The influence of offshore windpower on demersal fish

Dan Wilhelmsson, Torleif Malm, and Marcus C. Öhman

A significant expansion of offshore windpower is expected in northwestern Europe in the near future. Little is known about the impacts it may have on the marine environment. Here, we investigate the potential for wind turbines to function as artificial reefs and fish aggregation devices (FADs), i.e. whether they would locally increase fish densities or alter fish assemblages. Fish communities and habitat composition were investigated using visual transects at two windpower farms off the southeastern coast of Sweden, central Baltic Sea. Fish abundance was greater in the vicinity of the turbines than in surrounding areas, while species richness and Shannon—Wiener diversity (H') were similar. On the monopiles of the turbines, fish community structure was different, and total fish abundance was greater, while species richness and diversity (H') were lower than on the surrounding seabed. Blue mussels and barnacles covered most of the submerged parts of the turbines. On the seabed, more blue mussels and a lesser cover of red algae were recorded around the power plants than elsewhere. Results from this study suggest that offshore windfarms may function as combined artificial reefs and fish aggregation devices for small demersal fish.

D. Wilhelmsson and M. C. Öhman: Department of Zoology, Stockholm University, S-106 91 Stockholm, Sweden. T. Malm: Department of Biology and Environmental Science, Kalmar University, S-391 83 Kalmar, Sweden. Correspondence to D. Wilhelmsson: tel: +46 702 535365; fax: +46 8 167715; e-mail: dan.wilhelmsson@zoologi.su.se.

Introduction

A significant expansion of windpower is expected in northwestern Europe in the near future, with increasing emphasis on offshore windpower. Currently, some 170 offshore wind turbines are operational in northwestern Europe, but up to 10 000 offshore turbines are expected to be erected in the next few years (Shaw et al., 2002). The potential impacts of this exploitation on the marine environment include disturbance effects from noise, shadows, electromagnetic fields, and changed hydrological conditions (Westerberg, 1994; Peterson, 2001; Jensen et al., 2003). Changes in habitat structure are also of great concern (Petersen and Malm, 2006). Organisms that are likely to be affected by these changes include demersal fish that associate with the seabed during most of their life cycle. Several studies from various marine biotopes have described relationships between fish abundance and habitat features such as substratum complexity and the composition of sessile organisms (e.g. Macpherson, 1994; Öhman and Rajasuriya, 1998; Pihl and Wennhage, 2002), and changes in habitat structure may alter associated fish communities (Pihl et al., 1995; Bergman et al., 2001; Lindahl et al., 2001).

Fish are often attracted to solid man-made structures placed on the seabed (Seaman and Sprague, 1991). The construction and deployment of so-called artificial reefs, ranging from specially designed concrete or steel units to scrap materials such as car tyres and shipwrecks, is a widely used tool to enhance fisheries, to mitigate damage to the environment, to protect or rehabilitate certain habitats, or to increase the recreational value of an area (Hueckel et al., 1989; Milon, 1989; Ambrose, 1994; Brock, 1994; Chua and Chou, 1994; Guillén et al., 1994; Pickering et al., 1998; Rilov and Benayahu, 1998; Wilhelmsson et al., 1998; Clark and Edwards, 1999; Jensen, 2002). So-called secondary artificial reefs (Pickering et al., 1998), constructed for other purposes, such as oil platforms (Seaman et al., 1989; Rooker et al., 1997; Love et al., 1999; Helvey, 2002; Ponti et al., 2002), breakwaters (Stephens et al., 1994), pier pilings, and pontoons (Rilov and Benayahu, 1998; Mocquet et al., 1999), also serve as habitats for fish and invertebrate assemblages.

Several studies have shown artificial reefs to hold greater fish densities and biomass, and to provide better catch rates not only when compared with surrounding soft-bottom areas, but also in relation to adjacent natural reefs

(Bohnsack and Sutherland, 1985; Ambrose and Swarbrick, 1989; Brock and Norris, 1989; Bohnsack *et al.*, 1994; Wilhelmsson *et al.*, 1998). The reason for this is possibly enhanced protection and food availability (Bohnsack and Sutherland, 1985). Artificial reefs can further support assemblages of fish and epibiota that are different from natural communities (Ambrose and Swarbrick, 1989; Connell and Glasby, 1999; Rilov and Benayahu, 2000). Moreover, solid structures can change local abiotic conditions, such as hydrodynamics and light climate, influencing the composition of the epibiota in the surrounding bottom area (Guichard *et al.*, 2001), which could have additional effects on local fish assemblages (Wilkins and Myers, 1992). So-called Fish Aggregating Devices (FADs) are created differently from artificial reefs. They are positioned at the surface or in midwater, not on the bottom, and are a widely used tool to enhance fish catches by aggregating fish (White *et al.*, 1990; Relini *et al.*, 1994; Castro *et al.*, 2002). As wind turbines are placed on the bottom as well as cut through the water column, with various steel devices protruding horizontally from the main structure, they may act as both artificial reefs and FADs.

