Available online at www.sciencedirect.com

SCIENCE DIRECT®

Estuarine, Coastal and Shelf Science 69 (2006) 246–254

ESTUARINE COASTAL AND SHELF SCIENCE

www.elsevier.com/locate/ecss

Diel and semi-lunar patterns in the use of an intertidal mudflat by juveniles of Senegal sole, *Solea senegalensis*

C. Vinagre*, S. França, H.N. Cabral

Universidade de Lisboa, Faculdade de Ciências, Instituto de Oceanografia, Campo Grande, 1749-016 Lisboa, Portugal

Received 20 February 2006; accepted 13 April 2006
Available online 9 June 2006

Abstract

Intertidal mudflats are a dominant feature in many estuarine systems and may comprise a significant component of the feeding grounds available to fish. The Senegal sole, *Solea senegalensis* Kaup, 1858, is one of the most important flatfishes in the Tagus estuary (Portugal) and its juveniles feed in the large intertidal flats. Many aspects of the ecology and lifecycle of this species are unknown, including its behavioural adaptations to environmental variations like day–night and semi-lunar cycles. Such activity patterns may strongly influence its use of mudflat habitats. Two encircling nets were deployed on an intertidal flat, one in the lower and the other in the upper mudflat. Nets were placed during high tide and organisms collected when the ebbing tide left the flats dry. Sampling took place in June–July 2004, covering all possible combinations of the diel and semi-lunar cycles with six replicates. Monthly beam trawls were carried out to determine density and average length of the predators of *S. senegalensis* in the intertidal and subtidal areas, and sediment samples were also taken, to determine prey density in the intertidal and subtidal areas. *Solea senegalensis* captured were mostly 0-group juveniles. The density and average length of *Crangon crangon*, one of the main predators, was higher in the subtidal than in the intertidal. Prey density decreased from the upper intertidal to the subtidal area. The highest average density of *S. senegalensis* occurred during full moon at dawn/dusk. A semi-lunar activity pattern was detected. At spring tides abundance peaked at dusk/dawn, whilst at neap tides abundance peaked during the day. Predators' densities over these periods were analysed and predator avoidance is discussed. During quarter and full-moon nights *S. senegalensis* extended its distribution over the lower and upper mudflat, but during the new moon colonisation was restricted to the lower mudflat. It was concluded that, while diel patterns of activity are well studied and are probably associated with feeding rhythms, the influence of the moon cycle, despite its importance, is a more complex phenomena that needs further investigation.

Keywords: intertidal environment; lunar cycles; day–night cycle; sole; feeding behaviour; activity rhythms; eastern Atlantic; portugal; tagus estuary

1. Introduction

Estuarine intertidal mudflats are very important in the functioning of estuarine systems and it is generally recognized that they have a disproportionately high productivity when compared to subtidal areas (Elliott and Dewailly, 1995). These sheltered shallow waters provide important feeding grounds for juvenile fishes (e.g. Haedrich, 1983; Able et al., 1990; Costa and Elliott, 1991). Intertidal mudflats are however only available to fish during tidal inundation which means that the use of this habitat implies tidal migrations.

It is assumed that fish exhibit movements during their life cycles at various spatial scales, ranging from daily habitat shifts to larger movements between systems (Morrison et al., 2002). Morrison et al. (2002) remarked that while long migrations have been reported during the life cycles of many fish, comparatively little work has been done on smaller scale movements over short temporal and spatial scales for estuarine fishes. Such small scale movements have been thoroughly studied in flatfish that use coastal and estuarine intertidal areas

* Corresponding author.
E-mail address: catv@fc.ul.pt (C. Vinagre).

0272-7714/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2006.04.017

such as plaice *Pleuronectes platessa* and flounder *Platichthys flesus* and the conclusions point at feeding and predator avoidance as the main driving forces behind tidal migrations (e.g. Gibson, 1973, 1980, 1982, 1999, 2003; Burrows, 1994; Ellis and Gibson, 1995; Wirjatmodjo and Pitcher, 1980; Summers, 1980; Van der Veer and Bergman, 1987; Raffaelli et al., 1990; Gibson et al., 1998). Studies on other fish species suggest that these movements may be strongly structured by tidal and day–night cycles (Naylor, 2001; Morrison et al., 2002; Krumme et al., 2004), although Quinn and Kojis (1981) found no differences in fish assemblages between nights of full and new moon. Rafaelli et al. (1990) observed marked differences in the number and length of *P. flesus* using the intertidal in successive day and night tides, yet the full effect of the semi-lunar cycle is still scarcely understood in flatfish. Estuarine organisms are adapted to predictable environmental cycles and show rhythmic activity synchronized with tidal cycles (Neumann, 1981; Palmer, 1995). While some of these patterns are controlled endogenously, others seem to be controlled by direct response to environmental variations associated with the tidal cycle (Naylor, 1982; Naylor and Williams, 1984; Saigusa and Kawagoye, 1997).

