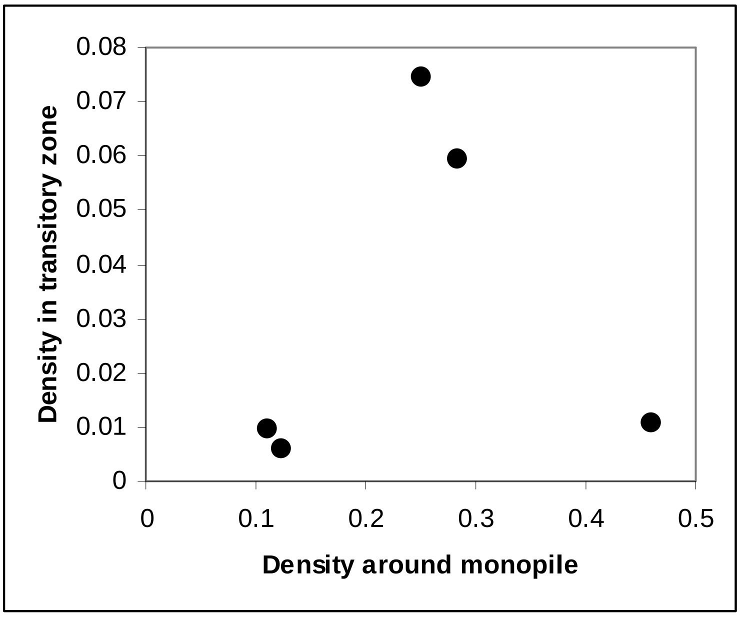


Figure 10: Relation between fish density near the monopile and in the transitory zone for each replicate.

4.3.3 Species and size composition

Some insight into the fish species and size composition directly around the monopiles was obtained by angling along a subset of monopiles. This showed that the majority of fish were mackerel and horse mackerel in the size range 25-35 cm. These two species made up around 75% of all fish caught. The rest consisted of cod, in the size range 30-55 cm.