The aim of this study was to investigate whether offshore windmills function as artificial reefs and FADs. Our hypothesis is that offshore windmills will induce changes in local demersal fish abundance and species composition.

Methods

Study area

This field study was carried out from 5 August to 20 September 2003 at two locations in the southern part of the Strait of Kalmar (Baltic Sea) in southeastern Sweden (Figure 1).

The salinity in the area is stable at around 7. The temperature of the surface water fluctuates between 15 and 20°C in summer and between 0 and 2°C in winter. Covering sea ice is rare, but it may occur during severe winters 1–2 times per decade; drifting ice is more regular (Juhlin, 1992). Lunar tides are negligible, but weather-induced water-level variations of up to 0.5 m from the mean water level may last for several weeks. Low-water periods are particularly common in spring (Malm and Kautsky, 2003). Normally, a south-flowing current passes through the strait, but at a highly variable speed, occasionally reaching up to 2–2.5 m s^{-1} (Andersson *et al.*, 1992).

One of the locations is situated at the shoal area "Yttre Stengrund", approximately 5 km from the mainland; five windpower plants were constructed there in 2001. The other locality, "Utgrunden", is situated farther north, 12 km from the mainland and 10 km from the shore of Öland Island; seven windpower plants were erected there in 2000. The shape of the wind turbines was similar at both locations; steel monopiles, 3–3.5 m in diameter, driven into the sea floor on submerged glacial boulder ridges. The depth at both locations ranges between 6 and 8 m.

Five windpower plants at Yttre Stengrund and three at Utgrunden were investigated, together with three control sites haphazardly sampled approximately 500 m north of Yttre Stengrund, and three control sites similarly sampled at the northern part of the Utgrunden ridge, approximately 1 km from the windfarm.

Field methods

Estimation of fish abundance and benthic composition was conducted by means of visual scuba census (Figure 2), covering 72 transects. All surveys were performed between 10:00 and 17:00. All transects were 10 m long and 1 m wide, extending 1 m above the bottom. To compare the fish composition at different radii from the wind turbines, the midpoints of the transects were positioned at fixed distances 1 and 20 m from the plants. The former transects thereby sampled the seabed 1–5 m from the monopiles of the turbines, and the latter sampled the seabed at a distance of approximately 20 m (20–21 m). The pattern was replicated on the opposite sides of the piles, giving a total of four transects conducted along the bottom at each site (Figure 2). Transects were positioned in random directions from the windmills. Two transects were also sampled on the vertical surfaces of each monopile, at 3 and 5 m deep. These transects had approximately the same length and width as those sampled on the seabed. The same sampling procedure was repeated at the six control sites, both along the bottom and in the water column 3 and 5 m deep.

To demarcate the transect area, a fibreglass tape measure was laid on the seabed or around the wind turbine monopiles. The same investigator conducted all fish counts. After 5 min for acclimatization, fish were enumerated along the transects on the side away from the turbines or on the lower side of the vertical transects. Fish were recorded by the diver, who moved slowly along the transect, stopping regularly every metre to search 1 m^3 at a time. Stationary individual fish or small groups were counted first, followed by an estimation of schooling fish. Finally, fish under rocks or in crevices, holes or algal turf were recorded. Before moving on, special attention was paid to pelagic species crossing the transect at any position. In addition to quantitative fish recordings along transects, general observations of fish habitat associations on the seabed and on the windmills were made.

The visibility in the water during the surveys ranged from 3 to 8 m, depending on the wind at the time. Temperature dropped approximately 5°C from the beginning to the end of the study period. To factor out the seasonal effects, the sampling order was randomized between turbines and controls at Utgrunden, whereas turbines and controls were examined one after the other at Yttre Stengrund owing to logistical constraints.

