Journal of Sea Research 127 (2017) 194–202

Contents lists available at ScienceDirect

Journal of Sea Research

journal homepage: www.elsevier.com/locate/seares

Burrow distribution of three sandeel species relates to beam trawl fishing, sediment composition and water velocity, in Dutch coastal waters

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ARTICLE INFO

Keywords:
Ammodytes tobianus
Ammodytes marinus
Hyperoplus lanceolatus
Burrow distribution
Fishing pressure
Environmental conditions

ABSTRACT

Sandeel partly spend their life buried in the sediment, without a permanent burrow opening or an inhalant opening in the sediment. We linked the presence of three sandeel species (*Ammodytes tobianus*, *A. marinus* and *Hyperoplus lanceolatus*) off the southern Dutch coast of the North Sea to sediment related environmental variables; (1) sediment composition, with a hypothesized preference for low silt content and high medium-coarse sand content, (2) water velocity near the seabed, with a hypothesized preference for high water velocity and (3) fishing effort of the beam trawl fleet targeting flatfish and shrimp, with a hypothesized negative impact of fishing on sandeel presence. Data originated from an intensive benthic sampling scheme, VMS and logbook databases and a hydrodynamic model. Statistical models were run including these environmental variables plus year, depth, water temperature and salinity. Sandeel presence was negatively correlated with flatfish and shrimp fisheries – both *Ammodytes* species with flatfish fisheries and *H. lanceolatus* with shrimp fisheries. Water velocity and silt content were correlated as hypothesized with the presence of all species, and sand content was positively correlated with both *Ammodytes* species. The remaining environmental variables also showed a significant relation with at least two sandeel species. These findings agree with and greatly expand on previous studies on the relation between sandeel and its environment.

1. Introduction

Sandeel contribute markedly to the total fish biomass in the North Sea (Sparholt, 1990). The oil-rich, highly energetic fish are a part of the diet of many top predators and the most important prey species for many seabirds (e.g. Engelhard et al., 2014; ICES, 2014; Rindorf et al., 2000). The most common and best studied species of sandeel in the North Sea is *Ammodytes marinus* (Raitt). In the North Sea it co-occurs with *A. tobianus* (Linnaeus) and *Hyperoplus lanceolatus* (Le Sauvage). Sandeel live semi-pelagic: most of the year the fish live predominantly burrowed in sandy substrates, except during a brief spawning period in winter (Hoines and Bergstad, 2001; Winslade, 1974b, both regarding *A. marinus*) and an extended period in spring and early-summer, when they spend part of the daytime foraging in the water column (Rindorf et al., 2000; Winslade, 1974a, 1974b, 1974c, regarding *A. marinus*, van Deurs et al., 2011, regarding *A. tobianus* and Reay, 1970, regarding all three species).

Sandeel are believed to exhibit high sand bank fidelity. Larvae can be transported over large distances but once juveniles settle on a sand bank, sandeel abstain from large-scale dispersion (Engelhard et al., 2008; Gauld, 1990; Jensen et al., 2011; Robinson et al., 2013). Also when foraging, sandeel tend to remain near their burrow sites (Kuhlmann and Karst, 1967; Reay, 1970; Robinson et al., 2013; van der Kooij et al., 2008). This small home range makes sandeel an ideal fish to study its relation with the environment.

Because of the semi-burrowed lifestyle it is likely that sediment related characteristics of the environment are important in explaining the distribution of sandeel. Besides being burrowed for the largest part of their lives, sandeel do not have permanent burrow openings or an inhalant opening in the substrate (Reay, 1970). Both easy penetration of the sediment and sufficient supply of oxygen in the sediment will thus play a role in the habitat choice of sandeel (Reay, 1970; Wright et al., 2000). Studies have shown that sandeel exhibit a preference for sediment with a high content of large-sized particles ('sand') and avoidance of sediment with high content of small-sized particles ('silt') (Holland et al., 2005; Reay, 1970, regarding sandeel in general; Wright et al., 2000, regarding *A. marinus*). The absence of an inhalant opening in the substrate is hypothesized to lead to a preference for locations with high water flow at the seabed, for oxygen supply (Meyer et al., 1979; Reay, 1970; Wright et al., 2000). Another sediment related

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http://dx.doi.org/10.1016/j.seares.2017.05.001
Received 13 January 2016; Received in revised form 12 December 2016; Accepted 3 May 2017
Available online 04 May 2017
1385-1101/

characteristic that may affect the occurrence of sandeel is the fishing intensity of beam trawl fisheries. Beam trawl ships tow their net over the sea floor, with a steel beam keeping the net open. Ships targeting flatfish also use tickler chains, which plough through the top layer of sediment. Beam trawl fisheries physically disturb the seabed up to at least the first 6 cm (Bergman and Hup, 1992; Watling and Norse, 1998). This type of fisheries extract many non-target benthic organisms from the seabed and can also kill, damage or deter the benthic organisms which are not fished up in numerous ways (Alverson et al., 1994; Broadhurst et al., 2006; Kaiser et al., 2006; Kelleher, 2005). Sandeel species residing in the upper layer of the sediment may thus be sensitive to the presence of such fisheries.

Thus, sediment composition, water velocity and fishing intensity of beam trawl ships are expected to have an influence on the burrow distribution of the three sandeel species. Only the relation of sediment and *A. marinus* has actually been studied in the past. Here, the influence of the three environmental characteristics on sandeel burrow distribution is examined in the Voordelta, an area off the southern Dutch coast, with the following hypothesized relations: (1) a negative relation of sandeel with the fishing effort of the beam trawl fleet, (2) a negative relation with silt content of the sediment and a positive relation with sand content, (3) a positive relation with water velocity at the seabed.