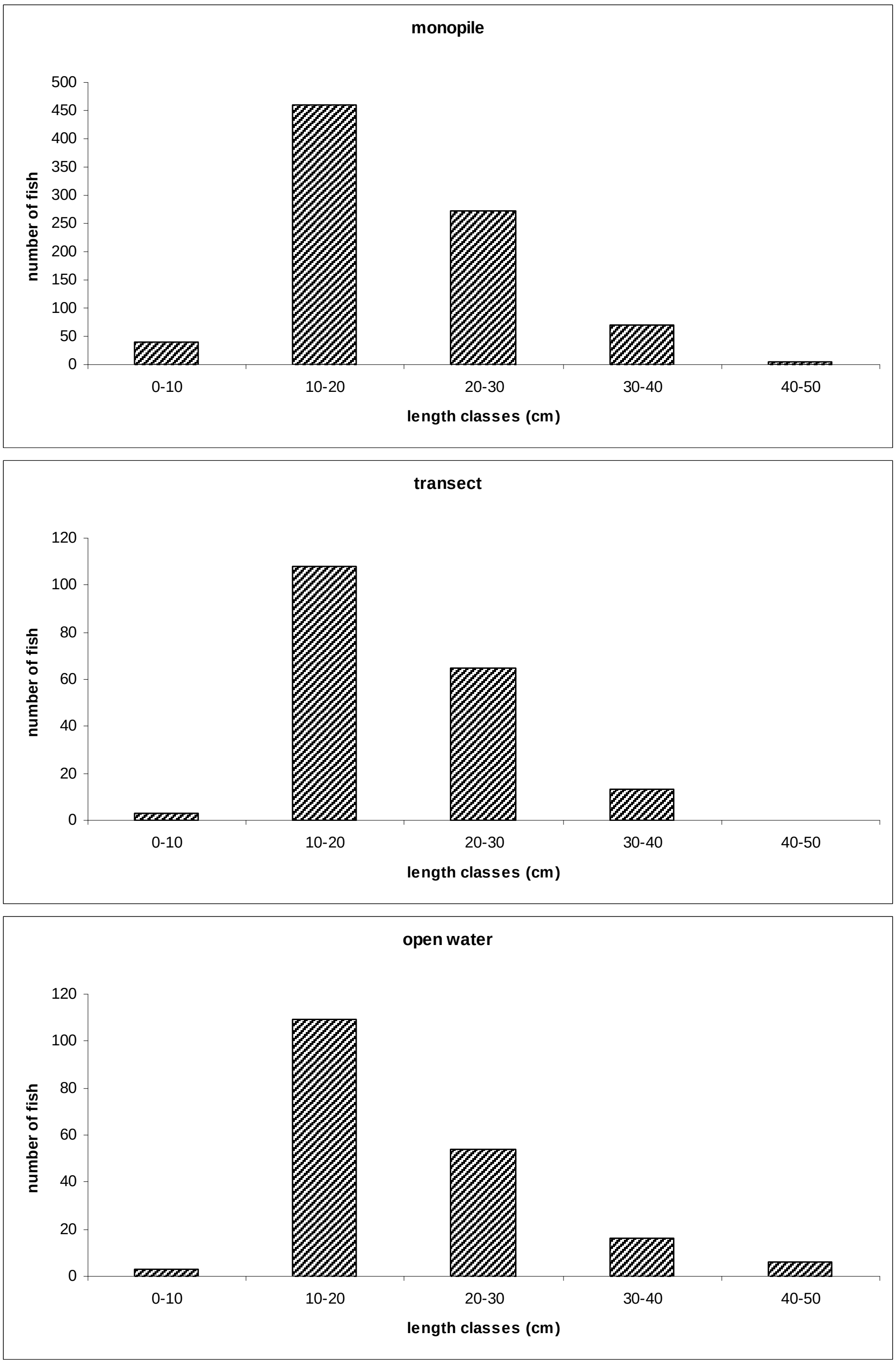


Figure 11. Length distribution of fish around the monopiles as measured from the DIDSON frames.

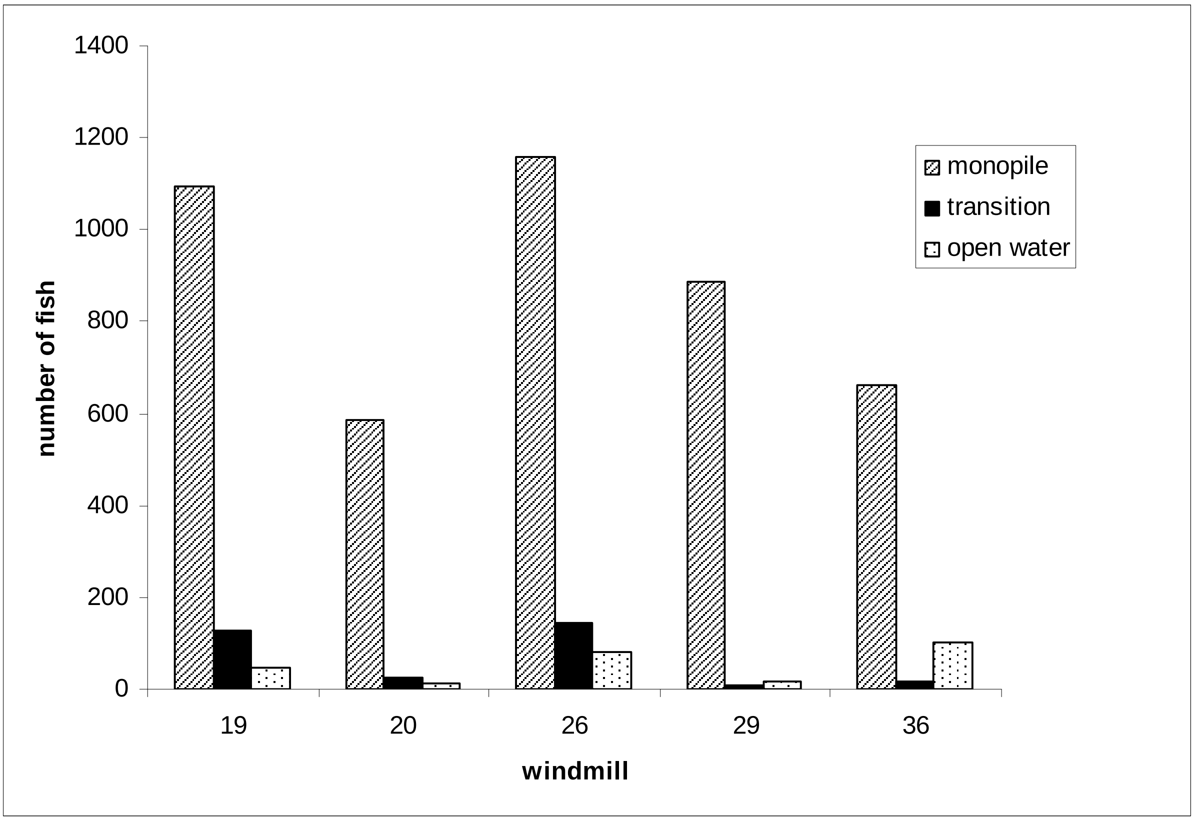


Figure 12. Total number of fish per monopile.

5 Discussion

The qualitative results from this study clearly show that the fish concentrations around the monopiles are much higher in the first 15 – 20 meters. Overall fish density was on average a factor 37 higher above the scour bed around the monopiles than in the open water habitat between monopiles. Length of the observed fish was mainly in the 10 - 40 cm range. The reason to collect observations directly near the monopiles was that fish densities around the monopiles might be very different at close range than farther away. This might lead to bias when comparing the baseline hydro acoustic observations with observations in the windfarms.