Both adults and young of the year (YOY) fish recruits were included in the survey. Shoals of two-spotted goby (*Gobiusculus flavescens*) and sand goby (*Pomatoschistus minutus*) were mainly of fish 15–30 mm long, with larger specimens (45–60 mm) clearly visible among them. For
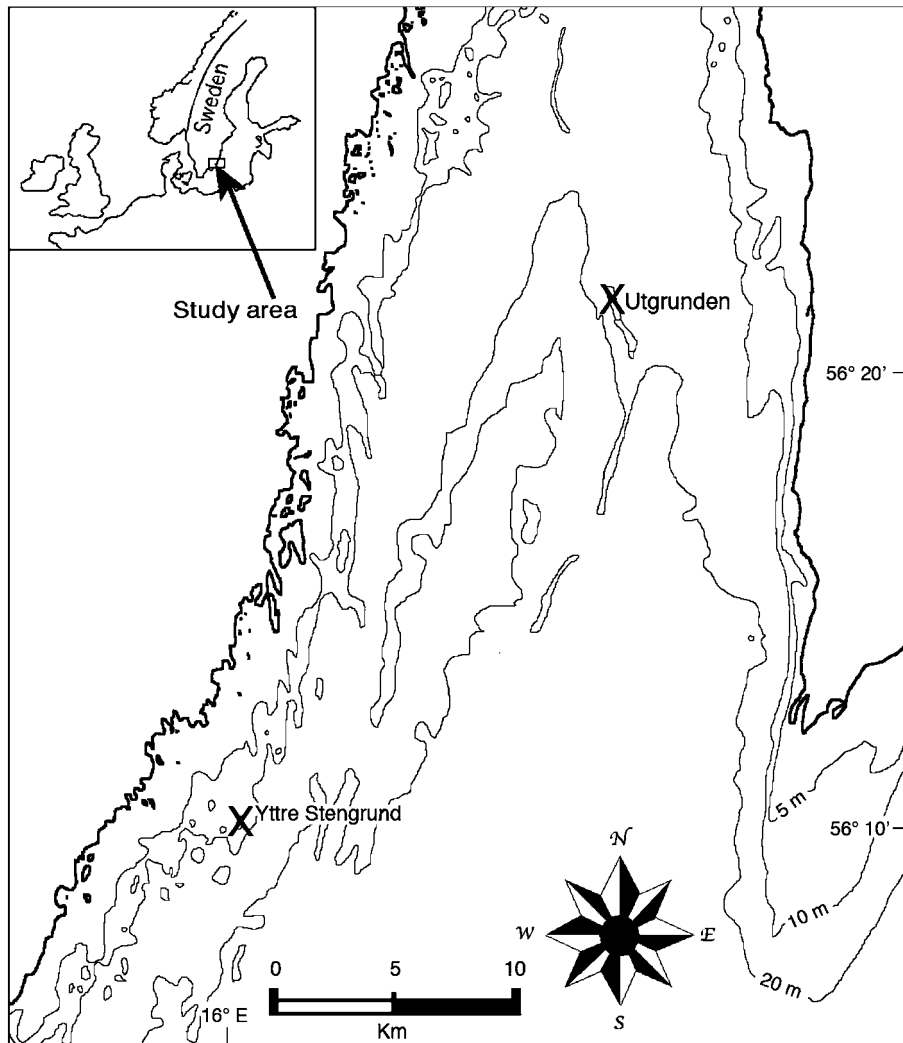
Figure 1. Map of the two study areas in the southern strait of Kalmar, central Baltic Sea.

the purpose of this study, the former category was defined as juveniles and the latter as adults (Shann, 1910). Two species of the genus *Pomatoschistus* are present in the Baltic proper, *P. minutus* and the common goby (*Pomatoschistus microps*). It is difficult to distinguish between them in visual surveys. At the depths surveyed here, 6–8 m, most of the *Pomatoschistus* spp. are likely to be *P. minutus* (Jansson *et al.*, 1985; Thorman and Wiederholm, 1986). Consequently, only the name *P. minutus* was used, although our data could include some *P. microps*. For the same reason, the two species of Cottidae recorded in the area, sea scorpion (*Taurulus bubalis*) and bullrout (*Myoxocephalus scorpius* L.) were referred to as cottids.

The area covered by algae and sessile animals was determined by a method modified from Jansson and Kautsky (1977). Scuba divers made continuous observations of covering organisms and the dominating type of substrata within

the same transects used for the fish counts. The percentage cover of the dominating sessile organisms, and the proportions of gravel/sand, stones, and boulders were estimated. To distinguish between different types of moraine fractions, the Udden—Wentworth grain-size scale was used, i.e. boulders >0.25 m in diameter, stones 0.04–0.25 m diameter, and gravel/sand <0.04 m diameter (Wentworth, 1922). Recent literature is inconsistent in the classification of blue mussels in the Baltic Sea, describing them as monostands of either *Mytilus edulis* or *Mytilus trossulus*, or hybrids (Zbawicka *et al.*, 2003; Rigonos and Cunningham, 2005). For the purpose of this study the blue mussels are referred to as *M. trossulus*.