2. Materials and methods

2.1. Dredge survey

The Voordelta is a shallow and dynamic coastal area. The fresh water outlet of the river Waal through the former sea inlet, but now dammed, Haringvliet (Fig. 1) causes high local gradients in salinity. There are several shallow sand banks, interspersed with deeper canals and open water areas. In the autumn of the years 2009–2012 an extensive fine-scaled grab survey was performed. The distribution of the 406 planned stations over the Voordelta is stratified according to the importance of areas for the benthic community (Fig. 1). Sampling was carried out on a regular grid, varying in cell size between 64 and 225 ha depending on the stratum, with one randomly chosen sampling point per grid cell. Aspects of habitat structure and benthic composition were taken into account in the survey design.

The sampling campaign took ca. 6 weeks, in September (43% of the samples), October (48%) and November (9%). Some locations were sampled but removed from the analyses due to missing sediment data or because no estimation could be made for the fishing effort in the vicinity. Of the planned stations, the majority was sampled adequately every year; 404 in 2009 and 2010, 402 in 2011 and 401 in 2012. In total the survey thus yielded 1611 samples. The stations were sampled with a trawled dredge. The blade of the dredge has a width of 10 cm and sampling depth is 9 cm. The dredge is trawled over a distance of 100 to 150 m. While towed, a strip of sediment with its biotic content is excavated and transported into the cage. The stainless steel cage has a mesh size of 0.5 cm. Depth of each sampling location was determined at approximately the midpoint of the transect, during the sediment sampling (see Section 2.1.2).

2.1.1. Sandeel identification

Sandeel were individually frozen and brought to the lab for identification to the species level, following Hureau and Monod (1979) and Wheeler (1969). Only fish that were intact (from tail to head) could be identified, because identification requires characteristics set over the whole length of the fish. This resulted in a large fraction of the caught sandeel not being identified. For every complete sandeel there were roughly 1.5 incomplete sandeel. The assumptions were made that (a) the species of sandeel and (b) geomorphological differences between stations do not influence the chance of being damaged by the dredge. We thus assumed that the identified sandeel are representative for the overall distribution of the species and can be used to investigate their relationship with the environment and fishing disturbance.

2.1.2. Sediment analysis

Sediment grain analyses were performed on sediment samples collected with a boxcorer approximately at the midpoint of the survey transects. The technical details of the sediment analyses are described in the Appendix. The following sediment classes were defined: “silt” (≤ 63 μm diameter) and sand identified as “very fine” (> 63 to ≤ 125 μm), “fine” (> 125 to ≤ 250 μm), “medium” (> 250 to ≤ 500 μm) and “coarse” (> 500 to ≤ 1000 μm). These five classes add up to 100%. The sediment in the samples consisted mostly of intermediate grains sizes (medium and fine sand), with mostly low concentrations of coarse and very fine sand and silt. The sediment traits are highly correlated among each other. The relationship between the five sediment classes in the field is described in the Appendix. Following the findings of previous studies (Holland et al., 2005; Reay, 1970; Wright et al., 2000), two sediment characteristics that show the strongest relation with the distribution of sandeel were used in the statistical models: the medium-coarse sand (250–1000 μm) content and the silt (0–63 μm) content. Sand is usually defined as having a median particle size of up to 2000 μm, but sand of 1000–2000 μm was removed from the samples before analysis.

2.2. Estimated abiotic variables

2.2.1. Estimated fishing effort

The most common fisheries in the Voordelta are the beam trawl fisheries with 260–300 horse power targeting flatfish (with a mesh size of 70–99 mm and using tickler chains) and shrimp (with a mesh size of 16–31 mm). Taking the site fidelity of sandeel into account, the effect of fishing is assumed to be long term: mortality by trawling over the past year (September–August) is expected to affect the distribution of sandeel in the subsequent autumn period. Fishing intensity of these fleets was estimated based on the VMS (Vessel Monitoring by Satellite) data of the Dutch beam trawl fleet, as collected for the Dutch Ministry of Economic Affairs. This information was linked to information in the ship's log book on gear, horse power and landings (Hintzen et al., 2012). For the technical details of this analysis, see the Appendix. The subsequent estimate of local fishing effort is expressed as fraction area trawled within a 50 m radius of a sampling location. For example, a fishing effort of 2.0 can be interpreted as the complete vicinity of a location having been trawled twice in the prior year - or half the area having been trawled four times.

2.2.2. Estimated environmental variables

A hydrodynamic model (see the Appendix for a technical description) was used to estimate the spatial and temporal dynamics of water velocity, temperature and salinity. Based on a set of standard model schematizations, hind cast simulations of the Voordelta area were run. As input for the model, empirical datasets were added for astronomical tidal constituents, fresh water river discharges, atmospheric forcing such as wind and pressure fields and atmospheric heating, and sea water and river temperature. Water level, temperature and salinity were calibrated with real-time measurements carried out during the dredge survey and collected by governmental surveys. The accuracy of the model results turned out to be appropriate (see the Appendix).

Per sampling location, the local values for water salinity at the bottom (‘salinity’), water temperature at the bottom (‘temperature’) and water velocity at the bottom (‘water velocity’) were averaged over the week before the dredge sampling dates.

2.3. Sandeel distribution models

For all three sandeel species a generalized linear mixed effect model (‘glmm’) was used (formula (1)). Because of the high percentage of