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Habitat distribution model for European flounder juveniles in the Venice lagoon

Matteo Zucchetta *, Anita Franco, Patrizia Torricelli, Piero Franzoi

Dep. Environmental Sciences, University of Venice, Castello 2737/B – 30122 Venezia, Italy

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ABSTRACT

In order to identify nursery habitats for *Platichthys flesus* in the Venice lagoon we developed a generalized additive model relating juvenile flounder's distribution to environmental variables. A field survey was conducted between March 2004 and June 2005 and between February and October 2008 in the central and Northern sub-basins of the lagoon. Each station was sampled by means of a beach seine net and characterized collecting the main chemico-physical variables, such as water temperature, salinity, turbidity, dissolved oxygen content and bottom grain size. Main winds fetches were also considered, and estimated in a GIS environment. A logistic model was fitted, and evaluated on an independent dataset. The response curves allowed to identify the role of the environmental parameters in explaining the distribution of the juvenile flounder: turbidity, salinity and sand content revealed to be the most important factors, showing the preference for mesohaline turbid waters together with a low sand content of the sediment. The application of this model to continuous surfaces of the environmental variables allowed the creation of potential habitat distribution maps. In this way it has been possible to recognize several areas covering a key role for the juveniles of flounder, located mainly in the inner part of the lagoon.

1. Introduction

Nearshore habitats have been largely recognized as important nursery areas for many species of fish and invertebrates (Beck et al., 2001, 2003). In particular, the nursery role of estuarine systems has been demonstrated for several flatfish species (Riou et al., 2001; Able et al., 2005; Cabral et al., 2007). Many flatfish species, in fact, share several common features in their life history patterns: spawning in the continental shelf, egg and larval migration toward coastal areas and concentration in estuarine or marine shallow areas (Able et al., 2005; Rijnsdorp and Witthames, 2005; Van der Veer and Leggett, 2005; Cabral et al., 2007). The use of these coastal areas by juveniles are explained by a number of advantages, such as food availability, refuge from predators and suitable conditions for a rapid growth (Beck et al., 2001, 2003; Able et al., 2005).

The European flounder, *Platichthys flesus* (Linnaeus 1758) is one of the marine flatfish species using estuarine systems as nurseries (Van der Veer et al., 1991), and it is one of the few flatfish species which can also use rivers as nursery areas (Andersen et al., 2005). *P. flesus* is a winter spawner which is commonly found in shallow waters of the Eastern Atlantic, from the North Sea to the Mediterranean and Black Sea, with Portuguese coasts (39th North parallel) representing its southern distribution limits (Cabral et al., 2007).

As for many other flatfishes, its commercial value contributed to raise scientific interest on this species (Gibson, 1997), leading to a good knowledge of its biology and ecology, mainly due to several studies carried out in the North Sea, in the Wadden Sea, in the English Channel and along the Portuguese coasts (e.g. Kerstan, 1991; Van der Veer et al., 1991; Grioche et al., 1997; Vinagre et al., 2005, 2008; Cabral et al., 2007; Martinho et al., 2007, 2008; Dolbeth et al., 2008).

Fewer studies on flounder have been conducted in the Mediterranean region. Here, Franzoi et al. (1985) and Rossi (1986) investigated the colonization dynamics of Northern Adriatic coastal lagoons (Po delta), showing that in the nursery areas used by juveniles, also adults can be found, as they carry out migrations between marine coastal areas and estuarine environments.

Flounder distribution in coastal and estuarine systems is strongly influenced by a number of abiotic and biotic factors (Able et al., 2005). For flatfishes many studies indicate depth, temperature, salinity and substratum type as the best environmental predictors of habitat use within a study area (Able et al., 2005), with a general preference for fine sandy and muddy bottoms, typical of more sheltered and less saline areas (Riley et al., 1981; Able et al., 2005). The distribution of *P. flesus* is commonly correlated with salinity (Riley et al., 1981; Kerstan, 1991; Jager, 1998, Andersen et al., 2005), temperature (Power et al., 2000), dissolved oxygen (Maes et al., 2007) and suspended solids (Power et al., 2000). In particular some of these parameters are reported to influence flounder juveniles distribution. In fact, there is an active choice for low salinity waters (Bos and Thiel, 2006), avoiding extreme conditions (0 and 35 PSU), which limit food intake and food conversion (Gutt, 1985).