Data analysis

The two 10-m^3 transects taken for each transect type (on the turbines, 1–5 m away, and 20 m away) at each site were
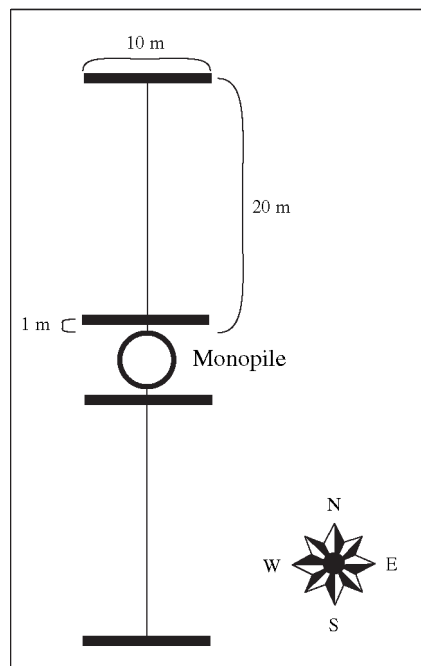
Figure 2. The position of the bottom transects in relation to the wind turbines.

not considered to be independent from each other. The data were therefore pooled and averaged for each pair of transects, to attain independent samples. The number of replicates for each statistical test described below was eight, which was the total number of wind turbines investigated (five at Yttre Stengrund, three at Utgrunden). The large shoals of juvenile *G. flavescens* and *P. minutus* skewed the data, concealing adult fish numbers. Therefore, analyses of fish abundances were performed both including and excluding the recordings of juvenile *G. flavescens* and *P. minutus* (<3 cm).

The non-parametric Wilcoxon's Matched Pairs Test was applied to compare fish densities, Shannon–Wiener diversity (H'), and species richness between the different distances from the turbines, as well as between the turbines and the seabed. The same parameters were calculated for the transects at the six control sites, but only for a general comparison with the turbine areas, and to obtain an idea of spatial patterns of fish abundance and diversity.

To test the degree of similarity in terms of fish community composition among the different transect types (on the turbines, 1–5 m away, and 20 m away) the data were analysed using an ANOSIM two-way crossed permutation test, based on rank similarity matrices and applying Bray–Curtis similarity measures (Clarke, 1993) on square-root transformed data when excluding, and log($x + 1$) transformed data when including, the juvenile gobies. In addition to a significance level, the ANOSIM test yields an absolute value for the degree of separation of the transect

types in terms of fish community through R values ranging from 0 to 1 ($R > 0.75$, well separated; $R > 0.50$, overlapping but clearly different; $R < 0.25$, barely separable at all; Clarke and Gorley, 2001). To identify the degree to which each species contributed to the differences in community structure, a Similarity Percentage Procedure (SIMPER) was applied (Clarke, 1993).

The habitat variables were analysed with the same approach as for fish described above. For pairwise comparisons between the 1–5-m and 20-m transects at each site, the data on percentage coverage of the two dominating categories of epibiota, namely red algae (lumped into one category, consisting mainly of *Polysiphonia fucoides* and *Rhodomela confervoides*) and blue mussels (*M. trossulus*), were analysed with Wilcoxon's Matched Pairs Test.

For a multivariate comparison of the benthic composition between the two different distances from the wind turbines, an ANOSIM two-way crossed permutation test, based on rank similarity matrices using an Euclidian distance measure (Clarke, 1993) on square-root transformed data was performed. The variables included percentage coverage of blue mussels and red algae, and percentage of the seabed consisting of boulders, stones, and gravel/sand. In the latter analysis, only seabed transects were included because the vertically orientated steel structures obviously differ in substratum composition. To identify the degree to which each variable contributed to the overall differences in benthic composition between the seabed 1–5 m from the turbines and 20 m from them, a SIMPER was applied (Clarke, 1993).

Results
Fish

Approximately 351 000 fish were recorded in the investigation, 99.7% of them juvenile gobies belonging to the species *G. flavescens* and *P. minutus*. Apart from these juvenile gobies, 1038 individuals belonging to 12 species were noted (Table 1). Large aggregations of *G. flavescens* were recorded on the turbine monopiles, and there was a sharp gradient of decreasing abundance of this species from the monopiles outwards. The average abundance of *G. flavescens* was one and two orders of magnitude higher on the monopiles than on the seabed 1–5 m away and 20 m away, respectively.

Including all gobies, the abundance of fish was significantly greater on the turbines than on the seabed 1–5 and 20 m away (Wilcoxon's $p = 0.02$ and $p = 0.01$). Excluding the shoals of juvenile *G. flavescens*, no significant differences were found (Wilcoxon's $p = 0.78$ and $p = 0.07$), although the average density was more than twice as high on the turbines than on the seabed 20 m away (Figure 3). The total abundance of fish was also higher 1–5 m than 20 m from the turbines, both with (Wilcoxon's $p = 0.04$) and without (Wilcoxon's $p = 0.02$) the juvenile gobies (Figure 3).