Size composition
Length measurements were carried out with the software provided with the DIDSON. Because most fish were observed at distances between 10-20 m, while the resolution is decreasing with distance, and because the orientation of individual fish could not accurately be seen at these distances, the precision of the measurements are course. The results indicate a length range of 10 – 40 cm. This finding is partly confirmed by rod-caught fish, which consisted of specimens of cod, horse mackerel and mackerel of 20 – 30 cm and by the anecdotic observations of divers, who reported mainly horse mackerel and cod. Divers observed horse mackerel picking invertebrates that came available from the substrate during their under water work. There is a danger of a bias towards bigger specimens because the bigger specimens are more likely to be detected at larger ranges. On the other hand fish lengths may have been under estimated during the post processing because it is not always possible to see whether a target (fish) was full length in the sonar beam or whether it swam diagonally towards or

away from the sonar. At close range up to 10 m, resolution of the DIDSON enabling length measurements, individual orientation and species recognition are best.

Observed fish behaviour
The overall impressions from the observations with the DIDSON was that fish around in the monopiles showed relatively stationary behaviour and appeared in loose aggregations rather than dense schools. Contrary to what was expected, fish aggregated on all sides of the monopiles, irrespective of the tidal currents. Given their size, the observations of divers and the anecdotal angling catches, these aggregations directly around the monopiles most likely consisted of predominantly horse mackerel and cod. Occasionally a small denser school would enter the beam showing more active and directional swimming (Video: "School vis rond windmolenpaal" http://www.didson.wur.nl/windmolenpark**)**. Given the size and behaviour of these more active denser schools, these may have consisted of smaller horse mackerel, mackerel or perhaps clupeids. The DIDSON observations gave no indications that species that were dominant in the hydro acoustic baseline surveys in 2003 and 2007 (i.e. sandeel and clupeids) were present around the monopiles in high concentrations.

There are biological reasons that make it unlikely that sandeel appears around the monopiles in high concentrations. Sandeel are restricted to sand habitats and are usually not found above rocky substrate (Wright *et al.* 2000). We could not determine whether clupeids are present around the monopiles and if so, in what proportion of the fish assemblage. It is well known that objects attract fishes, mainly gadoids. Artificial reefs are also very attractive for young fish, since they provides shelter in the form of shade or small holes and crevices. However the specimens involved are demersal species or species that do not school when in the juvenile stages (Charbonnel *et al.* 2002; de la Moriniere *et al.* 2004; Hunter en Sayer 2009) such as clupeids. Strikingly (Herrera *et al.* 2002) found indications that after the introduction of artificial reefs the number of predators increased, causing a dramatic reduction of juveniles of some other species. This does not support the presence of small clupeids. However the greater part of the fishes are within the range of 10-20 cm (Figure 11), which is in the range of size of clupeids found along the Dutch coast (Grift *et al.* 2004).

Sampling conditions
The DIDSON measurements could be carried out in comparatively good weather conditions with wave heights of less than 0.5 m and wind force less than 3. However, even under these conditions using a RIB as a platform gave beam movements that lead to less precision. Due to movements of the beam, recorded fish appear and disappear in and from the beam. Performing transects while slowly sailing with the RIB gave more stable images than from a stationary floating RIB, hence our choice for selecting transects as the method of observation. If logistically possible, a fixed position within the water column with a construction that is independent from wave action, will yield the best observations with a DIDSON.

Using the RIB might have interfered with the observed fish behaviour. We observed no response of fish within the aggregations when approaching with the RIB, both when drifting without using the engine, or when the engine was started and subsequently used. This gives confidence that our measurements, with fish mainly present at water depths between 7-18 m, are an accurate reflection of fish occurrence around the monopiles. At very close range < 7 m, the presence of the RIB might have caused some deviation in fish occurrence. There are no indications that this occurred more strongly around the monopiles or in open water and that therefore the observed differences in fish densities are valid.

Windfarm and monopiles, attraction or avoidance of fish?
Pelagic fish might respond to the presence of a windfarm with monopiles in many different ways and on different scales. On a large scale, fish might avoid the entire windfarm, e.g. due to underwater noise or maintenance activities (see Figure 13A). It is also possible that fish might favour the windfarm, e.g. due to the lack of fishing activity or increased prey abundance (see Figure 13B). On a small scale, fish might avoid individual monopiles, e.g. due to underwater noise, vibrations, unsuitable local habitat substrate (monopile and rocky scour bed) or the presence of more predators (see Figure 13C). In contrast, fish might be attracted to individual monopiles, e.g. due to favourable prey abundance, preference of hard substrate habitats or shelter for tidal currents (see Figure 13D). Finally, pelagic fish might be indifferent to the wind farm and monopiles and use all habitats to the same extent (see Figure 13E).

