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Spatial differences in growth of lesser sandeel in the North Sea

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ABSTRACT

Lesser sandeel, *Ammodytes marinus*, is a key prey to a variety of North Sea predators, including species such as single load seabirds which are highly sensitive to prey size and condition. Whilst differences in weight at age across the North Sea have been investigated previously, the scale and cause of this variation as well as the potential link to spatial differences in predator performance remains unknown. This study presents an analysis of spatial patterns in length and condition of the lesser sandeel in the North Sea and the relationship of these with physical and biological factors. Both mean length at age and condition was higher on warmer, deeper and central/north eastern fishing grounds. Sandeel in the water column exhibited large changes in condition over the season, having an initially low condition following spring emergence rising to a pronounced peak by June. Weight at age varied considerably both spatially and temporally, resulting in 4 fold and 1.9 fold variations in the number of sandeels required to obtain a specific weight, respectively. Hence, the value of sandeel as prey to single load predators varies considerably with values in central and northeastern North Sea being substantially higher than in northwestern and southern areas.

1. Introduction

The lesser sandeel, *Ammodytes marinus* (L.), is a small elongate planktivorous fish which forms an important prey source for numerous fish, seabirds and mammals (Daan et al., 1990; Furness, 1990; Engelhard et al., 2014). Beyond their first year of life, their growth season spans only a few months in spring and early summer (Winslade, 1974a; Pedersen et al., 1999; Bergstad et al., 2002) and their spatial distribution is highly restricted (Wright et al., 2000; Jensen et al., 2011), making their importance particularly impressive. Outside these months, sandeel older than 1 year remain buried in the sediment, emerging only in mid-winter to spawn.

In their role as prey for numerous predators, weight and length at age is of great importance as the benefit of sandeel prey to predators depends on the ratio between handling time and prey energy content (Stephens and Krebs, 1986), a ratio to which single prey loading seabirds are particularly sensitive (Wanless et al., 2005). Predators targeting sandeel are likely to experience only minor changes in handling time but profound changes in the weight of prey items with differing prey size. Weight and length at age has been reported to differ across the North Sea, although the evidence for this is partially confounded by differences in the years and areas sampled and the studies cover only a small part of the total distribution area (Macer, 1966; Wright, 1996; Bergstad et al., 2002; Boulcott et al., 2007). If present, spatial differences may potentially explain why strong links between sandeel density and dependent predators such as seabirds have been reported for the north western North Sea (Monaghan, 1992; Rindorf et al., 2000) whilst further south the eastern English kittiwake populations apparently maintain high breeding success even in years of sandeel recruitment failure and low adult sandeel biomass (Frederiksen et al., 2005; ICES, 2014).

The factors that may affect length and condition include prey and competitor abundance as well as temperature. Temperature directly determines several vital physiological processes in fishes (Jobling, 1985), including food consumption and assimilation rate (Brett, 1979). Positive direct thermal effects on the rate of increase in length and condition will occur when food availability is not limiting and temperature is within the aerobic scope for growth (Pörtner and Rainer, 2007). Over the North Sea, surface and bottom temperatures generally vary by around 3 to 5 °C during summer (Elliot et al., 1991) and hence spatial differences in temperature could potentially introduce variability in scope for growth. Sandeel are visual feeders on zooplankton, particularly calanoid copepods (Macer, 1966; Winslade, 1974a; van Deurs et al., 2014) and if food is limiting, growth rate will reflect the temporally and spatially varying abundance of prey. Several authors have suggested that growth rate decreases late in the season when food is less abundant (Pedersen et al., 1999; Bergstad et al., 2002) and high local densities may inhibit growth rate through food competition (Bergstad et al., 2002).

Sandeels accumulate large amounts of lipids in their somatic tissue over the foraging season for somatic maintenance and secondary

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gonad development during the overwinter phase (Hislop et al., 1991; Boulcott and Wright, 2008). The onset of overwintering depends on the build-up of lipid reserves with long or high condition sandeel burying earlier than small individuals (Bergstad et al., 2002; Wanless et al., 2004, van Deurs et al., 2011). Therefore, both regional differences in growth rate and size-differentiated timing of emergence periods may lead to temporal changes in weight at age. Such changes appear in commercial catches where weight at age seems to peak mid-season (Pedersen et al., 1999). However, as there are likely to be regional differences in length and condition, the observed pattern in weight at age may be a sampling artefact caused by temporal changes in the areas fished by the commercial fishery.

This study presents an investigation of length and condition at age of sandeel with the aim to determine (1) whether there are spatial differences in length and condition at age, (2) whether such spatial differences can be explained by differences in biophysical conditions, (3) whether a decrease in weight at age late in the season as reported by Pedersen et al. (1999) is an artefact caused by spatially dependent length and a geographical change in fishing effort, (4) whether site specific decreases in length and condition at age occur late in the season indicating early burial of long or high condition fish and finally, (5) what are the consequences of spatiotemporal differences in weight at age on the number of sandeel required to obtain a kg by area.