Table 1. Average fish abundance per 10 m³ at windmill sites. The contribution to the dissimilarity between transect types by each species is given by the SIMPER procedure. W, wind turbines; 1, on the seabed at a distance of 1−5 m from the turbines; and 20, on the seabed at a distance of 20 m from the turbines.

Species	Average abundance (including/excluding juvenile gobies)			Contribution to dissimilarity (%) for each comparison between transect types		
	W	1	20	W vs. 1	W vs. 20	1 vs. 20
Gobiusculus flavescens	20 193.75/17.50	1 617.50/5.75	133.82/1.69	99.26/42.25	99.55/55.70	32.46/21.86
Pomatoschistus minutus	0.00	6.44/3.94	2/0.69	0.24/14.70	0.11/3.90	19.80/20.49
Zoarces viviparous	0.57	2.57	1.5	0.12/9.15	0.08/7.91	16.32/19.15
Gobius niger	0.25	8.13	4.57	0.34/27.33	0.21/22.11	12.52/17.68
Cottidae (*T. bubalis*, *M. scorpius*)	1.06	0.50	0.06	0.02/4.31	0.01/4.78	6.69/7.45
Gasterosteus aculeatus	−	0.06	0.38	0.00/0.23	0.02/2.10	5.20/0.65
Spinachia spinachia	0.13	−	0.25	0.00/0.33	0.01/1.70	4.50/0.73
Syngnathus typhle	−	0.06	−	0.00/0.36	−/−	1.35/0.37
Hyperoplus lanceolatus	0.50	−	0.06	0.01/1.16	0.01/1.60	1.15/0.37
Platichthys flesus	−	−	−	−/−	−/−	−/−
Cyclopterus lumpus	0.06	−	−	0.00/0.17	0.00/0.19	−/−
Unidentified	−	0.31	0.19			

The similarity in fish abundance among the transects sampled on the seabed at the control sites 500−1000 m from the turbines, as well as between the control sites and the transects conducted 20 m from the turbines supports the positive correlation between the presence of monopiles and the high fish abundance in the vicinity of these structures (Figure 3, Table 2). Moreover, at the control sites, no fish were recorded in the surveys of the water column more than 1 m above the bottom.

The fish community on the turbines differed significantly in composition from that on the seabed 1−5 and 20 m away from the monopiles, both including (ANOSIM; $R = 0.97$, $p = 0.001$; and $R = 0.87, p = 0.001$) and excluding (ANOSIM; $R = 0.69$, $p = 0.002$; and $R = 0.77$, $p = 0.001$) juvenile gobies. The differences in community structure between the seabed 1−5 m away and the seabed 20 m away from the monopiles were significant, both when including (ANOSIM; $R = 0.26$, $p = 0.03$) and excluding (ANOSIM; $R = 0.44$, $p = 0.005$) juvenile gobies.

Higher densities of *G. flavescens*, *P. minutus*, black goby (*Gobius niger*), and eelpout (*Zoarces viviparous*) were found on the seabed 1−5 m from the turbines than 20 m from them. Apart from juvenile *G. flavescens*, these four species contributed about 20% each to the overall differences in fish community structure between the two different distances from the turbines (SIMPER). When including the juvenile gobies, *G. flavescens* contributed 32% to the differences (Table 1). For differences between the monopiles and the seabed, *G. flavescens* was the most important species, explaining 99% when including, and 42% (1−5 m away) and 56% (20 m away) when excluding, juvenile gobies (Table 1).

The diversity (Shannon−Wiener) and species richness of fish were significantly lower on the turbines than on the seabed 1−5 m from the monopiles (diversity, $p = 0.012$;

species richness, $p = 0.012$), and 20 m from them (diversity, $p = 0.012$; species richness, $p = 0.049$). There were no significant differences between the two distances from the turbines in this regard (diversity, $p = 0.78$; species richness, $p = 0.50$; Table 2).

In addition to the transect estimates, general observations were made. The fish recorded on the monopiles were often confined to certain structural features of the constructions. Cottids and *G. niger* were mainly found in pockets of steel mouldings encircling the piles, and when pockets were not of preferred width (5−15 cm), these species were rare. *Z. viviparous* and cottids were frequently observed in the sheltered corner where the wall met the seabed. Juvenile lumpsuckers (*Cyclopterus lumpus*) (∼3 cm) were only recorded on the zinc anodes extending horizontally 0.5 m from the piles into the water column. This species was observed three times, although only once within a transect during quantitative surveys. Shoals of *G. flavescens* were denser around the same zinc anodes and other three-dimensional steel devices protruding from the main structure, than adjacent to the plain wall. The only fish relatively frequently noted on the plain walls of the monopiles, besides *G. flavescens*, was *Z. viviparous*. Sandeels, assumed to be greater sandeel (*Hyperoplus lanceolatus*), and three-spined sticklebacks (*Gasterosteus aculeatus*), were occasionally noted in the water column around the turbines. Turbots (*Psetta maxima*) were observed on the seabed near the turbines.

