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Diel variation in feeding and movement patterns of juvenile Atlantic cod at offshore wind farms

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ABSTRACT

Atlantic cod (*Gadus morhua*) is a commercially important fish species suffering from overexploitation in the North-East Atlantic. In recent years, their natural environment is being intensively altered by the construction of offshore wind farms in many coastal areas. These constructions form artificial reefs influencing local biodiversity and ecosystem functioning. It has been demonstrated that Atlantic cod is present in the vicinity of these constructions. However, empirical data concerning the diel activity and feeding behaviour of Atlantic cod in the vicinity of these artificial reefs is lacking. Atlantic cod has a flexible diel activity cycle linked to spatio-temporal variations in food availability and predation risk. In this study we integrated acoustic telemetry with stomach content analysis to quantify diel activity and evaluate diel feeding patterns at a windmill artificial reef (WAR) in the Belgian part of the North Sea. Atlantic cod exhibited crepuscular movements related to feeding activity; a 12 h cycle was found and the highest catch rates and stomach fullness were recorded close to sunset and sunrise. It is suggested that the observed diel movement pattern is related to the prey species community and to predation pressure. Foraging at low ambient light levels (i.e. at dusk and dawn) probably causes a trade-off between foraging success and reducing predation pressure. Fish did not leave the area in-between feeding periods. Hence other benefits (i.e. shelter against currents and predators) besides food availability stimulate the aggregation behaviour at the WARs.

1. Introduction

Atlantic cod (*Gadus morhua* Linnaeus, 1758) is a demersal fish species occurring throughout the North Atlantic Ocean (Froese and Pauly, 2012). It has a considerable commercial value and many populations have been heavily exploited for several centuries (Serchuk and Wigley, 1992). This resulted in critically low population levels for many stocks in recent years (ICES, 2010; Svedäng and Bardon, 2003). Due to its commercial importance and its dwindling stocks, the life history traits (Lund et al., 2011; Olsen et al., 2004), abundances (Rose and Kulka, 1999; Svedäng and Bardon, 2003), movements (Lindholm et al., 2007; Metcalfe, 2006; Svedäng et al., 2007) and feeding behaviour (Adlerstein and Welleman, 2000) of Atlantic cod have been documented in many studies over a wide range of spatial and temporal scales using a variety of techniques and approaches.

However, natural behaviour, abundances and movements of Atlantic cod may be influenced by offshore human activities. Solid structures (e.g. gas platforms (Lowe et al., 2009), wind turbines (Reubens et al., 2011) and wave power foundations (Langhamer et al., 2009)) have been placed on the seabed all around the world and can be classified as artificial reefs. These artificial reefs have some environmental costs and benefits (Langhamer et al., 2009) which may influence local biodiversity and ecosystem functioning (Andersson et al., 2009). Numerous offshore wind farms are currently being constructed in the North Sea and research on the effects of these Windmill Artificial Reefs (further referred to as WARs) on the surrounding marine environment is required. Some demersal fish species for instance, are likely to be attracted to the WARs as shelter against currents or predators (Bohnsack, 1989) and increased food provisioning (Leitao et al., 2007; Reubens et al., 2011) may turn these substrates into suitable habitats for hard substrate dwelling fish.

Reubens et al. (2013) revealed the presence of large aggregations of juvenile Atlantic cod at WARs in the Belgian part of the North Sea (BPNS) during summer and autumn. However, empirical data concerning the reason why this species seems to be attracted by the reefs is unclear. Information on the diel movements and feeding behaviour of Atlantic cod in the vicinity of WARs is still lacking. The diel variation needs to be taken into account as this might shed light on the true added value of WARs. Next, Atlantic cod are also known to have a flexible diel cycle in feeding activity and habitat utilization which may differ between life stages, season and habitat (Clark and Green, 1990; Keats and Steele, 1992; Neat et al., 2006). It

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is often assumed that these differences in diel activity patterns are linked to spatio-temporal variations in predation pressure and food availability (Løkkeborg and Fernö, 1999; Righton et al., 2001).

The wind farm under consideration harbours a diverse epifaunal community with high species abundances (Kerckhof et al., 2010b). Many of these epifaunal species are potential prey for juvenile Atlantic cod (Froese and Pauly, 2012). Several natural predators of Atlantic cod are also present in the area. The harbour porpoise (*Phocoena phocoena* Linnaeus, 1758) is present year round and may reach high abundance during late winter, early spring. The harbour seal (*Phoca vitulina* Linnaeus, 1758), grey seal (*Halichoerus grypus* Fabricius, 1791) and the white-beaked dolphin (*Lagenorhynchus albirostis* Gray, 1846) are also observed in Belgian waters, be it in much lower numbers compared to harbour porpoises (Haelters et al., 2011). All types of fisheries are excluded in the wind farm, leading to less human disturbance of the associated fish aggregations. Therefore, this wind farm provides an ideal opportunity to investigate the diel behaviour of an Atlantic cod aggregation in relation to food availability and predator pressure. However, directly observing the behaviour of marine fish in the wild is logistically very difficult. As a result, other methods are essential to infer fish behaviour (Hall et al., 1995). In this study we integrated acoustic telemetry with stomach content analysis. The former method was used to empirically quantify diel movement behaviour, while the latter is used to evaluate diel feeding patterns. Several questions were addressed: (1) do Atlantic cod at WARs exhibit predictable diel activity and movement patterns? (2) is there a diel pattern in feeding rates and prey composition?

