

Latitudinal comparison of spawning season and growth of 0-group sole, *Solea solea* (L.)

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Received 14 October 2007; accepted 23 January 2008

Available online 2 February 2008

Abstract

0-Group sole, *Solea solea* (Linnaeus, 1758) were sampled in four nursery grounds: two on the Northern French coast and two on the Portuguese coast. Juvenile sole were collected at the Vilaine estuary (Northern Bay of Biscay) in 1992, in the Authie estuary (Eastern English Channel) in 1997, and in the Douro and Tagus estuary (Northern and central Portugal, respectively) in 2005. Left lapilli otoliths were used to estimate age and investigate variability in growth rates and hatch dates. In the French study areas nursery colonisation ended in early June in the Vilaine estuary and in late June in the Authie estuary. In the Portuguese estuaries nursery colonisation ended in May in the Douro estuary and in late June in the Tagus estuary. Growth rates were higher in the Portuguese estuaries, 0.767 mm d⁻¹ in the Tagus estuary and 0.903 mm d⁻¹ in the Douro estuary. In the French nurseries, growth rates were estimated to be 0.473 mm d⁻¹ in the Villaine estuary and 0.460 mm d⁻¹ in the Authie estuary. Data on growth rates from other studies shows that growth rates are higher at lower latitudes, probably due to higher water temperature. Spawning took place between early January and early April in the Villaine estuary's coastal area in 1992. In 1997, in the Authie estuary spawning started in late January and ended in early April. On the Douro estuary's adjacent coast spawning started in mid-January and ended in late March, in 2005, while on the Tagus estuary's adjacent coast spawning started in mid-February and ended in mid-April, in the same year. Literature analysis of the spawning period of sole along a latitudinal gradient ranging from 38°N to 55°N in the Northeast Atlantic indicated that there is a latitudinal trend, in that spawning starts sooner at lower latitudes. Results support that local conditions, particularly hydrodynamics, may overrule general latitudinal trends.

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Keywords: latitudinal variations; growth; spawning; *Solea solea*; nursery grounds; northeast Atlantic

1. Introduction

Determination of spawning period and 0-group juveniles' growth in fish is very important for the study of fish recruitment. Temporal changes in spawning can contribute to variations in year-class strength by influencing the spatial and temporal coexistence of larvae, prey availability, predator abundance, and favourable environmental conditions (Houde, 1987). Growth during the first months of life is also crucial for fish survival, since faster growth implies improved predator

avoidance and a wider choice in prey (Van der Veer and Bergman, 1987; Ellis and Gibson, 1995; Sogard, 1992, 1997).

However, the study of spawning in fish is generally difficult and time consuming, since it requires previous knowledge of the main spawning areas and several successive egg sampling surveys throughout the spawning period which generally extends over several months. The discovery of daily increments in the otoliths of marine fish (Pannella, 1971) provided a powerful tool to study the early life history of fish. Counts of such increments have been used to examine temporal and spatial variability in spawning and growth rates (Method, 1983; Yakovlich and Bailey, 1990). Hatch-dates of the young juveniles collected in coastal nursery grounds at the end of the settlement period can thus be back-calculated,

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overcoming the difficulties of traditional successive egg sampling.

The study of fish recruitment requires not only the determination of spawning periods and 0-group juveniles' growth but also the identification of the factors which govern their dynamics. Several studies suggest that the factors controlling recruitment of a species vary over its geographic range, e.g. along a latitudinal gradient (Houde, 1989; Miller et al., 1991; Pauly, 1994).

Gaston (1990) and Miller et al. (1991) developed the latter, called "species range hypotheses" (Leggett and Frank, 1997) which assumes that species differ in their susceptibility to different controls on recruitment due to different life history traits, and that species life history traits vary over their distribution range. Looking at the latitudinal and inshore–offshore variation in food, predation and abiotic factors, these assumptions lead to the following implications: (1) abiotic factors are most important at the edges of the species range; (2) predation plus abiotic factors control recruitment at the polar edge of the range; (3) food plus abiotic factors control recruitment at the equatorial edge. Miller et al. (1991) also predicted that recruitment would be more variable at the polar edge of the species range, least near the centre of the range, and be intermediate near the equatorial edge. However, they pointed out that inshore–offshore environmental gradients may swamp latitudinal effects. Some studies considering a wide spatial scale have found this pattern (e.g. Brunel and Boucher, 2006).