Habitat

There were significant differences in the cover of both blue mussels (*M. trossulus*) and red algae between the turbine monopiles and the seabed, and between the seabed at
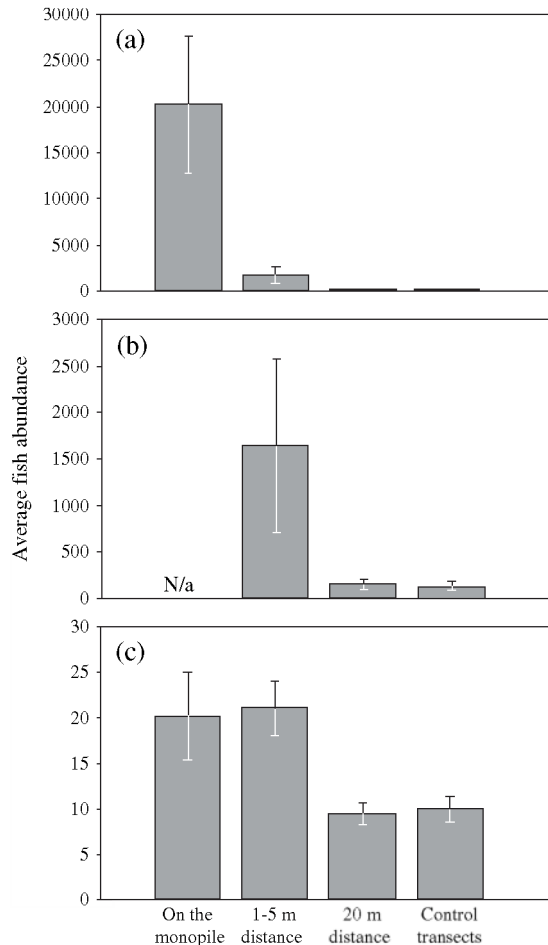
Figure 3. Average fish abundance ± s.e. per 10 m³ at different distances from the wind turbines. (a) Total abundance, (b) total abundance, bottom transects only, and (c) total abundance, excluding juvenile gobies.

different distances from the turbines (Wilcoxon's Matched Pairs Test, $p = 0.012$). The percentage coverage of blue mussels was highest on the monopiles, followed by the seabed 1−5 m away, and lowest on the seabed 20 m from the turbines. For algae, the pattern was opposite (Figure 4). Organisms in two layers covered the monopiles. Acorn barnacles (*Balanus improvisus*) covered most of the surface and were attached directly to the substratum. Blue mussels were mainly attached to the barnacles and covered on average 80% of the monopiles. On the seabed, the benthic composition was significantly different between the two different distances from the turbines (ANOSIM; $R = 0.36$, $p = 0.004$). A lesser cover of red algae closer to the monopiles contributed 30% to the differences (SIMPER). More abundant *M. trossulus*, and a larger portion of the seabed consisting of gravel/sand, 1−5 m from the turbines than 20 m from them each explained about 20% of the difference. A higher frequency of boulders 20 m from the turbines contributed another 20% (Table 3).

Discussion

The great abundance of fish on and near the monopiles strongly indicates that the turbines serve as artificial reefs and FADs for demersal and semi-pelagic fish in the area. The species contributing most to the spatial differences in fish abundance were *G. flavescens*, *P. minutus*, *Z. viviparous*, and *G. niger*. The most striking result of our study was the large number of *G. flavescens* closely associated with the monopiles.

The reason for the great densities of *G. flavescens* could be a combination of refuge and food availability, as well as enhanced recruitment. Normally *G. flavescens* forage on zooplankton just above the seabed and, especially during summer and autumn, in shallow (<5 m) rock areas in strong association with protecting macroalgae (Wheeler,

Table 2. Summary table for comparisons (Wilcoxon's Matched Pairs Test) of fish community parameters at the turbine sites. W, wind turbines; 1, on the seabed at a distance of 1−5 m from the turbines; and 20, on the seabed at a distance of 20 m from the turbines. Levels of significance are: *$p < 0.05$, **$p < 0.01$, and ns not significant. The control sites (three at Olsängs Yttre Kulle, three at Utgrunden) where the same survey design was applied are included for general comparison. At the control sites, the sampling of the monopiles was substituted by searching the open water column above the central reference point (C).

