CHAPTER 6

SMALL-SCALE DISTRIBUTION PATTERNS OF FLATFISH ON ARTIFICIAL HARD SUBSTRATES IN A BELGIAN OFFSHORE WIND FARM

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Since the last decade, many large-scale offshore wind farms are being built in European waters (Soares-Ramos *et al.* 2020). The majority of the turbines (81%) are fixed in the bottom with monopile foundations and accommodated with a scour protection layer (SPL) to keep the surrounding soft sediments in place (WindEurope 2021). The turbines and SPL's provide new habitats, especially in soft-sediment areas, influencing the local marine environment and its associated biota in various ways (Lindeboom *et al.* 2015; Degraer *et al.* 2020). A pronounced effect of introduced hard substrates is the attraction and concentration of fish and epifaunal organisms, generally referred to as the 'artificial reef effect' (Petersen *et al.* 2006). Significantly higher densities of round fish species such as cod *Gadus morhua* and pouting *Trisopterus luscus* (Reubens *et al.* 2013), but also crustaceans (e.g. European lobster *Homarus gammarus* and edible crab *Cancer pagurus*) (Krone *et al.* 2017), have been recorded near turbines and their foundations compared to the surrounding sediments, which is commonly explained by an increase in feeding and/or shelter opportunities (Bergström *et al.* 2013; Degraer *et al.* 2020).

Up till now, there are no indications that such an artificial reef effect also exists for flatfish species. Most studies that looked at the attraction of fish towards turbines and the surrounding SPL find no significant effect for flatfish species or even suggest avoidance behaviour in relation to hard substrates (Krone *et al.* 2017; van Hal *et al.* 2017). However, their sampling design did not specifically focus on flatfish, whose passive behaviour is very different from more active benthopelagic and pelagic species, and therefore a sampling bias could have occurred (Gibson 1997). Moreover, most mandatory monitoring programmes mainly focus on the effects on the soft sediment habitat at a distance of ca. 200 m from the turbines, while attraction to the hard substrate habitat often takes place at a much smaller scale (Bergström *et al.* 2013; Wilber *et al.* 2018).

The current study investigated the OWF artificial reef effect for different flatfish species, through 20 visual diving transects in the Belgian Belwind OWF. We focused on small-scale (< 50 m) distribution patterns in flatfish abundance around the turbines, covering both SPL and the nearby soft-sediment. The Belwind OWF is located on the Bligh Bank at a distance of 46-52 km from the Belgian coast where water depth varies between 15 and 37 m (Fig. 1). The Belwind OWF was constructed between August