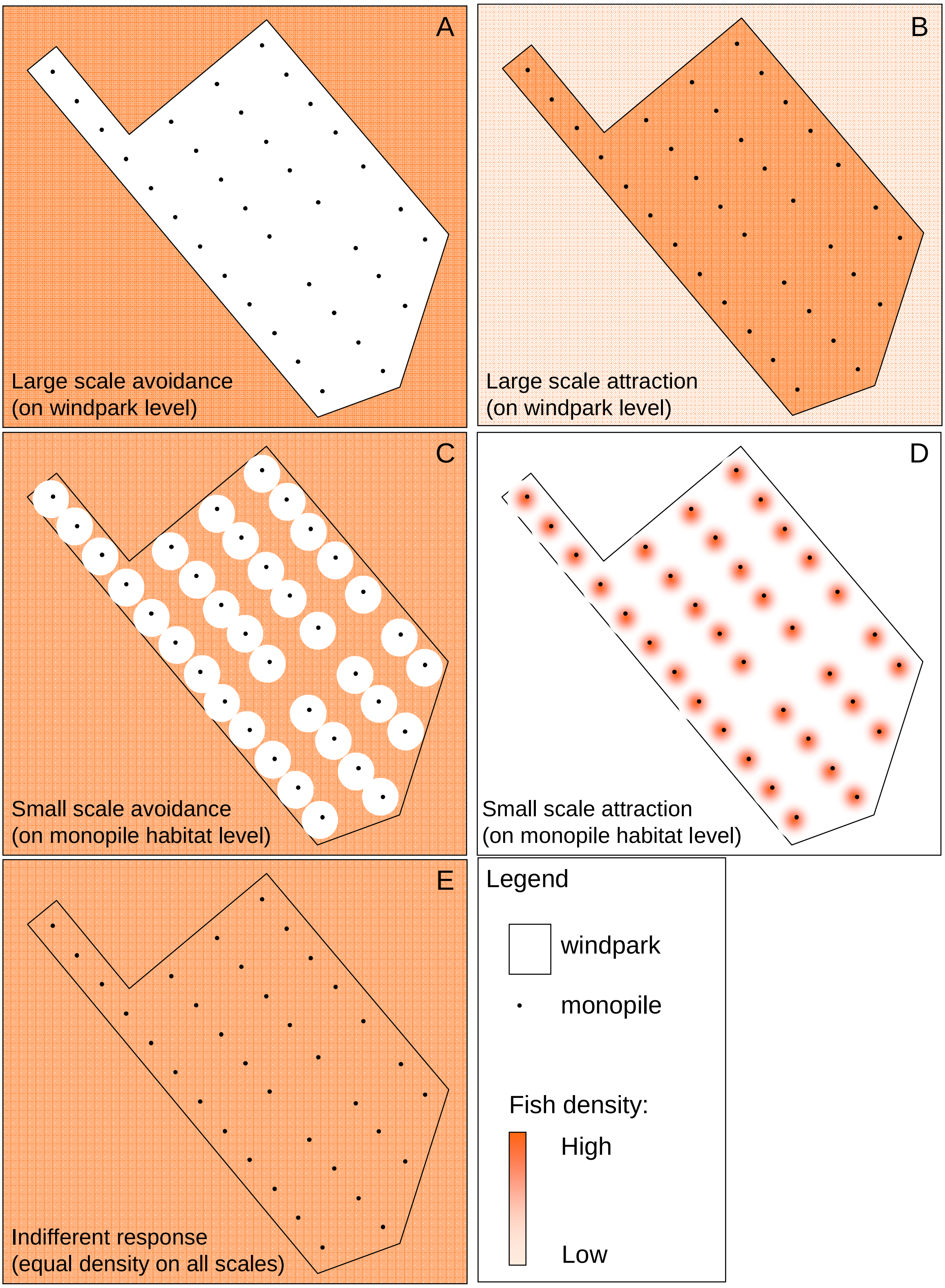


Figure 13. Schematic overview of potential responses of fish to the windfarm and monopiles leading to different distributions of fish density on different scales.

The response of fish to the windfarm and monopiles is likely to be highly species-specific given the large variation in behaviour, habitat needs and trophic level between species (Hunter en Sayer 2009). Large scale differences in response on a windfarm level can be accurately addressed by standard surveys. Small scale effects need to be studied using methods that are capable in measuring fish occurrence in very differently structured habitats with high resolution. The DIDSON method used in this study focuses on small scale effects.