Since then, several studies observed variation patterns that do not correspond to the "species range hypotheses" expectation (Walsh, 1994; Leggett and Frank, 1997; Phillipart et al., 1998). Van der Veer et al. (2000) concluded that the likely trends in food, predation and abiotic factors, on which Miller et al. (1991) based their hypotheses, will probably act only in the juvenile stage, while year-class strength appears to be established already in the pelagic phase (Leggett and Frank, 1997; Van der Veer et al., 2000). The dominance of density independent factors operating at a local scale on the eggs and larvae stresses the importance of hydrodynamic circulation as a key factor in determining recruitment in flatfish (Leggett and Frank, 1997).

The common sole, *Solea solea* (L.), is a flatfish of high commercial importance in Northwest Europe. This species is found in coastal waters of the eastern North Atlantic, from western Scotland and the western Baltic Sea to Southern Western Europe, including the Mediterranean and extending southwards along the African coast as far as Senegal (Whitehead et al., 1986). Sole spawns over winter and spring generally in coastal waters except in the western English Channel (Horwood, 1993) and in the northern Bay of Biscay (Koutsikopoulos and Lacroix, 1992) where the main spawning activity occurs offshore at depths around 50–90 m.

Several studies have assessed the factors affecting recruitment in sole and, although some conclusions may seem contradictory (e.g. Henderson and Holmes, 1991; Rijnsdorp et al., 1992; Henderson and Seaby, 1994), it is generally agreed that recruitment of sole is determined before the end of the first year of life and that water temperature plays an important role (e.g. Rijnsdorp et al., 1992; Van der Veer et al., 2000;

Wegner et al., 2003; Henderson and Seaby, 2005). However, all of these studies were carried out in temperate waters; in fact Van der Veer et al. (1994) concluded that most studies on flatfish recruitment were conducted in temperate systems which may have biased the conclusions. They also referred that recruitment variability increases towards lower latitudes. Due to more prolonged spawning and settlement periods, variability in juvenile size increases and therefore size-selective mortality becomes an important factor. More studies in subtropical and tropical areas are needed for a better understanding of the factors controlling recruitment in flatfish, and sole in particular (Pauly, 1994; Van der Veer et al., 1994). One of the interests of the present study is the comparison of sub-tropical populations with temperate ones.

The main objectives of the present work were to assess geographical differences in (1) timing of spawning and (2) growth rates of *Solea solea* juveniles during their first months following settlement, in the Northeast Atlantic.

2. Materials and methods

2.1. Study areas

Along the French coast the Villaine (in the Northern Bay of Biscay) and Authie (in the eastern English Channel) estuaries (Fig. 1) were chosen for this study because they are located at different latitudes and characterised by two distinct sole populations. In these two areas, sole population dynamics is well documented (e.g. Lagardère, 1987; Koutsikopoulos et al., 1989; Marchand, 1991; Amara et al., 1993, 1994). Climate in these areas is temperate.

Nursery areas studied in Portugal are located on the Portuguese West coast (Fig. 1). The Douro and Tagus estuaries were chosen for this study because they are two of the most important nursery areas for this species at its subtropical range (Cabral et al., 2007) and also because they are located at different latitudes and at a considerable distance (ca. 300 km) (Fig. 1). This is an important distance since this is a biogeographic transition region, so that the north of Portugal has a temperate climate while the centre and South has a subtropical climate. Cabral et al. (2007) have shown that while cold-water fish species are found in the northern estuaries, they are absent from the south and central coasts. While the Douro is a deep and narrow estuary, the Tagus is one of the largest estuaries in Europe (320 km²) and much of its upper area is composed of extensive intertidal mudflats. Climate in this area is Mediterranean with mild winters and warm, dry summers (Aschmann, 1973).

Water temperatures in the adjacent coast of the study areas during a broad period that encompasses the spawning period (in the area between the 50 m and the 100 m bathymetric) were gathered at the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT) and consist in Sea Surface Temperature derived from NOAA-AVHRR data. The range of SST values in this database is scaled between 0.125 °C and 31.75 °C (maximum temperature). The radiometric resolution is 0.125 °C. Data from all six of the passes that

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