

Habitat Suitability Index Models for the sympatric soles *Solea solea* and *Solea senegalensis* using GIS procedures

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Figure 1 – Tagus estuary

Abstract

Habitat Suitability Index (HSI) models were used to map habitat quality for the sympatric soles *Solea solea* and *Solea senegalensis* in the Tagus estuary, Portugal. Models of habitat suitability were developed for both soles based on published information and expert review. Using geographic information systems (GIS), habitat maps were developed for the months of peak abundance of *S. solea* and *S. senegalensis* (May and November respectively) consisting of 300m x 300m grid cells for depth, temperature, salinity and predominant substrate type. The HSI models were run in the GIS by reclassifying the habitat maps to a 0-1 suitability index scale. Presence of intertidal mudflats was also considered in the models. Following reclassification, the geometric mean of the suitability index values for each variable was calculated by grid cell, and the results were mapped. Model calculations were later conducted with prey density as a variable. Density of amphipods, polychaetes and bivalves were added to the model as a sixth variable each at a time, in order to determine if prey type could considerably improve the model. Models performance was evaluated by comparing model outputs for both species and data on its densities in the field surveys at the same time. Further model testing was performed using independent data. The model which better predicted *S. solea* density was the one that included amphipods density has a variable, while for *S. senegalensis* polychaetes density was the most important factor. Results show that there are two areas both in the upper estuary that provide the most suitable habitats for *S. solea* and *S. senegalensis* juveniles and that prey availability is a very important factor affecting its distribution within high quality habitats.

Introduction

There is a growing need to adopt ecosystem concepts into management plans and it is generally agreed that habitat quality assessment should play a decisive role in the environmental decision making process. Habitat suitability index modelling is a valuable tool for providing maps and information upon which environmental managers can make informed decisions (Terrel, 1984; Bovee & Zuboy, 1988). The HSI modelling method used in this study was based on the U.S. Fish and Wildlife Service (USFWS) Habitat Evaluation Procedures Program (USFWS 1980a, 1980b, 1981; Terrel, 1984; Bovee & Zuboy, 1988). The mathematical expression used for calculating a unitless index of habitat quality was derived from Brown et al (2000). The suitability indices reflect the habitat quality for sole juveniles of the species *Solea solea* and *Solea senegalensis* over a range of possible environmental conditions. Using GIS technology these values were mapped and analysed.

In order to adapt Brown et al (2000) models to these flatfish species a variable called intertidal was added. Sampling stations were given an index of 1 or 0, depending on its location over intertidal mudflats or in subtidal environments, respectively. Intertidal mudflats are important feeding grounds for these benthic species (Cabral, 2000).

Raw data suggested that the majority of the Tagus estuary has an overall high habitat quality for soles, yet both species' juveniles concentrate in rather small areas. It is generally recognized that prey availability is highly determinant in the distribution of flatfish (e.g. Gibson, 1994, 1997). It is also well known that macrobenthic species can use less than half of the suitable habitat due to limitations in settlement and/or juvenile survival (Armonies & Reise, 2003). This way habitat classification has highly suitable according to abiotic variables can actually be empty habitat in terms of prey (e.g. Buttman, 1986; Eckman, 1990; Armonies & Reise, 2003). Prey density was added to the model. Amphipoda, Polycheta and Bivalvia densities were chosen as variables since they are the most important groups in both species diet (Lagardère, 1987; Costa, 1988; Molinero & Flos, 1991; Beyst et al., 1999; Cabral, 2000). The four way distinct models were created for each species. One which included only abiotic variables and three which included not only abiotic variables but also prey density of the three prey groups considered separately.

Comparison of the models should tell us which variables should be taken into account in future management plans. The aim of this study is to produce a simple, yet effective, model to predict *S. solea* and *S. senegalensis* juveniles' distribution in the Tagus estuary, in order to contribute to future management of these species stocks.

Results and Discussion

Model outputs show that the upper estuary has the highest habitat quality for juveniles of both species. While the five variables model (Fig. 3, a; Fig. 5, a) indicates a broad area of high habitat quality for both soles, the inclusion of prey density as a sixth variable proved to be very important in restricting that area to smaller areas within the upper estuary. The model that included density of amphipods yielded very good results in predicting *S. solea* densities in its peak abundance month (Fig. 3b, Fig. 6), while the model that included polychaetes had the best results for *S. senegalensis* (Fig. 5c, Fig. 7). The Spearman test revealed a correlation between the spatial distribution of *S. solea* in the May 2001 survey and the distribution predicted by the model in which density of Amphipoda (HSLa) was used as a sixth variable ($r = 0.312$, $p < 0.01$). Concerning *S. senegalensis*, the Spearman test revealed a correlation between the spatial distribution in November 2001 and the model which used polychaetes as the sixth variable (HSLp) ($r = 0.183$, $p < 0.01$).