Of the pelagic fish species, our DIDSON results indicate that small scale attraction occurs for at least horse mackerel and possibly mackerel on a scale of 0-20m. On average, fish density directly around the monopiles were a factor 37 higher than in open water. This cannot be entirely attributed to pelagic fish, because the aggregations of fish around the monopiles consisted at least partly of demersal fish such as cod. Therefore, if (for instance) cod is attracted more strongly to the monopiles than by a factor 37, the attraction factor for horse mackerel might be less than observed. Nevertheless small scale attraction of horse mackerel to the monopiles is present. We found no indications of small scale avoidance of pelagic fish, but this might be due to the limited period and effort within which the observations were made. For some species, such as sandeel it might be very likely that small scale avoidance occurs. For herring, the results so far are inconclusive.

Effects of small scale response to monopiles on abundance estimates from hydro acoustic surveys
The question remains, to what degree does small scale response of pelagic fish interfere with density estimates based on hydro acoustic surveys during T0 and T1. Our DIDSON results suggest that attraction to the monopiles of at least some species occurs on a scale of 0-20m, i.e. is restricted to the area of the scour bed around the monopiles. If we assume that avoidance or attraction takes place on this scale, then we can calculate what the effect of a deviance in fish density directly around the monopiles on overall fish abundance estimates as derived from hydro acoustic surveys. For this, we determined overall fish density in the windfarm by dividing the area in two strata: 'open water' and 'scour bed around the monopile' and consider different fish density scenario's in which we set open water fish density to 1 and varied fish density around the monopiles. The scenario's used were 1) small scale 'total avoidance', i.e. fish density 0 around the pole, 2) Indifference, i.e. fish density around the pole equal (factor 1) relative to fish density in open water, 3) small scale 'attraction' to the monopole habitats in different degrees, i.e. increasing from a factor 10, 100, 1000 to 10000 higher fish densities around the monopole than in open water. Based on the surface area of each stratum, we then calculated what the bias in overall fish density was for each scenario, using only open water fish density to determine fish abundance in the windfarm (Figure 14), disregarding small scale avoidance or attraction.

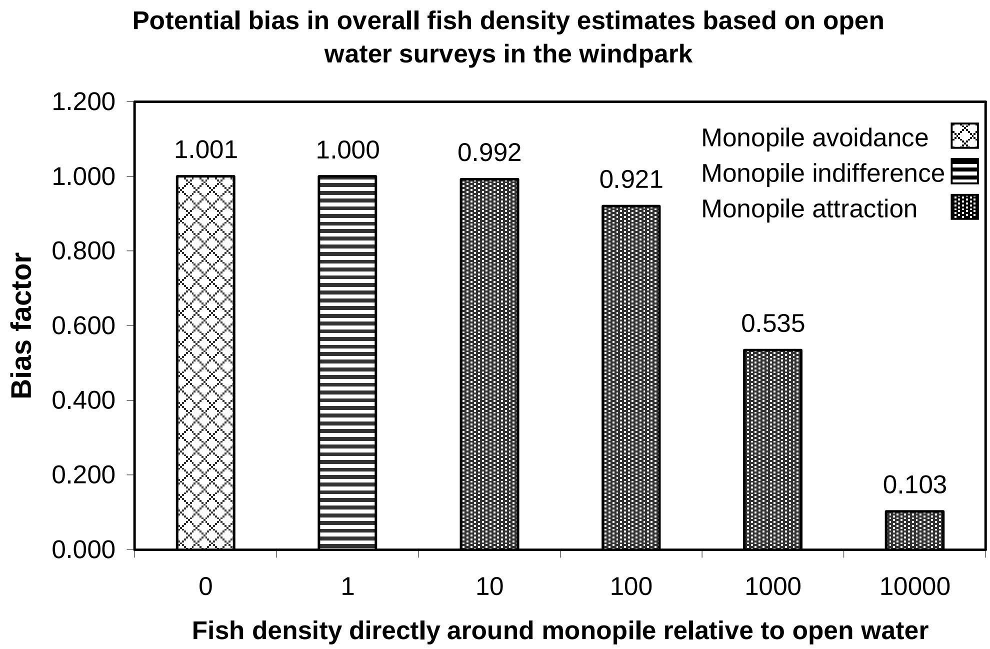


Figure 14. Potential bias in fish abundance estimates (based on hydro acoustic surveys) when small scale (<20m) attraction or avoidance to the monopiles in the wind farm OWEZ is not taken into account. Total avoidance leads to a neglectable overestimation, whereas strong attraction with 10.000 higher densities around the monopiles than in open water leads to an underestimation with a factor 0.1.

When exploring the potential bias for the different scenarios of 'avoidance', 'indifference' and increasing degree of 'attraction' to the monopile habitats, it is obvious from Figure 14 that avoidance on a scale of 20 m does not influence the overall fish abundance estimates (overestimation of 0.1%). Attraction to the monopile habitats with a factor 10 higher densities around the monopiles also leads to a neglectable bias. A factor 100 leads to an underestimation of 8%, a factor 1000 to an underestimation of 50% and a factor 10.000 to an underestimation of 90%. Thus, only when very strong attraction takes place, considerable underestimation can be expected. If the overall factor 37 and scale of <20m that our DIDSON results suggest holds for most pelagic fish species, then this would mean that overall fish abundance is underestimated by only 3%. Compared to other sources of variance in pelagic fish abundance in time and space, this can be considered very small.