2. Material and methods

2.1. Study site

The wind farm under consideration is situated in the BPNS at the Thorntonbank (Fig. 1), a natural sandbank 27 km offshore (coordinates WGS 84: 51°33′N–2°56′E). Two types of foundations are present in this farm: concrete gravity based and steel jacket foundations. Both function as WARs. All Atlantic cod used in the present study were caught at gravity based foundations. These foundations have a width of 14 m at the seabed, at a depth of about 22.5 m at mean low water spring (MLWS). The gravity based foundations are surrounded by a scour protection layer of pebbles and rocks with a total width of 44 m (1520 m^2). The surrounding soft sediment is composed of medium sand (mean median grain size 374 μm, SE 27 μm) (Reubens et al., 2009).

2.2. Sampling methods

2.2.1. Acoustic telemetry

To quantify the diel movement pattern of Atlantic cod at the WARs, the Vemco VR2W acoustic monitoring system was used. In this system self-contained, single channel (69 kHz) submersible VR2W receivers were used to detect the signals of pulse-coded acoustic transmitters (Vemco V9-1 L). Each transmitter has a unique ID, emitting a signal every 110 to 250 s.

The Atlantic cod tracked at the WARs, were collected between May and July 2011 (Table 1) in the study area using hook and line gear. After capture the individual fishes were kept in an aerated water tank for 2 h before surgical implantation of the transmitter (i.e. tagging). Surgical procedures were similar to those of Reubens et al. (2012), Arendt et al. (2001) and Jadot et al. (2006). Prior to tagging, the fish were anaesthetized in a 0.3 ml l^{-1} 2-phenoxyethanol solution. Following anaesthesia (i.e., fish showing no reaction to external stimuli, slow opercular rate and loss of equilibrium (McFarland and Klontz, 1969)), the fish were placed, ventral side up, in a V-shaped support. Most of the body, except the ventral side, stayed in the water and a continuous flow of aerated water was pumped over the gills to avoid dehydration and provide continuous oxygenation. A small incision (15–22 mm) was made on the mid-ventral line and an acoustic transmitter was inserted in the visceral cavity. The incision was closed with two sutures (polyamide

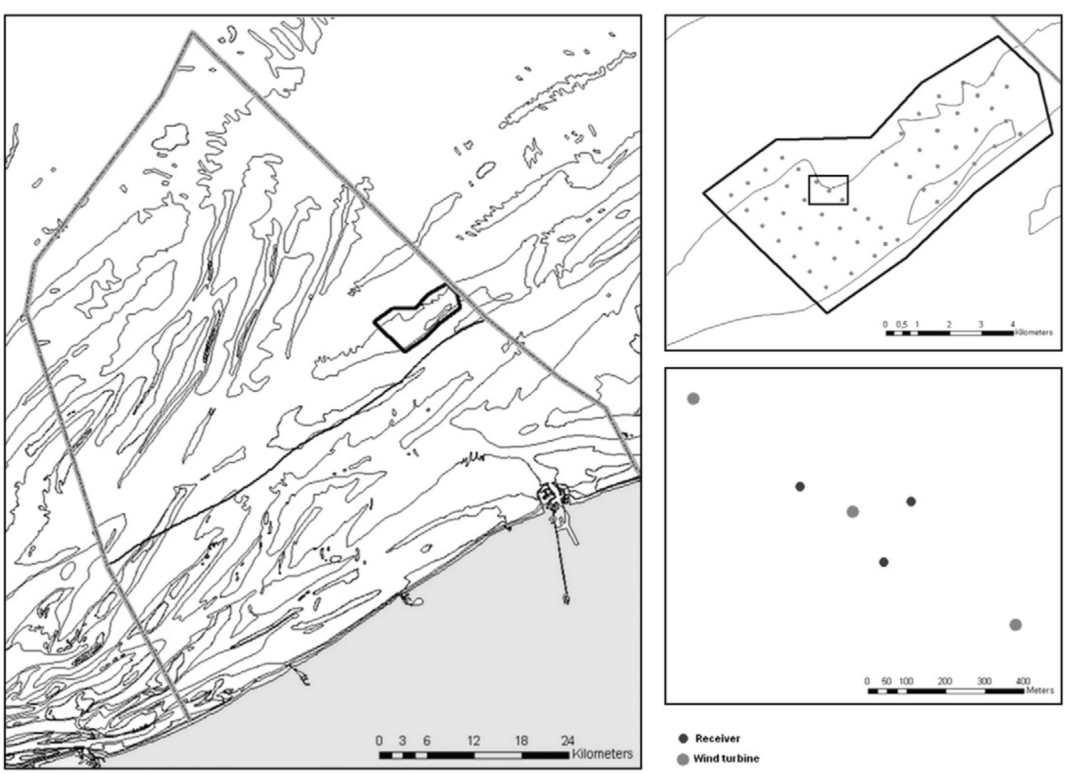

Fig. 1. Overview of the Belgian part of the North Sea, with indication of the wind farm concession area (left part); wind farm layout and receiver positions (right part).