| Parameter	Turbine sites ($n = 8$)			Comparisons between transect types at turbine sites			Control sites		
	W	1	20	W/1	W/20	1/20	C	1	20
Average fish abundance (including/excluding juvenile gobies)	20 196/20.1	1 635.5/21	143.1/9.4	*/ns	**/ns	*/*	−	118.1/9.8	103.8/9.4
Diversity (Shannon−Wiener, H')	0.007	0.27	0.57	*	*	ns	−	0.79	0.78
Species richness	2.5	4.3	4.0	*	*	ns	−	4.3	5.2
Community structure (including/ excluding juvenile gobies)				**/**	**/**	**/**			
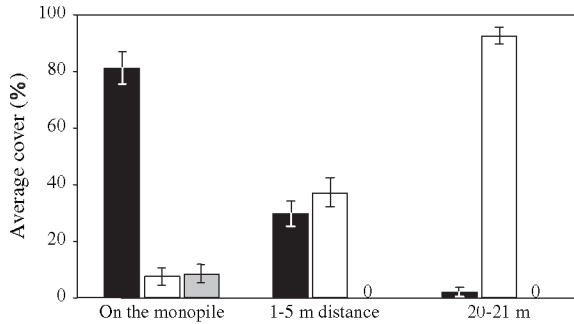
Figure 4. Average cover ± s.e. of *M. edulis* (black), *B. balanoides* (grey), and filamentous algae (white) at different distances from the turbines.

1969; Costello, 1992; Wilkins and Myers, 1992). High densities of planktivorous fish have been noted on other vertical artificial structures such as pier pilings (Rilov and Benayahu, 1998), high profile shipwrecks (Wilhelmsson et al., 1998), and experimental midwater structures (FADs; Rountree, 1989). The close association with vertical structures extending above the seabed reduces vulnerability to predation and allows planktivores to spend more time feeding at preferred depths in the water column (Rountree, 1989). Remaining near vertical structures also expose them to stronger currents and circular current patterns, which generate a high flux of plankton, as suggested by Rilov and Benayahu (1998). During this study it was noted that *G. flavescens* retreated towards the monopiles when disturbed. The structural complexity created by the blue mussels growing on the monopiles may further enhance the refuge function at least for juvenile *G. flavescens*. A correlation between a similarly fine-scaled epibiota on pier pilings and small-bodied planktivorous fish was demonstrated by Coleman and Connell (2001).

Compared with a low profile reef, a vertical structure cutting through the water column is more likely to be encountered by settling fish larvae, even more so for surface-orientated larvae, and can thereby enhance local

recruitment (Rilov and Benayahu, 2002). Rilov and Benayahu (2000) suggested that the design of the pier pilings in Eilat serves as a model for construction of artificial reefs to rehabilitate marine habitats. Similarly, midwater structures (FADs) increase recruitment rates of fish to nearby benthic artificial reefs (Beets, 1989). Therefore, as the monopiles of the turbines can be characterized as both artificial reefs and FADs, they may increase recruitment rates not only to the structures themselves, but also to the adjacent seabed. This could contribute to the abundance of juvenile *G. flavescens* in close association with the monopiles, and perhaps also to the numbers of *G. niger* and *P. minutus* on the adjacent seabed.

The submerged part of the turbines and the adjacent area may resemble a reef ecosystem, with its variety of interacting components. For example, the large numbers of fish and sessile organisms associated with the monopiles may contribute to an increased benthic productivity around the monopiles through the deposition of organic material, such as faecal matter, organic litter, and dead organisms, which may in turn attract benthos-feeding fish (e.g. *P. minutus*, *G. niger*, and *Z. viviparous*; Bray et al., 1981; Kellison and Sedberry, 1998). The monopiles seem to have altered the habitat composition of the adjacent seabed. Mussel beds had started to develop on the seabed close to the turbines, probably through dislodgement of the bivalves from the power plants. Such development has also been noted around oilrigs (Love et al., 1999).

Previous studies have pointed out the importance of blue mussels in influencing fish distribution patterns in the Baltic proper. For example, densities and biomasses of *G. flavescens* and *P. minutus* were shown to be enhanced by the prey associated with mussels (Zander, 1988). In a study by Jansson et al. (1985), areas dominated by mussels harboured the greatest abundance of fish, predominantly *P. minutus*. In comparison with surrounding areas, a larger portion of the seabed consisted of gravel and sand around the turbines, perhaps a consequence of the construction work, but perhaps also due to altered hydrodynamic conditions. Sand and gravel patches are habitats preferred by *P. minutus*

Table 3. Average percentage cover of major habitat components for the different transect types at the turbine sites, and at the six control sites (three at Olsängs Yttre Kulle, three at Utgrunden), using the same survey design. W, wind turbines; 1, on the seabed at a distance of 1−5 m from the turbines; 20, on the seabed at a distance of 20 m from the turbines; C at the control sites represents the open water column above the central reference point. The contribution by each category to the dissimilarity between 1 and 20 is given by the SIMPER procedure.

