Fisheries Research 189 (2017) 1–9

Contents lists available at ScienceDirect

Fisheries Research

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

Spatial structure of body size of European flounder (*Platichthys flesus* L.) in the Baltic Sea

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ARTICLE INFO

Article history:
Received 5 August 2016
Received in revised form
30 December 2016
Accepted 2 January 2017
Handled by George A. Rose
Available online 12 January 2017

Keywords:
Age-length distributions
Fish management
Maturation
Spatial structure
Stock identification

ABSTRACT

The spatial structure of fish species is important for stock identification and management. The European flounder (*Platichthys flesus* L.) shows morphological differences across the Baltic Sea Proper. However, it is not known whether flounders cluster into several distinct areas based on morphological characters, indicating discrete sub-populations, or whether they show continuous morphological variation along space indicating a more continuous population structure. Here, we study the spatial structure of body length and length-at-age distributions of the European flounder (*Platichthys flesus* L.) across the Baltic Sea Proper (International Council for the Exploration of the Sea (ICES) subdivisions 25–28) using high spatial resolution data (ICES rectangles) from fishery independent surveys 2008–2014. Our results are in agreement with genetic data suggesting a continuous gradient of decreasing body length from south-west to north-east. Further, we observed distance decay in the spatial synchrony of temporal changes in the length distributions, such that the temporal trends were correlated among adjacent ICES rectangles but independent across the whole study area. Length-at-age and maturity patterns that were calculated for each subdivision also showed a consistent spatial difference where SD 28 was significantly different from SD 25 and 26. Our results indicate that the European flounder in the Baltic Sea consists of several loosely defined sub-populations, which may warrant a reconsideration of assessment models, management targets and regulations across subdivisions.

1. Introduction

In the Baltic Sea Proper, the area between the Danish straits and the island of Åland (Fig. 1), the deeper (and anoxic) parts outside Gotland and Gdansk may be the only physical dispersal barriers for marine fish. However, the Baltic Sea has a salinity gradient, from 25 psu in Öresund to 3–4 psu in the Bothnian Bay (HELCOM, 1996; Olsson et al., 2012) that challenges both marine and freshwater adapted organisms affecting their distribution (Olsson et al., 2012). Temporal variation in salt water inflows, oxygen levels, eutrophication, climate change, and fisheries (Olsson et al., 2012, 2013; Niiranen et al., 2013) have also altered the Baltic Sea food-web structure over time (Casini et al., 2009; Olsson et al., 2013; Östman et al., 2016a). Spatial environmental variation may result in spatially structured sub-populations that are important to consider for management (Laikre et al., 2005; Spies et al., 2015; Östman et al., 2016b). The spatial structure of species could be formed by distinct sub-populations with specific characters (e.g. adaptations, morphology, life-history traits). Alternatively, populations may show continuous change in traits along geographical or environmental gradients. For exploited species, the failure to identify relevant spatial structures may result in overexploitation of some stocks whereas other stocks are not efficiently used (Palsbøll et al., 2007; Allendorf et al., 2008; Spies et al., 2015). Spatial structure of a species is also important for preserving stocks with unique biological properties such as a specific morph or life-history trait or local adaptation (Allendorf et al., 2008). Units for management should preferably be based on the spatial structure of different sources of biological data, i.e. 'Integrated Stock Definition' (Welch et al., 2015; Hawkins et al., 2016). These different biological data sources include for example spatial genetic population structure, life history traits, demography, morphology and stable isotopes or otolith chemistry which indicate where individuals have been during their lives (Begg and Waldman, 1999; Laikre et al., 2005; Cadrin et al., 2014; Östman et al., 2016b).

The European flounder (*Platichthys flesus*) inhabits most parts of the Baltic Sea. There are two genetically distinct ecotypes of flounder in the Baltic, coastal spawners with demersal eggs and offshore spawners with pelagic eggs (Hemmer-Hansen et al., 2007a; Florin and Höglund, 2008), which require different salinities for success-