Horse mackerel: comparison of the DIDSON results to the hydro acoustic results
For one important pelagic species, horse mackerel, our results indicate a small scale attraction to the monopole habitats in the OWEZ. Here we compare the DIDSON results to the hydro acoustic results during the 2003 hydro acoustic results for horse mackerel (Grift *et al.* 2004), as an example to elucidate the different factors that play a role when interpreting pelagic fish data in relation to responses to windfarm and monopiles. From the hydro acoustic data collected during surveys in April 2003 in the coastal area around the later to be built Near Shore Windfarm, density estimates expressed in kg/km^2 on a resolution of 0.5 nautical mile are available for both the area outside the planned wind farm and within the planned wind farm (Grift *et al.* 2004). During these surveys, average weight per horse mackerel was 0.157 kg. When assuming an equal average weight of horse mackerel in June 2009, and a conservative 25% of the numbers of fish observed during the DIDSON measurements consists of horse mackerel, we were able to estimate horse mackerel density from the DIDSON results as well. For this, we calculated horse mackerel density in the 'monopile scour bed', the 'transition' zone directly around the scour bed and the 'open water' habitats for each of the five monopiles that were measured with the DIDSON. We classified all density observations of the DIDSON and hydro acoustic surveys on a logarithmic scale. The distribution of the observed densities for the different habitats and surveys are given in Figure 15.