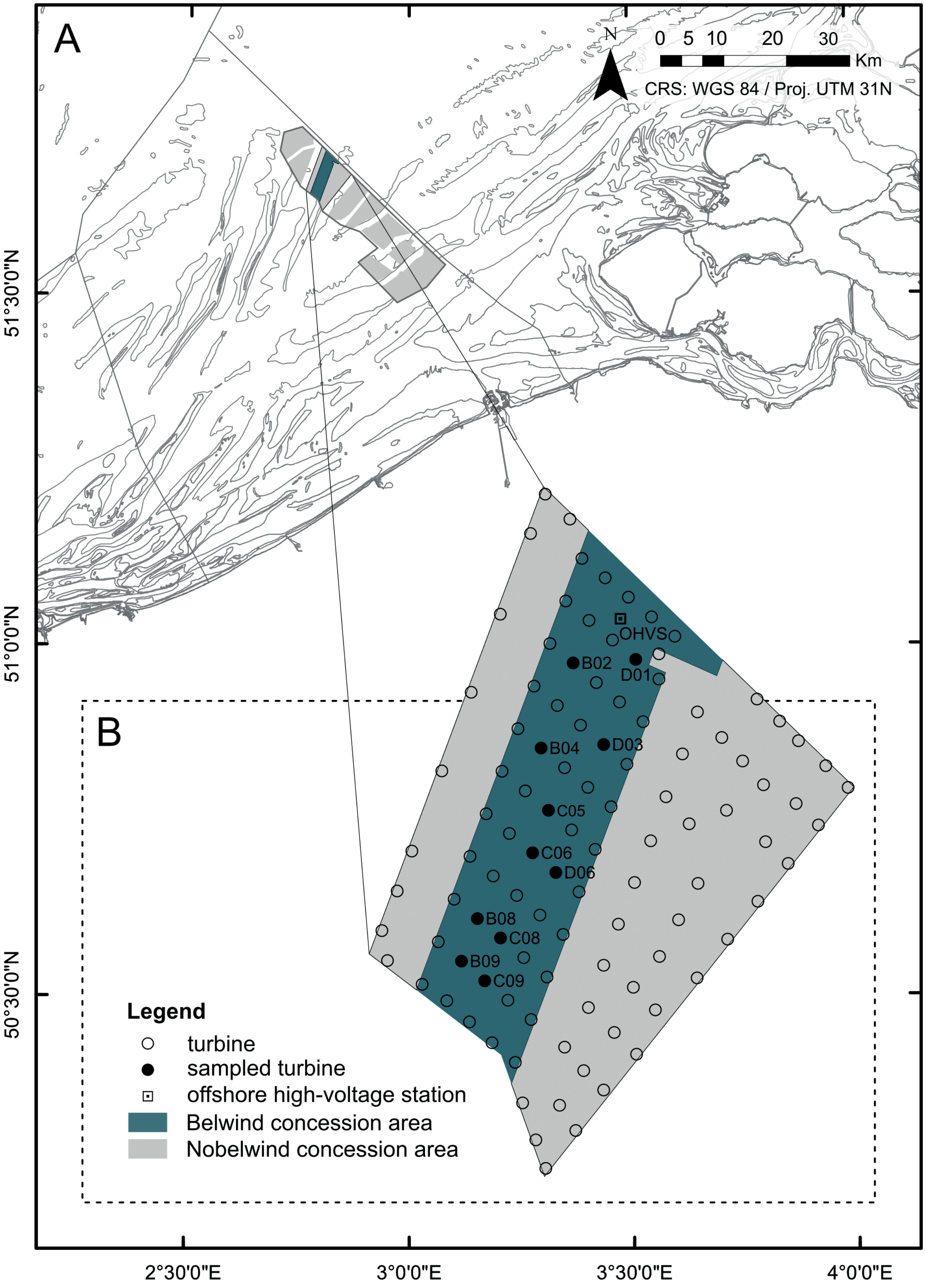

Figure 1. Location of the Belwind wind farm within the offshore wind concession area in the Belgian part of the North Sea (BPNS) (A) and overview of sampled turbines (●) in the Belwind wind farm (B).

2009 and December 2010 and consists of 56 turbines (55 monopile foundations - Vestas 3 MW and 1 jacket foundation - Haliade 6 MW, built in 2013), each surrounded by a rocky SPL. Between July and August 2019, we surveyed flatfish around 11 randomly chosen turbines, which were completely surrounded by other turbines to avoid any fringe effects.

Depending on the prevailing conditions such as visibility and current speed, one to three diving transects in different directions from the turbine were covered within each dive (Fig. 2). Two divers descended along the turbine, secured a measuring tape at the bottom of the monopile and started swimming in a straight line away from the turbine. As the SPL's had different dimensions, a fixed distance of 40 m was covered during each transect to standardize the data. One diver visually scanned the area for flatfish individuals at both sides of the measuring tape (covering approx. 3 m width), while the other diver filmed the transect with a GoPro camera. Flatfish individuals were visually identified and the habitat (SPL or sand) and its distance to the turbine were noted on a waterproof writing board. Also, water temperature, visibility and transect direction were noted for each dive. Since the number of transects varied per dive/turbine, the total searched area per habitat type (SPL/sand) per turbine was calculated as a measure for sampling effort. Subsequently, the number of individuals per species per habitat type (SPL/sand) was summed for each turbine.

