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A quantitative estimate of the function of soft-bottom sheltered coastal areas as essential flatfish nursery habitat

E. Trimoreau[a], B. Archambault[a], A. Brind'Amour[b], M. Lepage[c], J. Guitton[a], O. Le Pape[a,*]

[a] AGROCAMPUS OUEST, UMR985 ESE Ecologie et santé des écosystèmes, F-35042 Rennes, France
[b] Ifremer, Centre de Nantes, Rue de l'Île d'Yeu, B.P. 21105, 44311 Nantes, France
[c] Irstea, Unité Ecosystèmes Estuariens et Poissons Migrateurs Amphihalins, 50, Avenue de Verdun Gazinet, 33612 Cestas cedex, France

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A B S T R A C T

Essential fish habitat suitability (EFHS) models and geographic information system (GIS) were combined to describe nursery habitats for three flatfish species (*Solea solea, Pleuronectes platessa, Dicologlossa cuneata)* in the Bay of Biscay (Western Europe), using physical parameters known or suspected to influence juvenile flatfish spatial distribution and density (*i.e.* bathymetry, sediment, estuarine influence and wave exposure). The effects of habitat features on juvenile distribution were first calculated from EFHS models, used to identify the habitats in which juvenile are concentrated. The EFHS model for *S. solea* confirmed previous findings regarding its preference for shallow soft bottom areas and provided new insights relating to the significant effect of wave exposure on nursery habitat suitability. The two other models extended these conclusions with some discrepancies among species related to their respective niches. Using a GIS, quantitative density maps were produced from EFHS models predictions. The respective areas of the different habitats were determined and their relative contributions (density × area) to the total amount of juveniles were calculated at the scale of stock management, in the Bay of Biscay. Shallow and muddy areas contributed to 70% of total juvenile relative abundance whereas only representing 16% of the coastal area, suggesting that they should be considered as essential habitats for these three flatfish species. For *S. solea* and *P. platessa*, wave exposure explained the propensity for sheltered areas, where concentration of juveniles was higher. Distribution maps of *P. platessa* and *D. cuneata* juveniles also revealed opposite spatial and temporal trends which were explained by the respective biogeographical distributions of these two species, close to their southern and northern limit respectively, and by their responses to hydroclimatic trends.

1. Introduction

Coastal and estuarine nursery habitats are essential for many marine fish species (Peterson et al., 2000; Beck et al., 2001; Fulford et al., 2011), particularly for flatfish (Miller et al., 1984; Able, 2005). The suitability of these habitats influences juvenile growth and survival rates (Rijnsdorp et al., 1992; Gibson, 1994) and can act as habitat bottlenecks (Iles and Beverton, 2000). As a consequence, the vulnerability of coastal habitats to anthropogenic stressors (França et al., 2012; Halpern et al., 2007, 2008) can alter recruitment and future population renewal. Relationships between species and their habitats are a central issue to characterize the mechanisms determining habitat suitability. However, there is a lack of quantitative evidence of the importance of habitat suitability in patterns driving population dynamics. Despite the high number of studies which have focused on coastal habitat use by fish species, the value of habitats for fish population dynamics seldom remains quantified (Levin and Stunz, 2005; Fodrie et al., 2009). One required approach to bridge this gap from knowledge to quantitative estimates of EFHS consists of predicting geographic distributions of populations at different life stages, and especially for juveniles on nursery grounds, through habitat mapping (Rubec et al., 1999; Lauria et al., 2011). EFHS maps could constitute essential elements for prioritizing areas for conducting spatial ecosystem assessments (Brown et al., 2000; Cogan et al., 2009). They may solve questions about what constitutes high-value fish habitat for exploited species (Fodrie and Mendoza, 2006) and provide information needed for conservation purpose (Stoner, 2003). The identification and mapping of essential fish habitats, especially nursery grounds, may also help to prioritize management measures. Such maps would especially be appropriate for Marine Protected Areas design, to ensure that they are efficient in maintaining the potential of marine living resources renewal.

* Corresponding author.
E-mail address: Olivier.Le.Pape@agrocampus-ouest.fr (O. Le Pape).

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The Bay of Biscay, an arm of the North Atlantic indenting the west coast of France (ICES Division Area VIIIa/b; Fig. 1), is considered to be a stock management unit for many exploited marine fish species (Anonymous, 2011). The inshore waters of the Bay of Biscay support nursery areas for several commercially important species, notably flatfishes (Hermant et al., 2010). Estuaries and coastal areas have been studied for several decades in the Bay of Biscay and many scientific data on fish abundance are available (Brind'Amour and Lobry, 2009). For *Solea solea,* Le Pape et al. (2003b) provided maps of a density index over the Bay of Biscay and identified essential habitats. To follow up this first approach, the present study had two objectives:

