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Investigating spatial heterogeneity of von Bertalanffy growth parameters to inform the stock structuration of common sole, Solea solea, in the Eastern English Channel

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ABSTRACT

In fisheries science, a mismatch between the delineation of a fish stock and the underlying biological population can lead to inaccurate assessment and management. Previous results suggested a potential spatial structuration of the Eastern English Channel (EEC) stock of common sole, *Solea solea*, in three sub-populations. In this article, we propose to investigate the spatial population structure of common sole in the EEC using the von Bertalanffy Growth Function parameters as indicators of population segregation. In order to test the sub-population hypothesis and evaluate its robustness to data sources, we developed three models, all including an area effect on growth parameters. The first model was aimed at testing a potential data source effect (in addition to the area effect) using commercial and scientific survey data jointly. The two other models used either scientific survey or commercial fishery data and focused on spatial differences in growth parameters. Our results showed that the growth parameter estimates indeed differed depending on the type of data used, with higher estimated asymptotic length and length at age two (L_2) using commercial data. They also highlighted spatial differences in asymptotic length, consistent between models, which tend to confirm a spatial structuration of sole in the EEC. While these results need to be strengthened by marking and genetic studies, they constitute a first step towards a better understanding of the population spatial structuration of common sole in the EEC.

1. Introduction

Harvested species are usually assessed and managed at the stock-unit scale, a stock being defined as an intraspecific group of individuals randomly mating and maintaining its integrity in time and space (Ihssen et al., 1981). Boundaries of these stock units are supposed to reflect the underlying population structures in terms of biological rates such as mortality and growth (Cadrin et al., 2014; Kerr et al., 2016). Recent research suggests that a strong population structuration in marine fish is a relatively common situation (Ames and Lichter, 2013; Ciannelli et al., 2013; Reiss et al., 2009; Waples and Gaggiotti, 2006), and is mainly driven by oceanographic and environmental factors and larval diffusion (Cowen, 2006; Jorgensen et al., 2005), but also by species' specific migratory behaviour (Secor, 2015) and sequential occupancy of various habitats throughout the lifespan (Petitgas et al., 2013, 2010). An assumed single homogeneous population can sometimes turns out to be a set of sub-populations linked by dispersal, i.e., a metapopulation (Alex Smith and Green, 2005; Hanski, 1998; Kritzer and Sale, 2004). Mismatch between the stock-unit delineation and the true metapopulation structure may impede our capacity to provide adequate management recommendations (e.g., Total Allowable Catch) and may lead to overfishing of the less productive sub-populations while the more productive sub-populations are underexploited (Cadrin and Secor, 2009; Frank and Brickman, 2000; Fu and Fanning, 2004; Ricker, 1981). In the past decade, stock identification has been explored for numerous fish stocks, such as blue whiting, Atlantic cod, and horse

Abbreviations: VBGF, von Bertalanffy growth function; EEC, eastern english channel; SW, southwest; NE, northeast; ICES, International Council for the Exploration of the Sea; UK-BTS, UK beam trawl survey; NLR, non-linear regression; GNLS, generalized nonlinear least squares

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mackerel (Abaunza et al., 2008; Mahe et al., 2007; Zemeckis et al., 2014) and led to revise stock boundaries.

The Eastern English Channel (EEC) common sole, *Solea solea,* is a nursery-dependent flatfish species harvested across its entire range, from the Mediterranean to Baltic Sea (Wheeler, 1978). Reproduction occurs from winter to spring throughout the distribution area, resulting in several weeks of pelagic larval drift before settlement and metamorphosis in coastal and estuarine nursery grounds (Rochette et al., 2012). After two years, mature common soles are recruited to the stock and can in turn reproduce (Dorel et al., 1991; Riou, 2001). The common sole is a high value targeted fish in the EEC with some fleets highly dependent on it. Fishing mortality on EEC common sole has decreased over the last decade and was estimated below Fmsy - the fishing mortality that produces the maximum sustainable yield (ICES, 2017) - for the first time in 2017 (ICES, 2017) due to a series of low recruitments. However, the biomass is still below the targeted value (MSY Btrigger; ICES, 2017).

