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Swimming activity responses to water current reversal support selective tidal-stream transport hypothesis in juvenile thinlip mullet *Liza ramada*

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ABSTRACT

Swimming activity of thinlip mullet *Liza ramada* in response to water current reversal was investigated experimentally. A total of 130 young of the year thinlip mullet ranging in size from 22 to 36 mm were entered in trials with four different conditions over three weeks. The fish were subjected to current reversal (6.2/6.2 h) and a Light–Dark cycle (12/12 h). Swimming direction (with or against the current) was video-recorded throughout the experiments. The mullet showed an effective synchronisation of their swimming activity to water current reversal and Light–Dark cycle. This synchronisation could demonstrate the existence of a diurnal selective tidal-stream transport in the natural environment as observed in the two other European catadromous species.

1. Introduction

The thinlip mullet *Liza ramada* (Risso) is a species widely spread in the Atlantic Ocean, Mediterranean Sea and Black Sea (Gautier and Hussenot, 2005). It is a catadromous species that uses both marine and freshwater environments, developing in fresh water and reproducing at sea (McDowall, 1988). On the East Atlantic coast, adults migrate towards the sea to spawn during autumn and early winter (Cassifour, 1975; Le Dantec, 1955). Juveniles arrive on the continental shelf from January to June (Gautier and Hussenot, 2005), then gradually colonise the watersheds from the estuary mouth to the upstream parts of the rivers. Thinlip mullet are often observed in the upper part of the rivers, sometimes very far from the sea (e.g. in 2008, a school of thinlip mullet were observed swimming through a dam on the Loire river, 660 km from the sea (http://www.logrami.fr/node/27)).

During the estuarine migration, the two other European catadromous species (European eel *Anguilla anguilla* and European flounder *Platichthys flesus*) use selective tidal-stream transport (STST) (Bos, 1999a,b; Creutzberg, 1958, 1959; Jager, 1999, 2001; Jager and Mulder, 1999; Jellyman, 1977; McCleave and Kleckner, 1982; McCleave and Wippelhauser, 1987; Wippelhauser and McCleave, 1987). STST consists of horizontal transport with the fish entering the water column during one phase of the tide and descending to the bottom during the other (Forward and Tankersley, 2001; Gibson, 1978, 2003). During STST, vertical movements in the water column are cued by an internal circatidal clock controlled by environmental cues from river waters (Boehlert and Mundy, 1988), such as geosmin (Tosi and Sola, 1993), temperature (Tosi et al., 1990), and salinity (Sorensen, 1986).

In the water column, directional orientation to water currents is common among fish (Arnold, 1974, 1981). Fish can either swim with the current (negative rheotaxis) or against the current (positive rheotaxis). The behavioural response is elicited by visual and tactile stimuli (Arnold, 1974).

Most studies relating to STST consist of a comparison of experimental sampling under different tidal conditions. In the present work, we choose an experimental method that would record fish swimming behaviour under controlled conditions in order to analyse the underlying mechanism governing the STST and the cues that are timing and directing swimming activity. The video analysis of swimming behaviour was used to precisely discriminate the fish that were voluntarily swimming with the current and the fish that were swept away by the current. Such discrimination was impossible using traditional fishing methods.

This experiments goal was to experimentally investigate the synchronisation between the swimming activity of young of the year (YOY) thinlip mullet and changes in water current direction every 6.2 h combined with variation in salinity, under a 12 h Light/12 h Dark (L/D) cycle.

Abbreviations: STST, Selective Tidal-Stream Transport; MESA, Maximum Entropy Spectral Analysis; L/D cycle, Light–Dark cycle; YOY, Young Of the Year.

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2. Materials and methods

2.1. Fish collection

YOY thinlip mullet were caught with plankton nets (110 cm diameter) in the lower part of the Gironde estuary (southwest France, 45.5256° lat, −1.0426° long) in January (trial 1) and February 2008 (trial 2). The fishing gear was chosen to select fish smaller than 4 or 5 cm in length. YOY thinlip mullet length ranged from 22 to 36 mm (mean = 28.3 +/− 5.4 mm) in January and from 19 to 37 mm (mean = 30.1 +/− 6.7 mm) in February. Salinity was about 15 and water temperature about 11 °C during fish collection. Fish determination was performed using morphological criteria during sampling (Farrugio (1975) and Cambrony (1983) identification keys) and was verified at the end of the experiments using anatomical criteria. The boat speed during catch and the fish handling were carried out in order to avoid hurting the fish. After collection, the mullet were brought to the facility in an isotherm holding tank with an air pump. Transport by car lasted less than 1 h. Then fish were placed in an acclimation tank located in the experimental flume with the water temperature and salinity that were recorded during the catch. Because of careful procedures, the mortality rate from fishing to the end of acclimation was below 10%.

