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Juvenile nursery colonization patterns for the European flounder (*Platichthys flesus*): A latitudinal approach☆

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ABSTRACT

In this work, we analysed the latitudinal trends in the nursery habitat colonization processes of the European flounder (*Platichthys flesus*). This was accomplished by estimating the duration of the pelagic and metamorphic stages, as well as the duration of the spawning period, in several nursery areas across its geographical distribution range in the European Atlantic Coast: Mondego estuary (Portugal), Vilaine estuary (France), Slack estuary (France), Wadden Sea (Netherlands) and the Sørfjord (Norway). All juvenile flounders were captured with beam trawls in June/July 2010, and otolith microstructure was used to determine the duration of each stage by means of daily growth increments. The pelagic and metamorphic stages were longer at the middle of the distribution range, and lasted in total up to two months after hatching. The spawning period occurred between mid-January and early-July over the species' distribution range, with a time lapse of nearly two months between the Mondego estuary and the Sørfjord, as a consequence of warmer water temperature earlier in the season in southern areas. In general, total length of the captured fish showed a latitudinal cline between the northernmost and southernmost sampling sites, with higher values at the middle of the distribution range. The results also suggested the existence of a countergradient growth compensation mechanism in the northernmost populations. Apart from temperature, which sets the general metabolic pace of organisms, differences between sites were also related with local features, such as the extension of the continental platform and adaptations to transport and retention mechanisms.

1. Introduction

Estuarine and shallow coastal habitats provide important nursery grounds for many flatfishes worldwide (e.g. Grioche et al., 1997; Martinho et al., 2009, 2010; van der Veer et al., 1991, 2011). For most of the marine fish that use these areas as nursery grounds, spawning takes place offshore, implying the migration of pelagic larvae or recently metamorphosed benthic juveniles from the continental shelf into estuarine and coastal areas (Grioche et al., 1997; Koutsikopoulos and Lacroix, 1992). Larval dispersion across the continental shelf has several advantages, including the colonization of new settlement habitats and minimization of intraspecific competition (Bailey et al., 2005). However, an increasing duration of the pelagic stage might also lead to a longer exposure to unfavourable hydrodynamic conditions and predation, resulting in higher mortality rates (Duffy-Anderson et al., 2011; Hovenkamp and Witte, 1991). This is particularly important for flatfishes, since they represent an extreme in the process of metamorphosis between larvae and juveniles (Bailey et al., 2008; Geffen et al., 2007).

For flatfishes, recruitment strength is determined mainly during the pelagic stage (Bolle et al., 2009; van der Veer, 1986; van der Veer et al., 2000), being later regulated on post-settlement stages (e.g. Ustups et al., 2013; van der Veer, 1986). Nevertheless, some studies have suggested that the factors controlling recruitment of a species vary over its geographic range, along a latitudinal gradient (e.g. Miller et al., 1991; Pauly, 1994; van der Veer et al., 2000; van der Veer and Leggett, 2005; Vinagre et al., 2008). Hence, it becomes of interest to adopt a macro-ecological approach to examine fish–environment relationships, since the latitudinal position is a good descriptor of the adaptation of populations to the local environment and of their tolerance to climate fluctuations (Brunel and Boucher, 2006; Hermant et al., 2009).

Latitude is a proxy for several environmental gradients such as temperature, seasonality and insolation, which are cross-correlated and interact among them (Willig et al., 2003). In particular, temperature-mediated processes control a major part of a fish's life cycle (Fonds, 1979; Pauly, 1994), setting the fundamental rates of metabolism, energy uptake, storage and use (Kooijman, 1993; Neill et al., 1994), including also spawning, growth and reproduction migrations (Buckley, 1982; Fincham et al., 2013; Neuheimer et al., 2011; Sims et al., 2004; Vinagre

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et al., 2008). Hence, it is expected that the influence of latitude in the early stages of flatfish is mainly felt through differential environmental conditions related to their position along the geographical distribution range.

In the Eastern Atlantic, the European flounder (*Platichthys flesus*, Linnaeus, 1758) is a common species, occurring in the coastal, brackish and fresh waters of Western Europe and from the White Sea to the Mediterranean and the Black Sea, ranging between 40° N and 72° N. Presently, and apart from a geographically isolated set of populations in the Mediterranean and Adriatic Seas (Borsa et al., 1997), the current southern distribution limit of this species is assumed to be on the Portuguese coast (Cabral et al., 2007). The life cycle of flounder includes batch spawning in coastal areas, and the migration of young metamorphosing fish to nursery grounds, where benthic settlement concludes the pelagic larval stage (Nissling and Dahlman, 2010; van der Veer et al., 1991). In the particular case of flounder, the settling of larvae is considered to occur simultaneously with metamorphosis (ICES, 2008). This process is preceded by a combination of passive shoreward transport (Grioche et al., 1997) and active swimming adjusted to tidal rhythms (Jager, 1999), resulting in a more effective inshore transport of fish larvae into nursery areas (Grioche et al., 1997; Rijnsdorp et al., 1985).

Based on the work by Miller et al. (1991), who suggested that the patterns of recruitment variability occur over a latitudinal scale, the main objective of this work was to determine the existence of a latitudinal trend in the nursery colonization processes and in the spawning period of *P. flesus* across the northeastern Atlantic, where conspicuous gradients in environmental factors (mainly temperature) are anticipated. In particular, we estimated the duration of the spawning period, the pelagic and metamorphic stages, as well as the geographical differences in total length and length–weight relationships of juveniles, in order to determine whether latitude imposes a significant influence on the life cycle of flounder over its distribution range.