A general linear mixed model (GLMM) with a Poisson distribution was fitted with the species count data as response variable, habitat type (SPL/sand) as explanatory variable, turbine as a random factor and the log-transformed search area per habitat type as offset variable to correct for the variation in sampling effort. For visualisation purposes, count data was standardised to ind.100 m^{-2}. All data exploration, modelling and validation was carried out in R version 4.0.3 (R Core

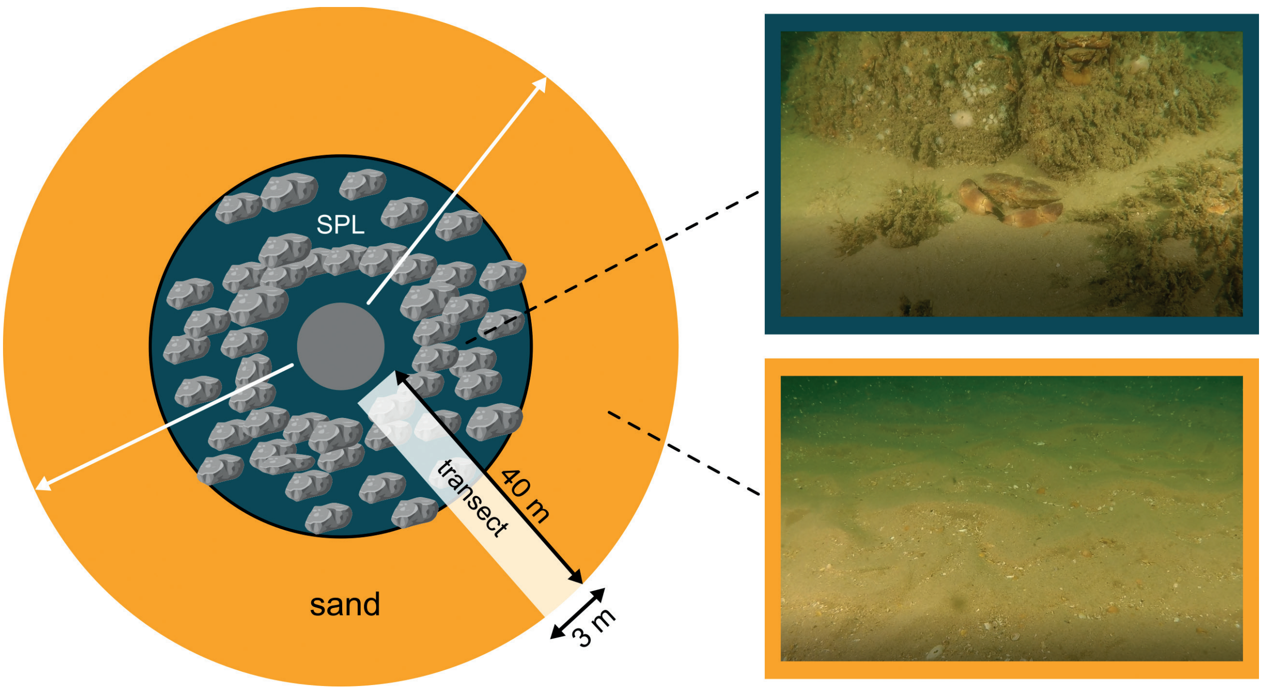

Figure 2. Schematic representation of the diving transects around a turbine in the Belwind wind farm. The blue circle represents the the scour protection layer (SPL) consisting of the visible armoured layer and sand in between the rocks, while the yellow circle represents the sand surrounding the SPL, where no rocks are present. The density of the armoured layer is higher closer to the turbine, but is more or less absent right next to it. White arrows indicate possible transect lines conducted by the divers during one dive. The white rectangle shows a schematic representation of a diving transect with a length of 40 m and width of 3 m. Pictures show the typical habitat at the indicated location. ©Film Johan Devolder

Table 1. Total number of individuals per flatfish species observed along the diving transects on the scour protection layer (SPL) and the surrounding sand.

Species	English name	SPL	sand
Pleuronectes platessa	plaice	23	8
Microstomus kitt	lemon sole	4	–
Solea solea	common sole	3	–
Limanda limanda	dab	1	–
Platichthys flesus	European flounder	1	–
Pleuronectiformes juv.	flatfish juvenile	–	1
Total		**32**	**9**
Total covered surface area (m^2)		982	1360

Team 2020). Five different flatfish species and a total of 41 individuals were detected during the 20 visual transects (Table 1). Plaice *Pleuronectes platessa* had by far the most sightings (n=31), followed by lemon sole *Microstomus kitt* (n=4) and common sole *Solea solea* (n=3). On average 2.05 (±1.50) or 1.74 (±1.34) ind.100 m^{-2} were sighted per transect and almost 80% of the flatfish were found on the SPL, while only 9 individuals were seen on the nearby sand surrounding the SPL. The mean length of the scour protection layer over all transects was 16.37 m (±8.41).

