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Effect of nursery habitat degradation on flatfish population: Application to *Solea solea* in the Eastern Channel (Western Europe)

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ABSTRACT

Estuaries and coastal waters are essential nursery habitats for many marine species, and especially for flatfishes. Thus, investigating how anthropogenic disturbances affect the quality of these habitats is of major importance to understand their consequences on the population renewal of marine species.
The aim of the present study was to analyse the effects of estuarine habitat degradation on the population of the common sole in the Eastern Channel, a key species in the fish community and fisheries in this area. We especially focused on the drastic drop in the surface area and on the low water quality of the Seine estuary, the main river of the Eastern Channel.
A geographic Information System (GIS) was used to develop quantitative maps of sole nursery habitats in the Eastern Channel by using a habitat suitability model based on bathymetry and sediment structure. This approach indicated that juvenile densities are low in the Seine estuary with regards to other nursery sectors. Then, thanks to historical maps of the Seine estuary, habitat suitability maps were built for key dates in the modifications of this estuary since 1850. This backward predictive approach suggests that habitat loss in the Seine estuary has led to a 42% decrease of its nursery capacity. As the density of juvenile sole in the Seine estuary is low in comparison to other sectors, this represents only a 3% loss at the sole population scale, in the Eastern Channel. However, when we assumed that prior to anthropogenic disturbance the juvenile density in the Seine estuary might have been equivalent to the current density of adjacent sectors with higher quality, the loss in abundance could be nearly 23% (8–36%). Results suggest that the loss in habitat surface combined with habitat degradation has led to an important loss in the contribution of the Seine estuary nursery to the whole sole population in the Eastern Channel.

1. Introduction

Estuaries and coastal areas are essential fish habitat because they act as nursery grounds for various marine fish species (Able, 2005; Beck et al., 2001; Miller et al., 1984). Juvenile growth and survival are determined by both the capacity and quality of these nursery habitats (Gibson, 1994; Iles and Beverton, 2000; Rijnsdorp et al., 1992). The increase of human activities along rivers, estuaries and in coastal areas affects ecosystems, in particular by pollution and habitat destruction (Coleman et al., 2008; Diaz and Rosenberg, 2008; Halpern et al., 2008). Habitat degradation is one of the most serious threats for the recovery of fish stocks (Hall, 1998). Quantitative and qualitative factors related to anthropogenic disturbance (Meng et al., 2000; Phelan et al., 2000) influence the quality of coastal and estuarine nurseries and thus recruitment and renewal of populations (Burke et al., 1993; Cowan et al., 2000; Ferber, 2001; Johnson et al., 1998; Peterson et al., 2000; Scharf, 2000; Thrush et al., 2008).

The inshore waters of the Eastern Channel (ICES Division VIId; Fig. 1) support nursery areas for several commercially important species, especially the common sole (*Solea solea*, L.) (Riou et al., 2001). The Bay of Seine is the largest estuary in the Eastern Channel and is thereby a potentially important nursery ground. However, this sector is highly disturbed through channel dredging, constructions of dikes and harbour extensions, which have substancially reduced the estuary area and subsequently suitable juvenile fish habitats, such as shallow muddy areas (>75% decrease; Lesueur, 1999). In addition, concentrations of organic chemical contaminants are high in this estuary, it being among the most contaminated in Europe (Gilliers et al., 2006), with episodes of oxygen depletion (Billen and Poulin, 1999). Thus, human disturbances have affected, perhaps reduced the nursery

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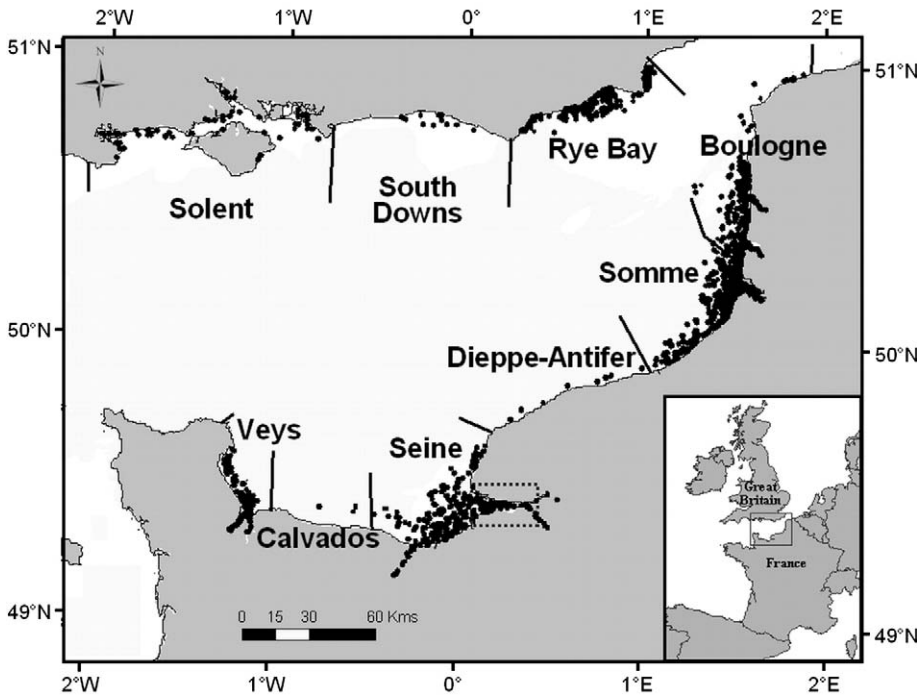