2.2. Experimental design and protocol

The thinlip mullet were observed in an annular flume (8 m long, 0.3 m wide, 0.6 m deep, 2 m^3, Fig. 1). Environmental conditions (water temperature, salinity, photoperiod, luminosity, velocity current and current reversal) recorded during the fishing were recreated in this flume.

The substratum was made up of a 5 cm layer of gravel (1 cm mean diameter). A pump generated a water current of 10 cm/s, far below the maximum swimming performance of fish of that size (Blaxter, 1969).

Two antagonist floodgates were used to mimic a water current reversal every 6.2 h, which corresponds with the tidal reversal in the fishing area and in the sea. The two antagonist currents were called Clockwise Current (CC) and Anti-clockwise Current (AC). The water was kept at 11 + 0.2 °C and was sterilised by UV light. A decrease in salinity was produced by a controlled freshwater addition to the flume every CC in order to mimic the salinity decrease occurring in natural environment during the ebb-tides. The salinity decreased from 15 to about 0 over a three week period. The salinity decrease was initially settled to 2 PSU every CC but was slow down when salinity reached low level. The water surplus was removed so that the water level remained constant.

All trials were conducted under a 12 h Light/12 h Dark photoperiod (L/D). The light intensity was set at 1.5 μW/cm² during light phases (Philips fluorescent lights, cool day–light quality, 6500 K) and 0 μW/cm² during dark phases.

The water temperature, conductivity and pH were continuously recorded by 3 sensors in the flume. All the equipment was controlled and automated from a remote terminal unit (S500, Sofrel).

We ended the acclimation period when the fish started to feed again, 2 days after collection. Thereafter, 65 YOY mullet were released into the annular flume, where they remained for 21 days. The number of fish studied was determined by preliminary tests for an optimal analysis. The fish were fed with artificial food (® Tyca pellets, 1.1 mm mean diameter) randomly every two or three days in order to prevent the apparition of behavioural rhythms. An automatic feeder controlled by the remote terminal unit dispersed the food in order to prevent human disturbance during the food distribution. The feed weighed 5% of the total weight of fish in the flume and was determined by preliminary test in order to keep fish in good condition.

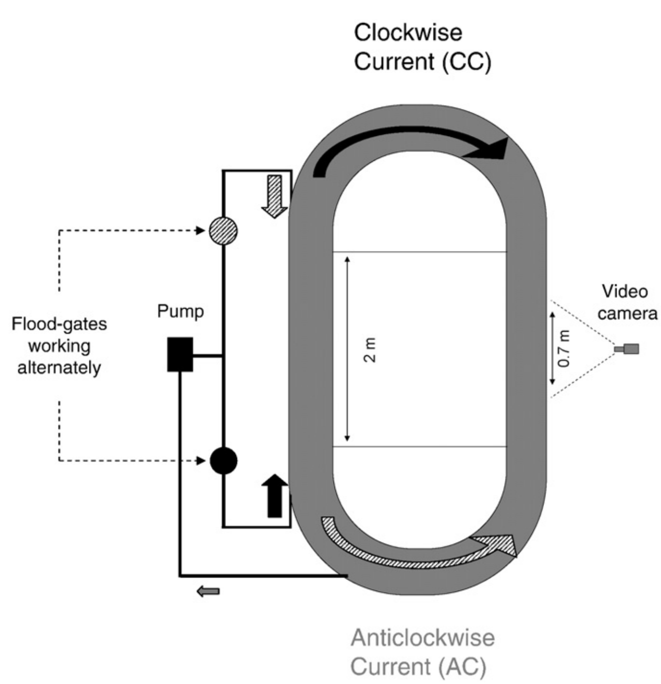

Fig. 1. Diagrammatic aerial view of the annular flume.