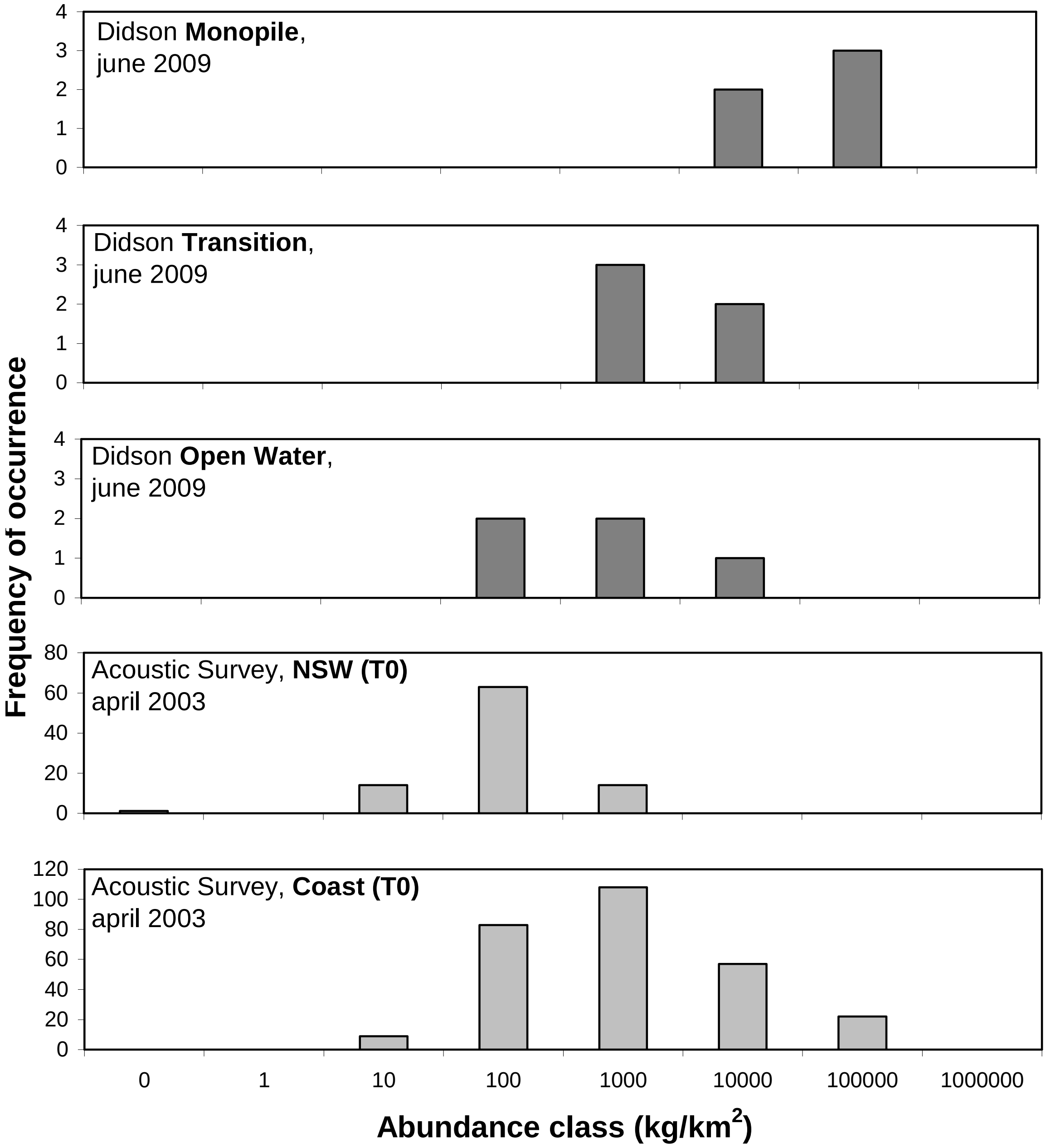


Figure 15. Frequency histogram of the estimated density of horse mackerel from the 15 DIDSON observations in three different habitats ('scour bed directly around the monopile', 'transition' habitat directly outside the scour bed and 'open water' in the windfarm) compared to the acoustic samples (92 intervals of 0.5 nautical mile) in the baseline 2003 hydro acoustic survey (divided in area where 'NSW' is planned to be built and 'coast').

The densities of horse mackerel found at the scour bed with the DIDSON are comparable to the highest densities found in the hydro acoustic surveys along the 'coast', whereas the densities of horse mackerels for 'open water' as indicated by the DIDSON results are comparable to the average densities found in the hydro acoustic surveys. It should be noted that variation in density is high. Spatial variation in densities during different hydro acoustic surveys performed in April, June and October is high and patchy as is illustrated in Figure 16 from (Grift *et al.* 2004).