2. Material and methods

2.1. Study sites and juvenile fish collection

Flounder 0-group juveniles were collected in several estuarine and shallow coastal nurseries covering a range of 20° in latitude: Sørfjord (Norway), western Dutch Wadden Sea (The Netherlands), Slack estuary (France), Vilaine estuary (France) and Mondego estuary (Portugal) (Fig. 1). The sampling sites were selected in order to cover most of the geographical distribution range of *P. flesus* in European waters. More information of the sampling areas is presented in Table 1. 0-Group juvenile flounders were collected in the estuarine nurseries between mid-June and mid-July 2010, using several beam trawl tows. The sampling dates were chosen based on the spawning period reported in literature, in order to ensure that spawning and larval migration towards the nursery grounds had finished. Since the aim of this study was not to analyse trends in juvenile densities, differences between sampling methods were not accounted for. All beam trawls were fitted with a 5 mm mesh size in the cod end, in order to ensure a similar selectivity for flounder juveniles. After collection, all fish were transported in ice-boxes to the laboratory and frozen for later analysis.

Average monthly sea surface temperature (SST) data for 2010 in the coastal area was obtained from the International Comprehensive Ocean–atmosphere Data Set (ICOADS) online database (http://dss.ucar.edu/pub/coads, dataset 540.1, Worley et al., 2005), covering the 1° Lat × 1° Long square nearest to each nursery ground sampled.

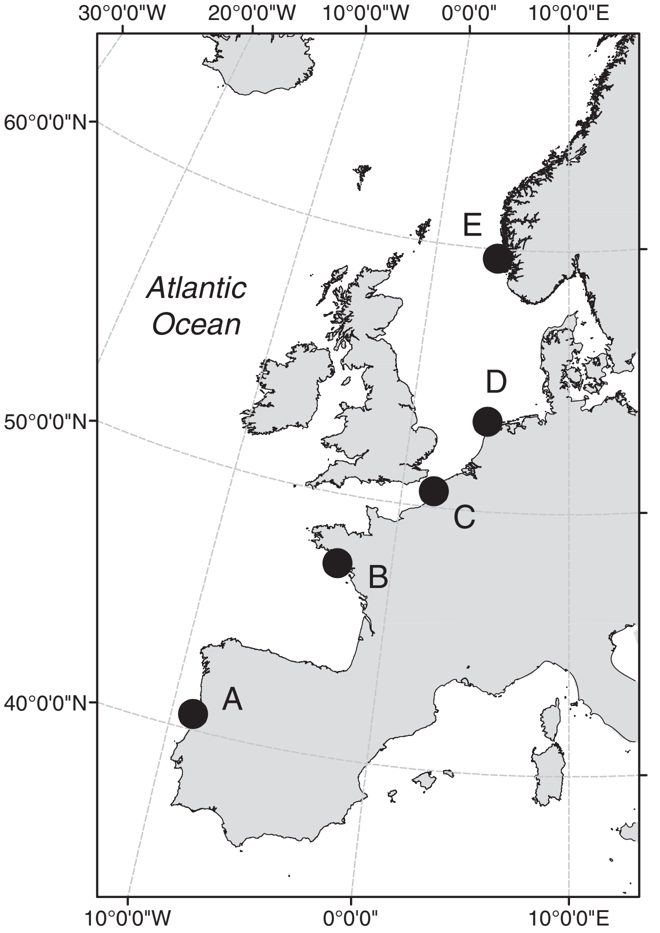

Fig. 1. Geographical location of the five sampled nursery areas of 0-group *Platichthys flesus* in the Eastern Atlantic: A — Mondego estuary, B — Vilaine estuary, C — Slack estuary, D — Dutch Wadden Sea, E — Sørfjord.

2.2. Data analysis

All fish were measured (total length, TL, mm) and weighed (wet weight, W, g), and the respective length–weight relationships were determined for each population. In a sub-sample of randomly chosen juvenile fish from each location covering the whole range of total lengths observed, left sagittae otoliths were removed, cleaned and mounted with sulcus up on microscope slides (Sørfjord, n =14; Wadden Sea, n = 14; Slack Estuary, n = 17; Vilaine Estuary, n = 17; Mondego estuary, n = 12). Left otoliths were chosen due to their more symmetrical shape, when compared to the right one (ICES, 2008). Otoliths were polished in the sagittal plane using 0.1 µm sandpaper until the daily rings in the nucleus were visible. All daily increment counts were made using a light microscope at 100× and 400× magnifications for the peripheral areas, and at 1000× magnification for

Table 1
Summary of the main features of each *Platichthys flesus* nursery area sampled in this study.

Nursery area	Country	Latitude	Longitude	Area (km^2)	Sampling Date
Sørfjord	Norway	60° 30′ N	5° 24′ E	74.2	17.07.2010
Wadden Sea (Balgzand)	Netherlands	53° 04′ N	5° 03′ E	52.0	17.07.2010
Slack Estuary	France	50° 48′ N	1° 36′ E	0.01	01.07.2010
Vilaine Estuary	France	47° 30′ N	2° 30′ W	11.3	02.07.2010
Mondego Estuary	Portugal	40° 08′ N	8° 52′ W	8.6	17.06.2010