The Senegal sole, *Solea senegalensis*, Kaup 1858, is a benthic fish distributed from the Bay of Biscay to Senegal and western Mediterranean (Quéro et al., 1986). It is a species of increasing interest in aquaculture and is commonly cultured in the Portuguese and Spanish southern coasts (Dinis et al., 1999). This species is one of the most important flatfishes in the Tagus estuary (Cabral and Costa, 1999). Exactly where settlement of this species' larvae occurs is still unknown. It is possible that it takes place in the intertidal as it happens for the very similar species *Solea solea* (van der Veer et al., 2001). The main predators of other 0-group juvenile flatfishes are the crab *Carcinus maenas* and the shrimp *Crangon crangon* (Pihl and Van der Veer, 1992; Modin and Pihl, 1996). These are also thought to be the main predators of *S. senegalensis* because of similarity in size and form and based on our own aquarium observations (unpublished data). *Solea senegalensis* is an important predator of amphipods, polychaetes and bivalves (Cabral, 2000) and is therefore of great importance for the dynamics and composition of the biological communities in many of the estuarine and coastal systems where it occurs. Cabral (2000) reported that intertidal mudflats are very important feeding grounds for *S. senegalensis* juveniles, yet many features of this species' use of the intertidal are still unknown. Observation of this species distribution over the mudflats in all combinations of diel and semi-lunar cycles will advance our understanding of its ecology as well as of estuarine fish dynamics. The present study aims to evaluate the diel and semi-lunar patterns in the use of the intertidal mudflats by *S. senegalensis.*

2. Materials and methods

2.1. Study area

The Tagus estuary (Fig. 1), with an area of 325 km^2, is a partially mixed estuary with a tidal range of about 4 m. This estuarine system has a mean depth <10 m and about 40% of its area is composed of intertidal areas, which are predominantly mudflats. Although its bottom is composed of a heterogeneous assortment of substrates, its main sediment is muddy sand in the upper and middle estuary and sand in the lower estuary. The mean river flow is 400 m^3 s^{-1}, though it is highly variable both seasonally and annually. The mudflat where this study took place is located in the upper estuary in a sheltered south bank branch (Fig. 1). The tidal regime is semi-diurnal. The intertidal mudflat is inundated daily for two periods of approximately 3.5 h at its upper part, and 5 h at its lower part. The subtidal area (channel) is always submerged. Salinity in this area varies from 4, in winter, to nearly 30 in summer, while water temperature ranges from 8 °C to 26 °C (Cabral et al., 2001). Maximum depth in the mudflats during high tide is 2.5 m.

2.2. Sampling

In order to study the distribution of Senegal sole across the tidal flats during high tide, two encircling nets were placed in the mudflats, one in the lower mudflat (closer to the channel), the other in the upper mudflat (closer to the salt marsh) and distanced approximately 150 m (always at the same intertidal level). Preliminary work in this area had shown that captures were considerably higher using this technique comparing to bottom trawl.

The nets had a perimeter of 100 m and a mesh size of 5 mm. They were supported by wooden sticks and deployed (simultaneously) by boat at high tide peak. The operation took the shape of a closed circle trapping the nekton inside. Metal weights were attached to the bottom of the nets so that they would be naturally buried in the mud when deployed. Twenty wooden sticks supported each net. In order to avoid the scaring of the fish the boat was operated with sticks, motor was turned off and silence was kept. At low tide the mudflat drains completely leaving the organisms trapped in the nets. Organisms were hand collected, frozen at −20 °C and later identified and measured. Net perimeter was used to calculate the area of the sampled circle in order to estimate densities of the organisms captured.

All possible combinations of diel and semi-lunar cycles were covered in June–July 2004. Six replicates of each combination of these cycles were carried out (three in each month, whenever the combinations existed); samples were taken on three consecutive days in each lunar phase (Table 1). Since the tidal regime is semi-diurnal two surveys per day could be conducted.

Three beam trawl replicates (Fig. 1) of 10 min duration and covering a length of approximately 600 m (3 m of opening and 3 mm mesh size) were carried out by boat in the intertidal and in the channel (on the same day, just minutes apart), each month, in order to determine density and average length of *Solea senegalensis* predators (because encircling nets were impossible to use in the channel, trawls were necessary in order to obtain comparable densities). At the beginning and at the end of each trawl coordinates were