Plaice was the only species with high enough abundances to fit a GLMM (Fig. 3). The model showed a highly significant effect of habitat type ($p < 0.001$), with four times more plaice found on the SPL (2.15±0.57 ind.100 m^{-2}) than on the surrounding sand (0.52 ±0.20 ind.100 m^{-2}). These results suggest a strong attraction of plaice towards the SPL, meaning there is an artificial reef effect present. As stated above, this might be explained by increased feeding and shelter possibilities (Bergström *et al.* 2013; Degraer *et al.* 2020). Leonhard *et al.* (2006) estimated a 50 times increased food availability for fish after the introduction of hard substrates in Danish wind farms. Video footage taken by divers in a Dutch wind farm showed that cod *Gadus morhua* and pouting *Trisopterus luscus* actively used the hard substrates for shelter and food (Lindeboom *et al.* 2011), which was also observed near gravity based foundations in a Belgian wind farm (Reubens *et al.* 2013). Follow-up studies, including stomach content analyses and high-resolution acoustic tagging, will further investigate how plaice uses this new SPL-habitat in the Belwind OWF and how this influences its distribution on small (turbine) and wider (wind farm) spatial scales.

The higher plaice abundances on the SPL compared to the surrounding sand seem to contradict the findings of other studies. Many wind farm monitoring programmes focus on a larger spatial scale and use trawling devices 200 m away from the turbines (Lindeboom *et al.* 2011; Stenberg *et al.* 2015; Wilber *et al.*

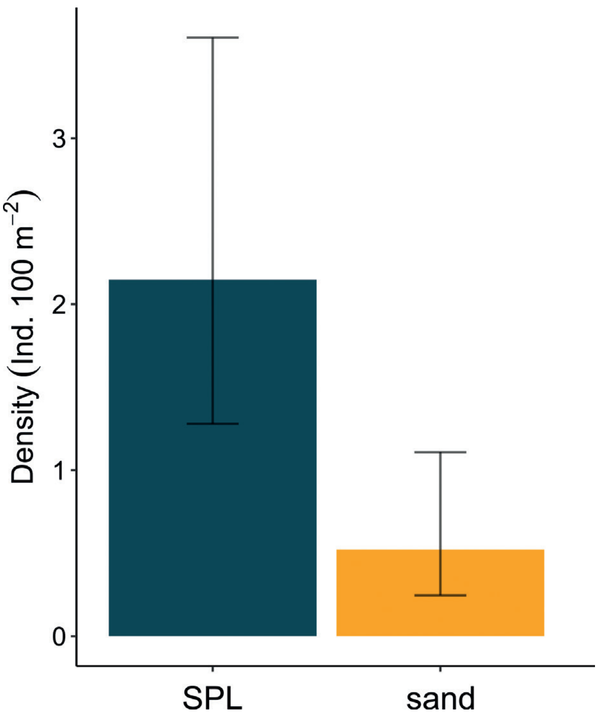

Figure 3. Least-squares means for the final GLMM model showing the number of plaice per 100 m^2 for both habitat types (SPL = scour protection layer). Error bars represent 95%-confidence intervals.

2018), which may mask small-scale attraction at the turbine scale (Bergström *et al.* 2013; Vandendriessche *et al.* 2015). However, studies that did look at small-scale attraction of plaice also found no effect or even demonstrated avoidance behavior in relation to the hard substrate (Krone *et al.* 2017; van Hal *et al.* 2017). Most probably, this discrepancy with our results is linked to the configuration of the SPL. In the Belwind wind farm, the rock density of the SPL is sufficiently low (or sedimentation sufficiently high), at least further away from the turbines and closer to the edge of the SPL, to allow for the (natural) development of sandy patches. Actually, all flatfish observed by the divers in the SPL zone were found on these sandy patches, which benefits the burrowing behaviour of flatfish species (Fig. 4). In the study of Krone *et al.* (2017), the scour protection around the monopiles in the Riffgat wind farm are described as 'closed rock fields', which is in clear contrast with the configuration of the Belwind SPL. Furthermore, video footage and pictures of the SPL at other European wind farms, such as OWEZ (NL) and Horns Rev (DK), showed much higher densities of rocks with no visible sediment patches (Leonhard *et al.* 2006; Lengkeek *et al.* 2017), which may explain the lower presence of flatfish on the SPL in these wind farms.