- The previous quantitative description of habitat suitability for the *S. solea* population of the Bay of Biscay was conducted to develop an early quantitative assessment of its nursery habitats using bathymetry, sediment structure and estuarine influence. The EFHS model has been used to identify the habitats in which juvenile *S. solea* were concentrated. Similar approaches on juvenile *S. solea* were previously developed in the Eastern Channel (Riou et al., 2001; Eastwood et al., 2003; Rochette et al., 2010) and along the Portuguese coasts (Vasconcelos et al., 2010) with the same conclusions about the interest of shallow soft bottom areas inside or near estuarine influence. However, all these EFHS models were based on the distribution of young of the year (0-group) *S. solea* and led to a high non-explained variability (*e.g.,* in the Bay of Biscay: >70% for a model including both descriptors of habitat features and mesoscale variability among geographical sectors but close to 90% when only habitat descriptors were used; Le Pape et al., 2003b). The first objective of the present study was to improve the EFHS model for juvenile *S. solea.* Several studies have shown that coastal exposure affects habitat structure and juveniles of most flatfish species prefer sheltered parts of the coast and embayments (Howell et al., 1999). However, few studies have quantified the impact of coastal exposure (Pihl and Van der Veer, 1992) and integrated its effect in EFHS mapping (Maxwell et al., 2009; for adult fish including *S. solea*). Indicators for wave exposure of the coastal areas were thus used to improve the description of nursery habitat suitability (Fodrie and Mendoza, 2006) in the Bay of Biscay.
- *S. solea* was the single studied species in previous juvenile fish habitat mapping approaches in the Bay of Biscay. Thus there is a need to assess the impact of the habitat descriptors and potentially extend the mapping procedure to other estuarine and coastal dependent flatfish species. The two other most common estuarine and coastal dependent flatfish species during the last three decades (*P. platessa*, *D. cuneata;* Désaunay et al., 2006; Hermant et al., 2010) were selected in addition to *S. solea*, both being of interest for fisheries. *P. platessa* has a life history similar to *S. solea*, characterized by winter offshore spawning areas, post-larvae settling on inshore nursery grounds during spring and juveniles growing within nursery areas until they mature to adult age and move to the continental shelf (Koutsikopoulos et al., 1991; Hermant et al., 2010). The coastal nursery dependence of *D. cuneata* is similar but this species is a summer spawner (Hermant et al., 2010). The juvenile distribution patterns of juvenile *P. platessa* has been investigated from habitat suitability models and/or quantitative mapping procedure in numerous other areas in Western Europe, the Baltic (Pihl et al., 2000; Wennhage et al., 2007), the North Sea (Van der Veer et al., 2011) and the Eastern Channel (Riou et al., 2001). These studies described the *P. platessa* preference for shallow soft bottom areas and indicated the interest to include coastal exposure as descriptor of habitat suitability. In contrast, knowledge of *D. cuneata* is scarce, without any existing quantitative estimate of habitat suitability.

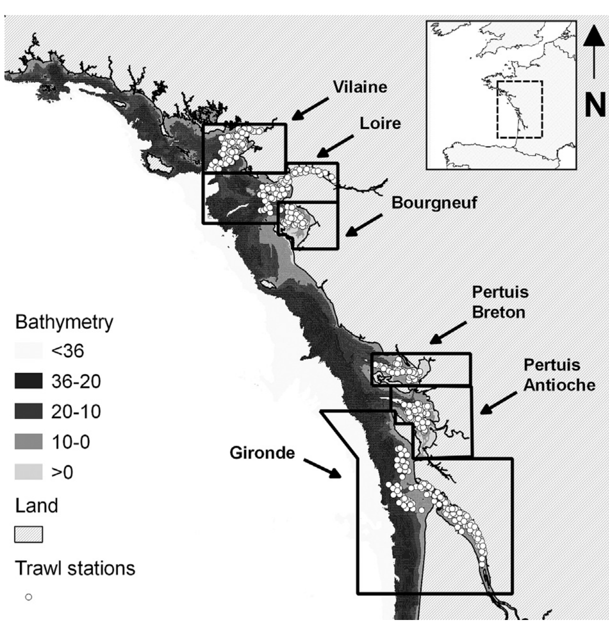

Fig. 1. Map of the study area showing the six investigated sectors and the trawl hauls locations (dots). In the upper right corner: general location of the study site in Western Europe.

The analysis is based on the 0-group of these three species on which data have been gathered from surveys conducted over a 30-year period throughout the estuarine and coastal areas of the Bay of Biscay. Achievement of the two objectives relies on quantitative mapping based on the relation between 0-group flatfish densities and habitat descriptors to identify nursery habitats of major importance. EFHS models were developed from generalized linear models to describe habitat related patterns in flatfish juvenile distribution. These models outputs and Geographic Information System (GIS) were then combined to provide quantitative habitat maps and relative contributions of the different habitats to the total proportion of juvenile flatfish at the scale of the Bay of Biscay population, while accounting for interannual variability.

2. Material and methods

2.1. Fish survey data

2.1.1. The study area

The Bay of Biscay study area (Fig. 1) includes six major nurseries (Le Pape et al., 2003b) which have been considered as independent sectors due to the coastal morphology: Vilaine, Loire and Gironde, three estuaries, and Bourgneuf, Pertuis Breton and Pertuis d'Antioche, three bays. Other coastal sectors of the Bay of Biscay were considered as unsuitable nursery areas from previous approaches (Le Pape et al., 2003b) and were not included in the analysis. As the 6 considered sectors constitute almost the entire area of distribution at the scale of the Bay of Biscay for the juveniles of the three considered species, extrapolation at the scale of the management unit (Bay of Biscay) can be performed. As this study focuses on marine species, the study area was restricted to the upstream limit of the oligohaline zone (*i.e.* higher than 5PSS, the limit of marine species extent; Courrat et al., 2009; Nicolas et al., 2010; Rochette et al., 2010) within rivers. The off-shore limit was set at the 35 m isobath, as juveniles of flatfish species are scarcely present in deeper waters (Riou et al., 2001).