Habitat component	% cover at turbine sites ($n = 8$)			% contribution to the overall dissimilarity ($p = 0.001$) between 1 and 20	% cover at control sites		
	W	1	20		C	1	20
Red algae	1.58	25.23	74.41	29.77	−	60.82	58.62
Blue mussels	79.76	42.74	14.76	20.87	−	32.04	33.62
Boulders	−	46.80	66.29	20.40	−	74.58	75.00
Gravel/sand	−	40.70	18.44	18.57	−	8.71	4.13
Stones	−	12.50	15.27	10.39	−	16.71	20.88

(Wheeler, 1969). Non-availability of nest material, such as bivalve shells, could limit their distribution and reproductive success, as noted from the northern Baltic proper (Nellbring, 1986; Lindström, 1988; Nellbring, 1993). Therefore, the relatively large patches of blue mussels in conjunction with the sand and gravel seabed close to the monopiles could be particularly attractive for *P. minutus*, and perhaps also for *G. flavescens* which sometimes use bivalve shells for deposition of eggs (Wheeler, 1969). Further, the diets of *G. niger* and *Z. viviparous* include small gobies, bivalves, and small crustaceans commonly found in mussel beds (Wheeler, 1969; Fjøsne and Gjøsæter, 1996; Svensson *et al.*, 2000). The large supply of *G. flavescens* as well as the mussel beds around the turbines could enrich the feeding grounds for these species. Consequently, the fish may be affected both directly by the physical structure of the monopiles and by subsequent changes in the seabed habitat.

Structural complexity is a habitat feature that has been shown in a number of studies to have positive effects on fish species diversity (Luckhurst and Luckhurst, 1978; McCormick, 1994; Öhman and Rajasuriya, 1998). Results from the present study indicate that added structures on the monopiles attract species that would not have been there otherwise. The protruding zinc anodes, crevices in the wall, and the area where the monopile met the seabed, all seemed to have a positive effect on species numbers. These observations could be considered when constructing offshore wind turbines, because enhanced structural complexity could attract additional species.

Depth-related distribution patterns of fish and sessile biota are common near the shore (Gibson, 1969; Pedersén and Snoeijs, 2001; Ponti *et al.*, 2002). Vertically orientated structures combined with the typical zonation of sessile biota would be expected to provide a selection of habitats and favourable depths for fish, locally enhancing species numbers (Aabel *et al.*, 1997; Rilov and Benayahu, 1998). In the present study, no clear zonation patterns were observed, and both species richness and diversity of fish were lower on the vertical surfaces of the turbines than on the surrounding seabed. However, the monopiles were sampled at fixed depths of 3 and 5 m, which is probably not sufficient to quantify depth effects. Compared with the bottom habitat, the walls of the monopiles also exhibited little variation, because they were almost solely covered by blue mussels, offering limited protection for most fish species. This study was further conducted in a brackish water area of comparably poor species diversity (Elmgren and Hill, 1997). It is tempting to speculate whether wind turbine construction in a true marine environment, such as shallow areas of the North and Irish Seas, with their larger selection of sessile species to enhance structural complexity, and a stronger niche differentiation among fish (Thorman and Wiederholm, 1986), may enhance local species richness and diversity, especially if they are placed in soft substrata.

Artificial reefs may influence pelagic and larger demersal fish species several hundred metres from the physical construction (Grove *et al.*, 1991). A consequence of that extended influence may be that windfarms of the future, containing tens to hundreds of turbines, will have additional synergistic effects on the fish community structure, with biological interactions between the biota around the turbines. Also, if fishing effort is limited around the farms, they may act as marine protected areas (MPAs), which worldwide are used to manage fishery resources (Alcala and Russ, 1990; Horwood *et al.*, 1998; Chapman and Kramer, 1999). Aggregations of cod (*Gadus morhua*), saithe (*Pollachius virens*), and mackerel (*Scomber scombrus*) have been recorded in close association with vertical steel constructions in the North Sea (Soldal *et al.*, 2002). Small fish around FADs, as recorded in this study, can attract commercially important fish looking for prey (Klima and Wickham, 1971; Brock, 1985). Small cod are frequent predators on *Pomatoschistus* spp. and *G. niger* (Wheeler, 1969; Nellbring, 1985; Magnhagen, 1988), and the abundance *G. flavescens* has been suggested to regulate cod populations in some areas (Fosså, 1991). Therefore, large concentrations of these gobies, as found around the wind turbines in the Strait of Kalmar, could have positive local effects on commercial species. It is worth noting, though, that the effects of sounds from the turbines on commercial fish species are not clearly established (Wahlberg and Westerberg, 2005).

Acknowledgements

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