The rock density hypothesis is further supported by the flatfish distribution pattern observed in relation to the distance from the turbine. Flatfish densities were high very close to the turbine, much lower just a few meters further away, followed by increasing densities with distance from the turbine till the edge of the SPL (Fig. 5A). The observed numbers of flatfish on the surrounding sand, at distances between 20 and 40 m from the turbine, were again much lower. This distribution pattern can be largely correlated with the density of the rocks (and sandy patches) of the SPL layer (see Fig. 2): almost no rocks are present in the immediate surroundings of the turbine, as the armoured SPL layer was deployed after the installation of the turbines; a few meters from the turbine, the rocks are stacked on top of each other leaving no patches of sand in between them; with increasing distance from the turbines, the rock density decreases until the edge of the SPL merges into natural sandy habitat. Following this rationale, it is plausible that over time an attraction effect of flatfish to the hard substrate may appear in other wind farms as well, if sedimentation rates are high enough to allow for the formation of sandy patches in between the rocks. As for now, it remains unclear whether higher abundances of plaice (and other flatfish species) on the SPL also lead to an increased production or only results in an aggregation of individuals

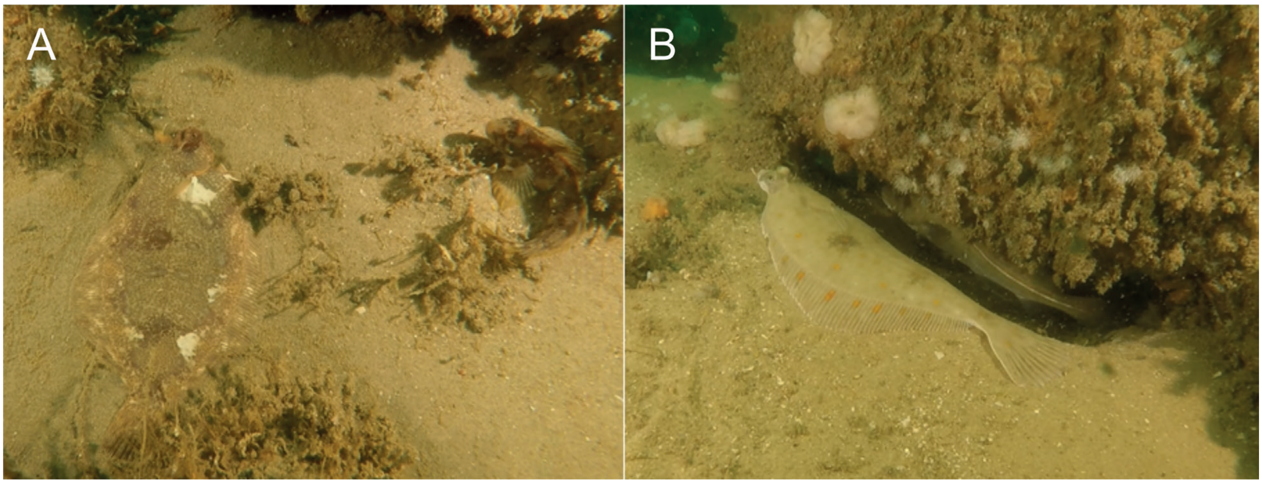

Figure 4. Pictures of (A) lemon sole *Microstomus kitt* and tompot blenny *Parablennius gattorugine*; (B) plaice *Pleuronectes platessa* and juvenile cod *Gadus morhua*, taken during a diving transect over the scour protection layer at turbine D3 in the Belwind wind farm. ©Film Johan Devolder.

from the surrounding areas (Andersson *et al.* 2010; Reubens *et al.* 2013; Degraer *et al.* 2020). Long-term monitoring of the SPL is therefore recommended.