Habitat distribution models are among the available tools that allow to relate species distribution to environmental conditions. Such

* Corresponding author. Tel.: +39 0412347732; fax: +39 0415281494.
E-mail address: matzuc@unive.it (M. Zucchetta).

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models use quantitative methods to infer species environmental requirements from conditions at known occurrences (Guisan and Zimmermann, 2000). Their popularity is largely justified by their numerous applications: in the field of conservation biology (e.g. Ferrier et al., 2002; Burgman et al., 2005), to forecast the potential range of invasive species (Dark, 2004; Richardson and Thuiller, 2007) for wildlife management (Scott et al., 2002), and to explore future climate scenarios (Thomas et al., 2004; Araújo et al., 2006). Habitat distribution models are encountering an increasing favour even for modelling aquatic species distribution (Valavanis, 2008).

A number of applications is available even for flatfish species (for a recent example see: Maxwell et al., 2009) and some applications exist for flounder distribution in riverine systems (Maes et al., 2007; Lassalle et al., 2008), and in coastal waters, for larval stages (Koubbi et al., 2006), juveniles (Florin et al., 2009), and for adult populations (Vaz et al., 2008). Some authors developed as well habitat models aimed at identifying nursery habitats of some flatfish species, both in coastal waters and in estuaries/lagoons (Stoner et al., 2001, 2007; Manderson et al., 2002; Eastwood et al., 2003; Le Pape et al., 2003, 2006; Nicolas et al., 2007).

A common strategy employed in this kind of models is to predict the likelihood of occurrence of the investigated species on the basis of habitat attributes, calibrating a statistical model which relates presence and absence of the species to the environmental factors (for a review of methods see Guisan and Zimmermann, 2000; Moisen et al., 2006; Elith and Graham, 2009). Such a model was calibrated in the present study to quantify the relationship between flounder juveniles presence–absence and the main environmental drivers, with the aim of identifying potential nursery habitats for flounder in the Venice lagoon, the larger coastal lagoon in the Mediterranean basin. The application of the calibrated model to continuous maps for the whole basin allowed to obtain a spatial explicit prediction of the distribution of the species' juvenile stages.