2. Material and methods

Length and condition were analysed separately in this study. These two parameters differ in that length is generally monotonically increasing whereas condition may decrease and increase again over the course of the year. Hence, a decrease in length at age is likely to be caused by the removal of large individuals from the population whereas this cannot be assumed for a decrease in condition or weight at age. Analysing length and condition rather than weight at age has the further advantage that they are statistically independent and can therefore be compared without the risk of spurious correlations arising. Variation in length and condition was analysed spatially, ignoring cohort and other temporal effects, as the data available were too unbalanced to allow a joint analysis of spatial and temporal variations.

2.1. Sandeel fishing ground definition

Fishing ground distribution was used to determine the distribution of foraging habitat (Jensen et al., 2011). Sandeels show extensive movements within fishing grounds but very limited movements between grounds (Kunzlik et al., 1986; Jensen et al., 2011). Therefore, all data on physical and biological conditions were averaged within fishing grounds before further analyses. The only exception to this was the largest fishing ground, where analyses indicate that some spatial structures exist in length composition (Jensen et al., 2011).

2.2. Sandeel biological data

Sandeel data for the analyses were derived from a co-operation between the Danish Fishermen's Association and the Technical University of Denmark that started in 1999. Samples of sandeel data up to 2010 were included in analyses, providing a full time span of 12 years. After 2010, the number of samples is lower and the spatio-temporal coverage changed in some years due to severe limitations on the fishery. The fishery targets several species of sandeel of which *A. marinus* is by far the most important and the focus of this study. Samples were collected by fishers directly from fishing vessels and the exact location and time of shooting and hauling of the trawl and the estimated total weight of the catch in the haul were recorded for each sample. Approximately 1 kg samples of sandeel were taken randomly from the catch. Bycatch of other species in the sandeel fishery consists of a very low percentage of gadoids and these were not included in the samples. In the laboratory, sandeel were sorted by species, and total length, L, in a subsample of *A. marinus* measured to the nearest half cm below. Comparison of the length distribution of these samples with randomly selected port samples taken from vessel landings indicated that there was no bias induced by fishermen's sampling. 5 to 10 sandeel per half cm group were randomly selected and age estimated using the sagitta otoliths. Age estimation was conducted by two readers following ICES protocols on the seasonal appearance of translucent and opaque zones in sandeel otoliths and the identification of secondary growth structures using daily increments (Wright, 1993; ICES, 1995). Reader agreement tested in workshops with other institutions was 83% for all ages (e.g. ICES, 2006). As age estimation agreement tends to decrease with age (ICES, 1995), fish of age 4 and older were grouped into a plus-group. Fishing ground was assigned to samples from the location of the midpoint of the haul.

Mean length at age was estimated by combining sampled length distributions with age–length keys. Age–length keys were produced separately for each fishing ground in each week and year using the method described by Rindorf and Lewy (2001) on all data available from the given fishing ground, week and year. Where possible, only data from the particular week in which a length sample was taken were used to estimate the age–length key for the sample. If less than 50 sandeel were aged in a specific week or weekly data resulted in confidence intervals of the predicted proportion at age which were larger than 0.25, 2-week periods were used to estimate the age–length key. No further temporal aggregation of samples was conducted to ensure that no bias was introduced in length at age by using incorrect age–length keys. Each haul resulted in one mean length at age for each age group except if the predicted number at age was below 5. Mean lengths based on less than 5 fish were judged to be highly uncertain and excluded. Hence, the number of mean lengths available differed between ages as not all ages were sufficiently represented in all samples. Age 0 sandeels were only partly selected by the fishing gear and hence were not included in analyses of length and condition. Due to uncertainty in the true age of 4+ sandeel, this age group was not included in the von Bertalanffy analyses. There was no subsequent weighting of the samples to reflect the catch in the haul from which the sample was taken or the number length measured in the sample.

Average condition C of fish of length L in each sample was estimated from the average weight W of fish of this length in the sample (Le Cren, 1951):

$$C = W/L^b. \tag{1}$$

The parameter b was the exponent estimated from the length–weight relationship derived from all samples together:

$$W = C_m L^b \tag{2}$$

where C_m denotes the monthly average condition across all years and fishing grounds. The error around the relationship was assumed to be gamma distributed as the variation in weight increased with the mean. The average condition of each age group recorded in a sample was estimated as the average between half cm groups, weighted by the number of fish of the given age in the half cm group.

Catch in numbers per minute was assumed to be an index of density (Hilborn and Walters, 1992) and was estimated by combining catch in kg/min haul time with the number of sandeel per kg in the particular haul. The geometric average catch in numbers per minute (all ages together) on each fishing ground in the particular week averaged over all years was used as an index of sandeel density.

2.3. Biophysical conditions

Average predicted biophysical conditions were derived from models as samples with sufficient spatio-temporal coverage were not available.