Gibson (1994, 1997) considered prey availability and predation risk to be highly important factors in determining the distribution of juvenile flatfishes. Sole juveniles of the 0-1 group feed primarily on amphipods, polychaetes and bivalves (e.g. Lagardère, 1987; Costa, 1988; Molinero & Flos, 1991; Beyst et al., 1999; Cabral, 2000), all of which are found in close association to muddy and sandy substrates. Sole are also known to bury into fine grained sediments, probably to avoid predation (Dorel et al. 1991; Rogers, 1992). The models produced here clearly confirm these assertions. It was also confirmed that there are areas classified by the abiotic model as highly suitable that are in fact empty habitat concerning prey availability and should therefore have its suitability index lowered. Only marginal differences in the spatial distributions of both soles could be attributed to variations in temperature and salinity. This is probably a facet of the sampling regime, in that had samples been collected over a broader temperature and salinity range then a stronger relationship may have emerged.

Other authors have concluded that models may be constrained to defining nursery habitat at a particular season and geographic location due to the lack of model testing in other situations (e.g. Eastwood et al., 2003). Further testing of the present models would allow an assessment of the models applicability to a broader set of time periods and geographic locations.

Materials and Methods

Study area

The Tagus estuary has an area of 325 km² and is a partially mixed estuary with a tidal range of 4.6m. About 40% of the estuarine area is intertidal mudflats (e.g. Cabrita & Moita, 1995).

Data Analysis

For each species data from its peak abundance month of the 2001 surveys was selected and information on environmental variables in 42 sampling stations throughout the Tagus estuary and adjoining coastal area was gathered (Fig. 1). Data was interpolated using the inverse distance to a power method and digital environmental maps were developed in a grid format using the software Surfer 7.0®.

For each model, SI values from 0 to 1 were assigned to ranges of each environmental variable. Each environmental variable was reclassified by grid-cell to the suitability index scale.

Concerning the variables related to prey availability, namely density of amphipods, density of bivalves and density of polychaeta, its 90th and 70th percentile were calculated. Densities under the 70th percentile were given an index of 0.1, densities between this value and the 90th percentile value were given an index of 0.5 and densities above the 90th percentile value were given an index of 1. Since the spatial distribution of these organisms is aggregated this procedure ensured that only areas with high densities played an important role in the model, since high prey density will be an attracting factor for both sole species.

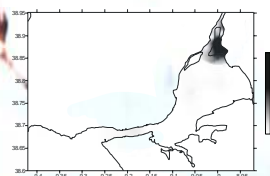


Figure 2 – *S. solea* density (ind./1000m²) in May 2001

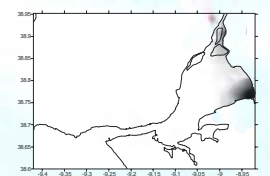


Figure 4 – *S. senegalensis* density (ind./1000m²) in November 2001

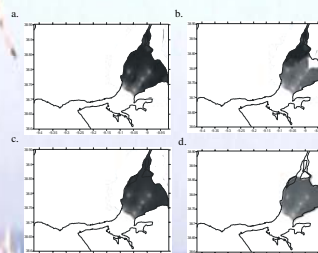


Figure 3 – Mapped habitat suitability for *S. solea* according to the different models tested:
a. HSI = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal))^{1/5} ;
b. HSLa = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(amphipods))^{1/6} ;
c. HSLp = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(polychaetes))^{1/6} ;
d. HSLb = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(bivalves))^{1/6}

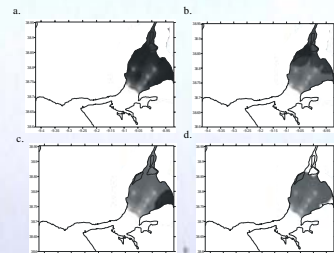


Figure 5 – Mapped habitat suitability for *S. senegalensis* according to the different models tested:
a. HSI = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal))^{1/5} ;
b. HSLa = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(amphipods))^{1/6} ;
c. HSLp = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(polychaetes))^{1/6} ;
d. HSLb = (S(salinity) . S(temperature) . S(substrate) . S(depth) . S(intertidal) . S(bivalves))^{1/6}

Final Remarks

The HSI modelling method used in the present study was generally successful for mapping habitat quality for the selected species.

Individual species habitat suitability maps can be used to identify areas of exceptionally high habitat quality. Rather than wishing to obtain accurate maps of the maximum extent of suitable habitats, managers are more likely concerned with identifying the most important areas in the species life cycle. (Langton & Auster, 1999).

Inclusion of prey abundance data proved to be very important in the definition of high suitability habitat for both sole species and in the prediction of high density areas.

The most important nurseries for both sole species are located within the Nature Reserve of the Tagus estuary limits. Despite this classification human impact has been increasing in this area, therefore habitat degradation could be a problem in the near future.

Because of the dynamic nature of habitat features nursery grounds can expand, contract and shift in location over time (Stoner et al., 2001). The identification and protection of these critical habitats is essential for the long term conservation of commercial fish stocks.

Acknowledgements

This study was funded by the "Fundação para a Ciência e a Tecnologia".

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