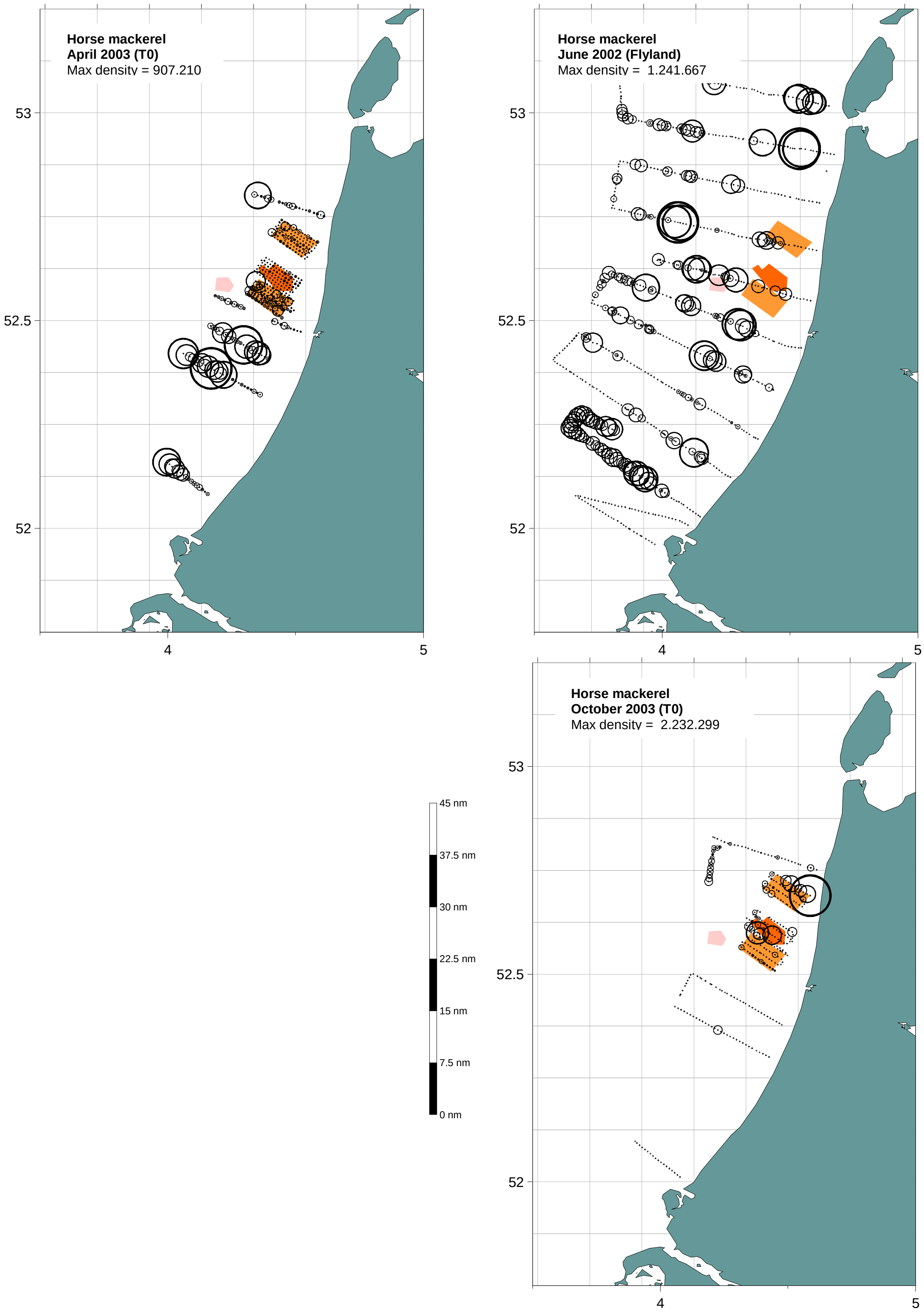


Figure 16. Distribution of horse mackerel (kg/km2) in the coastal zone during three surveys (April and October 2000: baseline, June: Flyland) on a proportional square root scale to the largest value (max density). (From: (Grift *et al.* 2004)).

Of course, the detection of single target fish by means of the DIDSON differs from echo integration, the method been applied in the baseline survey of the windfarm (Grift *et al.* 2004). Essentially the approach is technically different: in echo integration the total amount of reflected sound under favourable conditions is used as the basis for the calculation of biomass, while the use of DIDSON resembles the detection of single target from a noisy background in a technique known as “echo counting”. In addition, the scale of the DIDSON observations is much smaller than the hydro acoustic survey applied in 2003 and 2007. When applying echo integration, one integrates the acoustic energy of all schools in an area while with a DIDSON sonar, one counts individual fish often wondering whether one is actually in the middle of a school or whether one is looking at single swimming fishes. In addition, the resolution of the observations with 0.5 nautical miles for hydro acoustic data and 0.01-0.1 nautical miles for the DIDSON results precludes a direct comparison between the two data sets. However, the order of magnitude of the ‘open water’ results are similar, and the DIDSON results suggest that aggregations around the monopiles are high (comparable with the maxima found within hydro acoustic surveys), but not outside the range of densities observed in the ‘open sea’.

Temporal and spatial dynamics of pelagic fish in relation to wind farms
The abundance estimates made in the wind farm area before and after construction of the monopiles with hydro acoustic surveys as well as the DIDSON observations are point estimates in time. It should be emphasized that differences in abundance and distribution cannot simply be attributed to the situation with or without a windfarm (Grift *et al.* 2004). Likewise the small scale distribution of fish around the monopiles are based on observations during a very short period in a week with relatively good weather conditions (sunny, low wind speed). The observations made give no information about seasonal variation. Several studies indicate that fish assemblages vary during the day and the season and depend also on weather conditions (Stanley en Wilson 2000; Fabi *et al.* 2002; Santos *et al.* 2002).

Therefore, for a complete understanding of the species-specific response of pelagic fish to wind farms and monopiles, more insight in the spatial and temporal dynamics of pelagic fish occurrence is needed. For this, hydro acoustic surveys and DIDSON observations are complementary, focusing on different spatial and temporal scales ranging from meters to kilometres, and from tidal, daily to seasonal.

Recommendations
For using the DIDSON in determining small scale behavioural responses to monopile habitats we recommend:
Application of the DIDSON within wind farms:

- Exploring the use of other platforms for DIDSON observations, such as Remotely Operated Vehicle (ROV). The ROV used for underwater observations in the nearshore wind farm by Wals Diving appears very suitable for this. The disturbance is probably less than from a RIB and the possibilities for doing observations in different water layers in the water column with minimum disturbance by wave action, resulting in stable DIDSON images and observations at close range (< 10m) enabling better species determination are good.
- Developing robust constructions that enable fixed observations with the DIDSON for longer periods, e.g. encompassing a full tidal or daily cycle.
- Exploring the use of different other fishing or observation techniques to aid species identification of fish assemblages.

Measurements and analyses performed during T(1) and T(5) :

- Our DIDSON results suggest that at least for some species strong aggregations can occur that may lead to bias in fish abundance estimates. To tackle this, DIDSON can be used to study these aggregations simultaneously during hydro acoustic surveys.
- In addition to this first pilot study using DIDSON technology to study small scale dynamics of pelagic fish around monopiles, attention should be focused on species identification in follow-up pilots. For instance by using fixed constructions that allow observations at closer ranges. But also by applying additional techniques e.g. video, set gill nets and other (experimental) fishing techniques.
- Addressing seasonal dynamics in occurrence of pelagic fish.
- Linking behaviour of pelagic fish species to demersal fish species, e.g. behaviour of cod around poles, for instance by using telemetry techniques.

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7 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.

Justification

Report: C138/10
Project Number: 430.250.13.11

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

Approved: dr. ir. R. Hille Ris Lambers,
Researcher

Signature:

Date: 9 November 2010

Approved: Drs. J. Asjes
Head of Department Fish

Signature:

Date: 9 November 2010