When looking at the relation with transect direction, flatfish species do not seem to clearly prefer a particular side or direction of the turbine, although slightly higher densities might be discerned on the eastern side of the turbines (Fig. 5B). However, diving was always performed around slack tide and the direction of the tidal current was taken into account as well when deciding which transect to swim, which might have influenced the results. More data need to be collected over a longer time period to further investigate the potential effects of water currents on the SPL and the presence of flatfish. The use of acoustic telemetry may be beneficial in this, as electronic tags could register flatfish movements independent of the prevailing currents.

Our findings are important when a nature-inclusive design is opted for in new offshore wind energy developments (Degraer *et al.* 2020). The SPL 'eco-designing' is already mandatory for the construction of offshore wind farms in the Netherlands (Ministerie van Economische Zaken 2019). However, different species have different needs when it comes to, for example, the size of the crevices or the scour material. If the goal is to promote flatfish species, and specifically plaice, the advice would be to construct a SPL with a rock density that is sufficiently low so that sediment patches can develop in between the rocks. Therefore, eco-designing of future wind farm projects will need separate discussions concerning which species to promote. Ideally, the focus lies on a couple of umbrella species, because measures taken for such species will benefit the larger community (Lengkeek *et al.* 2017). Such discussions should preferably be conducted in a quadruple helix framework involving not only scientists, but also the industry, policy makers as well as the general public. This is necessary, as the outcomes of these discussions will not only have ecological implications, but may equally affect recreational and commercial fisheries (Gill *et al.* 2020).

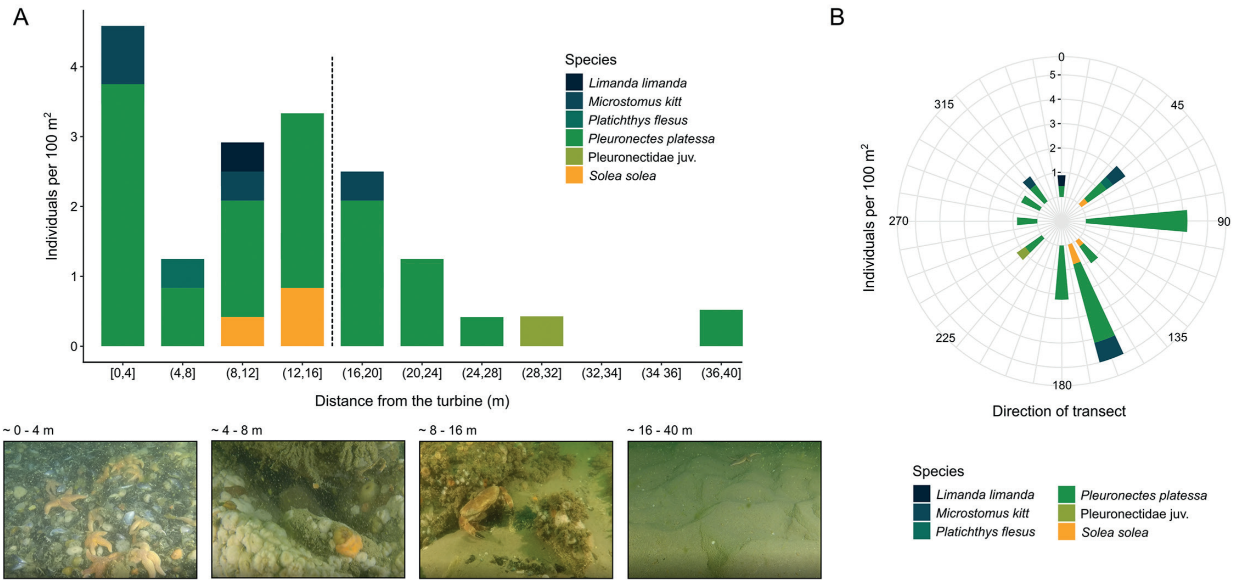

Figure 5. Barplot showing the number of flatfish per 100 m^2 found at different distances from the turbine (A) and at different directions in relation to the turbine (B). The mean length of the scour protection layer over all transects was 16.37 m, which is shown by the dashed black line. Colours represent the different species that were observed along the transect. The pictures show what the typical habitat looks like at the defined distances from the turbine, but some variation exists between turbines. ©Film Johan Devolder/A. Norro/RBINS 2019.

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