Contrasts in the length structure of French landed common sole between the North and South of the EEC raise concerns about a possible misunderstanding of the stock structure (Du Pontavice et al., personal communication). The fleets fishing on the EEC sole are segregated in space, across areas corresponding to potentially different components of the population. It is therefore crucial to improve our knowledge of spatial structuration and population connectivity within the EEC stock and to check whether the hypothesis of a unique stock matches the underlying population structure. A body of research already investigated the level of connectivity of common sole population in the EEC at different stages of the life cycle. First, larval advection to coastal nursery grounds has been shown to limit the connectivity between the different spawning and nursery grounds (Rochette et al., 2012). Second, previous analyses evidenced juveniles common sole as sedentary in their nursery grounds during the two first years of life (Coggan and Dando, 1988; Le Pape and Cognez et al., 2016). Finally, former mark-recapture surveys suggested low mobility of adult common sole (Burt and Millner, 2008; Kotthaus, 1963). On the basis of these results, recent modelling studies hypothesized the existence of three sub-populations spatially structured within the EEC (Fig. 1; (Archambault et al., 2016; Rochette et al., 2012). Archambault et al., (2016) assessed the effect of adult-mediated connectivity on population dynamics and stock assessment and concluded that ignoring possible metapopulation could lead to overexploitation of local populations in the EEC. The authors also suggested that research should focus on the adult-mediated connectivity, which remained largely unknown and which magnitude could be a strong driver of spatial structuration within the EEC (Frisk et al., 2014). Recently, the improvement and the multiplication of stock identification tools has made stock delineation increasingly precise (Cadrin et al., 2014; Kerr et al., 2016; Pita et al., 2016). In particular, the use of life-history parameters (e.g., age, growth and mortality) is particularly relevant and cost-efficient (Cadrin et al., 2014). For instance, Barrios et al. (2017) coupled individual growth trajectories and length-at-age datasets in mixed-effects models to investigate stock identification of whiting in the North East Atlantic. Erlandsson et al. (2017) suggested a reconsideration of assessment models of European Flounder based on the spatiotemporal structure of body size in the Baltic Sea. Given the before-mentioned differences in EEC common sole length structure, we propose to study the spatial heterogeneity in length at age as a way to identify spatial structuration within the stock and to test the three common sole sub-populations hypothesis mentioned earlier. Growth is usually modelled using the von Bertalanffy Growth Function (VBGF; Von Bertalanffy, 1938) which provides a non-linear relationship between length and age of organisms. In the present work, we do not aim at describing the growth processes but rather at summarising the characteristics of the length-at-age relationship in delineated subareas in the EEC stock using the three parameters of the VBGF. To avoid bias in the analysis, length-selection in data collection must be avoided and the spatial and temporal coverage has to be representative of the spatial entity considered. In the EEC, two types of data were available to us: data from a scientific survey (the UK Beam Trawl Survey, UK-BTS) and sampling data from French commercial landings. Differences in length-at-age between survey and commercial data can be expected: scientific survey are designed to reflect the length structure of the population, while the length structure of commercial landings is influenced by the minimum landing size imposed by EU on common sole, through fishing strategy (e.g., commercial fisheries tend to fish in areas with the biggest common soles), size-selectivity, and discarding practices.

In this study, we investigated the spatial variability in VBGF parameters within the EEC stock of common sole in order to inform current

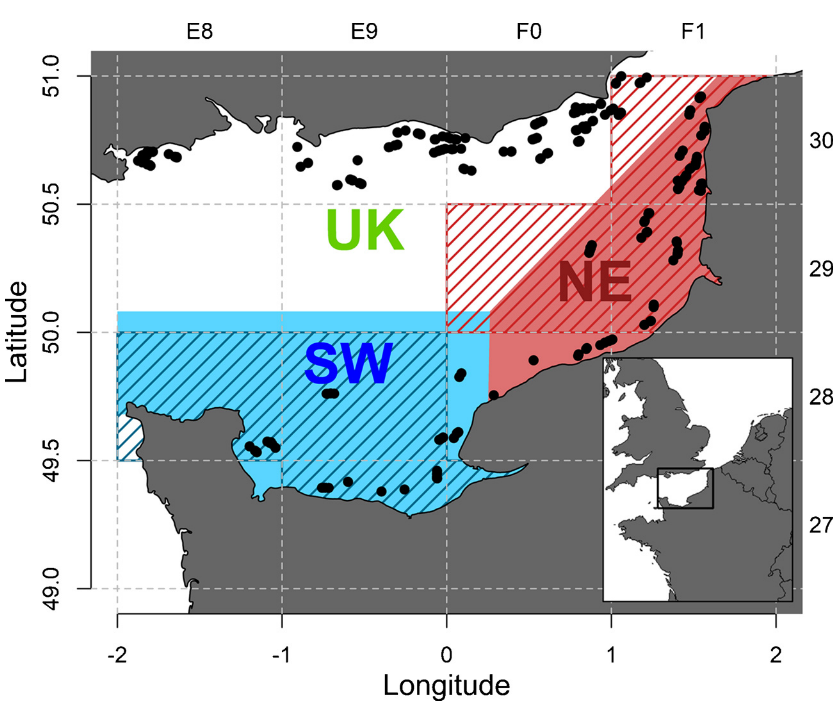

Fig. 1. The three subareas of the Eastern English Channel as proposed in (Archambault et al., 2015; Rochette et al., 2012) (UK: United Kingdom, NE: Northeast, SW: Southwest). The points represent haul positions of the UK-BTS (UK Beam Trawl Survey). The two coloured areas SW and NE in represent the subareas with French commercial sampling and the cross-hatching ICES (International Council for the Exploration of the Sea) statistical rectangles were assigned to the Northeast and Southwest subareas respectively. Top and right axes correspond to the ICES statistical rectangle coordinates.