Fig. 1. Division of the Eastern Channel in 9 coastal and estuarine sectors. The dotted rectangle represents the internal Seine estuary. Points represent the position of the trawling stations, generally repeated annually during the survey periods (Table 1).

function of this estuary (Le Pape et al., 2007): its contribution to the renewal of flatfish stocks in the Eastern Channel is currently low (Riou et al., 2001) and fish growth performance and population density are significantly lower than in other nursery areas (Gilliers et al., 2006).

The present study aims to quantify the effects of human disturbance on sole nursery grounds in the Seine estuary and establish their consequences on the sole population of the Eastern Channel. A habitat suitability model, constructed for the recent period, was used in combination with historical habitat maps to provide backward projections of the potential juvenile sole densities. A two-step approach was used: 1) A quantitative map of sole nursery habitats in the Eastern Channel during recent times was first developed in a Geographic Information System (GIS). A database was built by collating trawl surveys undertaken throughout the coastal and estuarine parts of the Eastern Channel during the three last decades. A generalized linear model (GLM) was developed to identify key factors explaining variations of juvenile sole densities in various habitats, featured by different subregions, bathymetry and sediment structure. Using this GLM and a GIS, key sites for the early life-history stages of sole were identified. 2) Historical maps of the Seine estuary were used to construct habitat suitability maps for key dates in the modifications of this estuary since 1850. Combining the historical suitability maps and the GLM model of sole densities, the historical productions of the Seine estuarine nursery were calculated and related to its contribution to the sole population.

2. Material and methods

2.1. Survey data and numeric maps of physical habitat

2.1.1. Beam trawl survey data

From 1974 to 2007, different beam trawl surveys focused on juvenile flatfish species have been undertaken throughout the Eastern Channel coastal zone (Fig. 1, Table 1). Riou et al. (2001) collated these survey data until 1998. Data used in the present study were for a large part identical to this database, with an upgrade with the surveys undertaken between 1999 and 2007 (UK surveys on the English coast, French surveys in the downstream of the Seine estuary and in the Bay of Somme). In 2006, French estuaries and bays of the Eastern Channel (Bay of Veys, Orne, Seine, Somme, Canche and Authie) were investigated (Courrat et al., 2009) in the context of the European Water Framework Directive. These new surveys provided additional data in the inner part of these estuaries, until the upstream limit of freshwater.

To standardize our approach, we selected the surveys that were carried out between the end of August and the beginning of October. This period covers the time between the settlement of soles on nursery grounds and their autumnal migration (Dorel et al., 1991). Low mobility and relatively fixed distribution pattern of juvenile sole at this season (Dorel et al., 1991) allow us to consider the samples taken at this period as being representative of the distribution on nursery grounds. This season is also the most documented (90% of the scientific trawl hauls). The resulting database includes about 5300

Table 1
Sampling protocol in the different nursery sectors.

Sector	Number of hauls	Period of investigation	Gear (BT = Beam Trawl)
Bay of Veys	119	1977–1981 2006	BT4, BT3 BT1
Bay of Seine	529	1977–1978; 1981 1995–2002 2006	BT4 BT2a, BT3 BT1
Somme	1383	1977–1983 1987–2007 2006	BT4 BT2a, BT3 BT1
Boulogne	315	1977–1983 1987–2007 2006	BT4 BT3 BT1
RyeBay	1596	1974; 1981–2006	BT2b
South Downs	268	1974; 1981–1999	BT2b
Solent	1137	1974; 1981–1999	BT2b