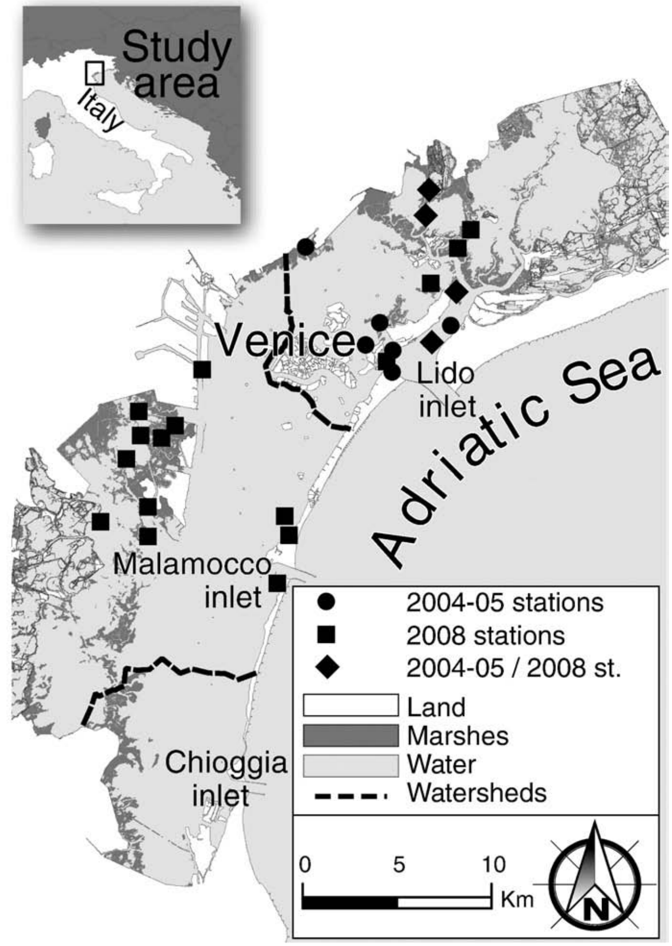

Fig. 1. Study area and sampling stations.

2. Materials and methods

2.1. Study area

The Venice Lagoon is situated in the Northern Adriatic Sea, has an area of about 550 km^2 and it is the largest lagoon in the Mediterranean basin (Fig. 1). It is a shallow coastal lagoon ecosystem (average depth 1.2 m; Molinaroli et al., 2007), where large shallow areas, covering about 75% of the total surface (Molinaroli et al., 2009), are connected by a network of channels, whose depth is mostly less than 2 m (Solidoro et al., 2002). Deeper channels are connected to three wide mouths (Lido, Malamocco and Chioggia), which maintain the lagoon–sea communication, allowing tidal flows entering the lagoon, with a range of $\pm$50 cm during Spring tides (Umgiesser et al., 2004). About one third of the water (390×10^6 m^3) on average is exchanged during each tidal cycle (Gacic et al., 2004), although the connection with the sea is strongly influenced also by meteorological conditions (Cucco and Umgiesser, 2006). The basin can be divided by two watersheds in three main sub-basins (Fig. 1) (Solidoro et al., 2004a). The bottom sediments of the basin consist mainly in clayey silt, with a mean mud content of about 80% in dry weight, with a north–south decreasing pattern (Molinaroli et al., 2007). The salinity is influenced by freshwater inputs, with a yearly mean inflow of 35.5 $m^3\,s^{-1}$ (Zuliani et al., 2005), and more of the 50% of it being located in the northern sub-basin (Zonta et al., 2005; Zuliani et al., 2005).

2.2. Sampling and data collection

Fish sampling was carried out during daytime, fortnightly in the periods March–December 2004 in 10 stations of the Northern sub-basin located along the major environmental gradient (20 samples collected in each station). Sampling activity was replicated the following year between March and June 2005 (7 samples collected in each station). In 2008 samples were collected fortnightly in the main period of flounder juvenile immigration (February–April) and monthly from May to October in 8 stations of the northern sub-basin and in 12 stations of the central basin (11 samples collected in each station). A large beach–seine net (23.0 m long, 1.0 to 3.0 m high, with a mesh size of 2.0 to 4.5 mm) was trawled on shallow waters (max. depth 1.1 m) in the sampling sites.

Body size of sampled specimens was measured by means of the individual total length ($\pm$ 0.1 mm). In case of abundant samples, random subsamples of at least 50 individuals were measured. Sampled specimens with a total length smaller than 160.0 mm were classified as juveniles (Franco et al., submitted for publication). For this study only presence or absence of flounder juveniles were considered.

In each station, water temperature ($\pm$0.1 °C), salinity ($\pm$0.5 PSU), turbidity ($\pm$0.01 FTU), and concentration of dissolved oxygen ($\pm$0.1 mg l^{-1}) were recorded for the mid-water column during each sampling.

One sediment core was collected *una tantum* in each station, stored at −20 °C, and the percentage of sand was measured in the upper 15 cm-thick layer, by mechanical sieving following the methods described in Guertin et al. (1984).

In order to estimate wind induced disturbance, fetch distances were computed for each station, as suggested in the Shore Protection Manual (Rohweder et al., 2008). Directions of the dominant winds were considered: the *Bora* wind (0° and 45° directions) and the *Scirocco* wind (135°) (Marotta and Guerzoni, 2006). A maximum fetch index was computed as an integrative measure: at each station fetch distances were computed for each compass heading, with 15°