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http://dx.doi.org/10.1016/j.fishres.2017.01.001
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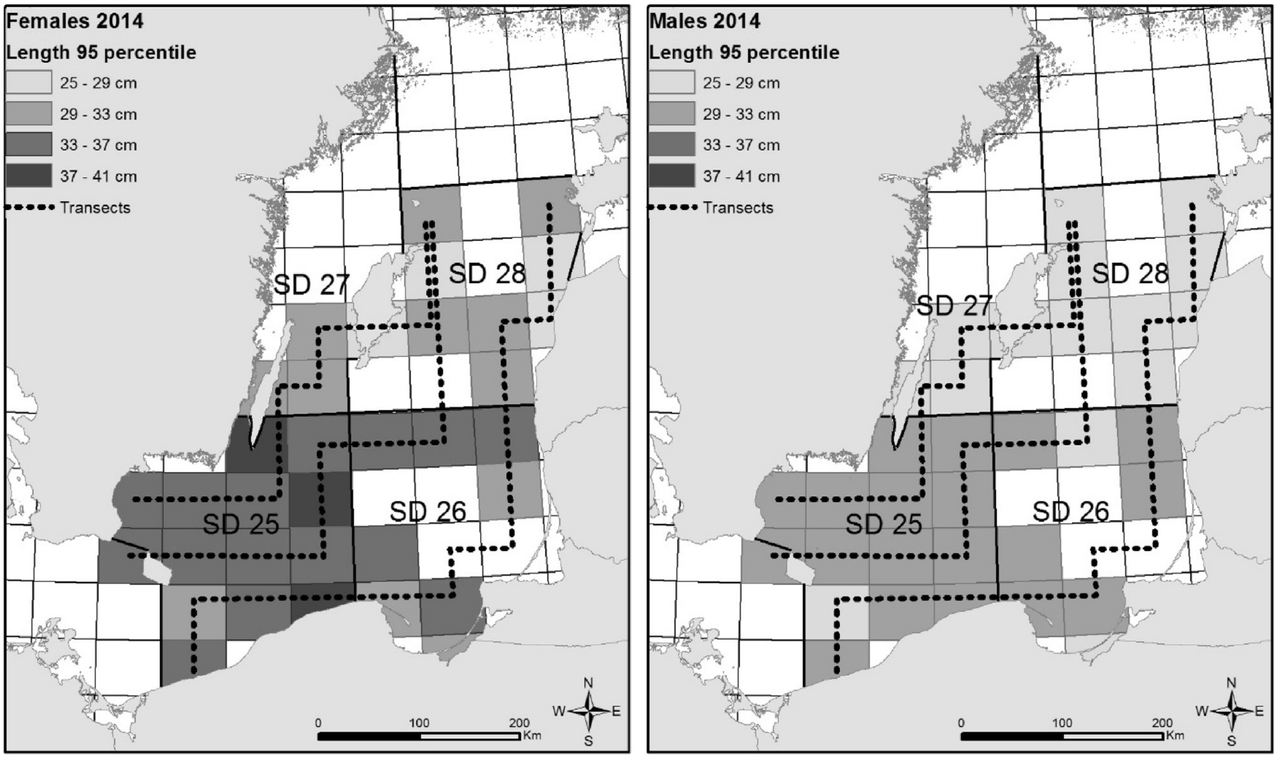

Fig. 1. Map of the studied area with *L95* (shaded cells) for 2014 for each ICES rectangle (thin lines). Thick lines show subdivisions (SD). The broken lines show the three transects for the semivariogram analyses.

ful reproduction and show different fecundity and growth (Nissling et al., 2002; Nissling and Dahlman, 2010). These two ecotypes are divided into separate stocks for management (ICES, 2014a, 2015). Despite that the tagging studies of European flounders have indicated short dispersal range in the Baltic and the deeper parts can act as barriers for dispersal (Aro, 1989, 2002), the coastal spawning flounders show no spatial genetic structure and is treated as one stock in ICES Subdivisions SD 27, 29–32. In contrast, the offshore spawning flounders show a genetic isolation-by-distance pattern (Florin and Höglund, 2008) and is currently assessed as three separate stocks by ICES: one unit in the straits (ICES Subdivisions, SD, 22–23), one western unit in SD 24–25 and one eastern unit in SD 26 and 28 (ICES, 2014a; ICES, 2015; see Fig. 1 for ICES subdivisions).

Earlier studies of European flounder show spatial variation in demographic, morphologic and life-history traits across the Baltic Sea. Mean length-at-age was found to decrease gradually along the coast from the Great Belt to the Gulf of Finland in (quarter 4) 1994 (Drevs et al., 1999). Up until year 2007, flounders in the central Baltic Sea Proper (SD 28) were on average smaller than in the southern Baltic Sea (SD 24–26), while small differences in length was observed within the southern Baltic Sea (Gårdmark and Florin, 2007).

Higher salinity improves reproduction and somatic growth of offshore spawning flounder (Nissling et al., 2002) while high population density may have negative effects on body growth. For example, Florin et al. (2013) found that length-at-age of European flounder was lower in a high density no-take zone compared to a fished area in SD 28, likely reflecting negative density dependent body growth. Thus, temporal variation in abiotic and biotic factors may affect the length distribution and spatial structure of European Flounder over time.

In this study, we extend on previous studies of spatial differences based on genetics, eggs and sperm characteristics, length-at-age and tagging studies (ICES, 2014a) by studying the spatial structure of length distributions of the European flounder across the Baltic Sea Proper using more detailed data. First we use high spatial resolution data (ICES rectangles) on length distributions from the fishery independent Baltic International Trawl Survey 2008–2014 to study the spatial structure of European flounder body length distributions. Specifically, we study whether the European flounder displays distinct and significant spatial differences in length distributions between areas indicating sharp transition zones or whether there are more continuous (i.e. gradual) differences that increase with distance between rectangles. Next, we investigate the temporal stability of spatial differences in length-at-age and age-and size specific maturity at the spatial scale of ICES subdivisions. The overall aim is to study if body size shows consistent gradual changes or distinct spatial patterns over time, and if so to identify eventual boundaries of areas with similar length distributions and life-history traits that could indicate subpopulations, enabling a more integrated stock definition of offshore European flounder in the Baltic Sea.

2. Materials and methods

2.1. Data extraction

Data were compiled from the ICES data base (DATRAS, https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx) from the Baltic International Trawl Survey (BITS) in Quarter 1 and 4 including Latvian, Polish and Swedish data for ICES subdivisions (SD) 25–28 (excluding Gulf of Riga) over the time period 2008–2014 (Fig. 1). During this time period the same age determination method (using sectioned and stained otoliths) has been used by all three countries. For a detailed description of the trawl survey see ICES (2014b). European flounders spawn in March-May and the spatial structure in Quarter 1 is therefore more likely to reflect the spatial structure of spawning individ-