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Delineating recurrent fish spawning habitats in the North Sea

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ABSTRACT

The functional value of spawning habitats makes them critically important for the completion of fish life cycles and spawning grounds are now considered to be "essential habitats". Inter-annual fluctuations in spawning ground distributions of dab (*Limanda Limanda*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) were investigated in the southern North Sea and eastern English Channel, from 2006 to 2009. The preferential spawning habitats of these species were modelled using generalised linear models, with egg distribution being used as proxy of spawners' location. Egg spatial and temporal distributions were explored based on six environmental variables: sea surface temperature and salinity, chlorophyll *a* concentration, depth, bedstress and seabed sediment types. In most cases, egg density was found to be strongly related to these environmental variables. Egg densities were positively correlated with shallow to intermediate depths having low temperature and relatively high salinity. Habitat models were used to map annual, i.e. 2006 to 2009, winter spatial distributions of eggs, for each species separately. Then, annual maps were combined to explore the spatial variability of each species' spawning grounds, and define recurrent, occasional, rare and unfavourable spawning areas. The recurrent spawning grounds of all four species were located in the south-eastern part of the study area, mainly along the Dutch and German coasts. This study contributes knowledge necessary to the spatial management of fishery resources in the area, and may also be used to identify marine areas with particular habitat features that need to be preserved.

1. Introduction

Fish spawning takes place in spatially limited areas (or grounds) with attributes that favour reproductive success through higher egg survival (Bellier et al., 2007; Planque et al., 2004). Areas offering favourable environmental conditions often correspond to frontal zones (Munk et al., 2002, 2009), which are transitional areas between water masses, such as upwellings, areas affected by tides, river plumes or estuaries (Bakun, 1996; Munk and Nielsen, 2005). Monitoring fish spawning grounds has been identified as one of the key steps for an ecosystem-based approach to marine management (Anon, 2002). Spawning can indeed be affected by, and reflect, adult stock depletion, habitat disturbance, climate change and other processes (Begg and Marteinsdottir, 2002; Rijnsdorp et al., 2009). Moreover, knowledge of the location and extent of fish spawning areas is also required for environmental risk assessment in the case of industrial developments, such as offshore energy and aggregate extraction for sand and gravel (Stelzenmüller et al., 2010). Therefore, knowledge and preservation of spawning grounds are essential for interpreting fish stock fluctuations, improving the management of stocks and hence maintaining appropriate population levels.

The eastern English Channel and North Sea sustain one of the richest commercial fisheries in the world, in terms of both diversity and abundance. These areas are also ecologically important, due to a number of fish spawning and nursery areas (ICES, 2009; Martin et al., 2009). Many fish species display a year to year consistency in their spawning location, thereby reflecting a certain fidelity to particular grounds (Daan, 1981; Fox et al., 2000, 2008), and suggesting the existence of preferential spawning habitats. The frontal zones to which egg distributions are often linked may, however, vary from year to year (Munk et al., 1999). Repeated in situ observations are an effective approach to study the spatio-temporal variability of fish spawning habitats (Bellier et al., 2007), and can be carried out at high spatial resolution using the Continuous Underway Fish Egg Sampler (CUFES; Checkley et al., 1997). This way, grounds that are repeatedly used for laying eggs can be identified and delineated. The CUFES is relatively easy to operate and provides reliable estimates of egg abundance (Lo et al., 2001) and distribution (e.g. sardine, *Sardina pilchardus* and whitehead's round herring, *Etrumeus whiteheadi*; van der Lingen et al., 1998). It has successfully been used to

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map egg distribution and spawning grounds of pelagic fish species (Lelièvre et al., 2012a; Petitgas et al., 2006).

Habitat may be defined as geographical locations where biotic and abiotic conditions allow presence, or favour abundance, of a given fish species at a given life stage (Benaka, 1999). A number of statistical modelling techniques are available to predict species habitats (Guisan et al., 2006; Planque et al., 2011). For instance, Generalised Linear Models (GLM; McCullagh and Nelder, 1989) belong to the family of linear regressions, and can be used to model the mean of response data that are not necessarily normally distributed. This approach consists in generating a model that summarises the relationship between a species' presence, or abundance, and a set of explanatory environmental variables. The model can then be used to predict the species' average distribution, using that of the environmental variables in the model (Martin et al., 2012).

The present study aimed to explore spawning grounds' spatio-temporal dynamics in the eastern English Channel and southern North Sea. Here, the focus is on four fish species, all of commercial importance: dab (*Limanda limanda*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*) and whiting (*Merlangius merlangus*). These species spawn between January and June, with peaks in January for plaice (Simpson, 1959), February for cod, and March for whiting and dab (Munk and Nielsen, 2005). GLMs, coupled with a Geographic Information System (GIS), were used to map annual spawning habitats of each species, based on environmental variables. Then, the temporal variability of these habitats was assessed to define recurrent spawning areas, considered as the core of the spawning ground, i.e. where spawning takes place every year. Finally, areas deemed to be of upmost conservation value were delineated, based on the recurrent spawning habitats of dab, plaice, cod and whiting together.

2. Materials and methods

2.1. Sampling surveys

The International Bottom Trawl Survey (IBTS) takes place annually in the North Sea and part of the eastern English Channel (Fig. 1) to estimate stock abundance and recruitment level of the main exploited fish species (ICES, 2004). Taking advantage of the survey's path, data on fish eggs and environmental variables were collected from 2006 to 2009 (January, February), on-board *RV* Thalassa (Table 1).

2.2. Biological data

The four species investigated in this study spawn pelagic eggs that may drift with currents (Bunn et al., 2000). Under calm conditions, eggs are expected to accumulate close to the surface, showing a clear peak in abundance in the upper layer (up to 20 m depth) (Adlandsvik et al., 2001; Conway et al., 1997; Pépin et al., 2005). Using CTD profiles and vertical egg tows, Lelièvre et al., 2012a have shown that in the southern North Sea, strong currents and winter wind conditions generally result in a well-mixed water column, so CUFES samples are usually representative of egg density over the entire water column. Although the CUFES alone cannot be used for a precise estimation of total egg density, it was shown to accurately depict the spatial distribution of eggs under the conditions of the present study.

Sub-surface samples were collected using the CUFES, which continuously pumped water 5 m below the surface, through a 5 cm diameter inlet protruding slightly from the hull and pumping water perpendicularly to the current. To enhance the catching efficiency, a metallic scoop was bolted on the side of the ship and was directed into the current.

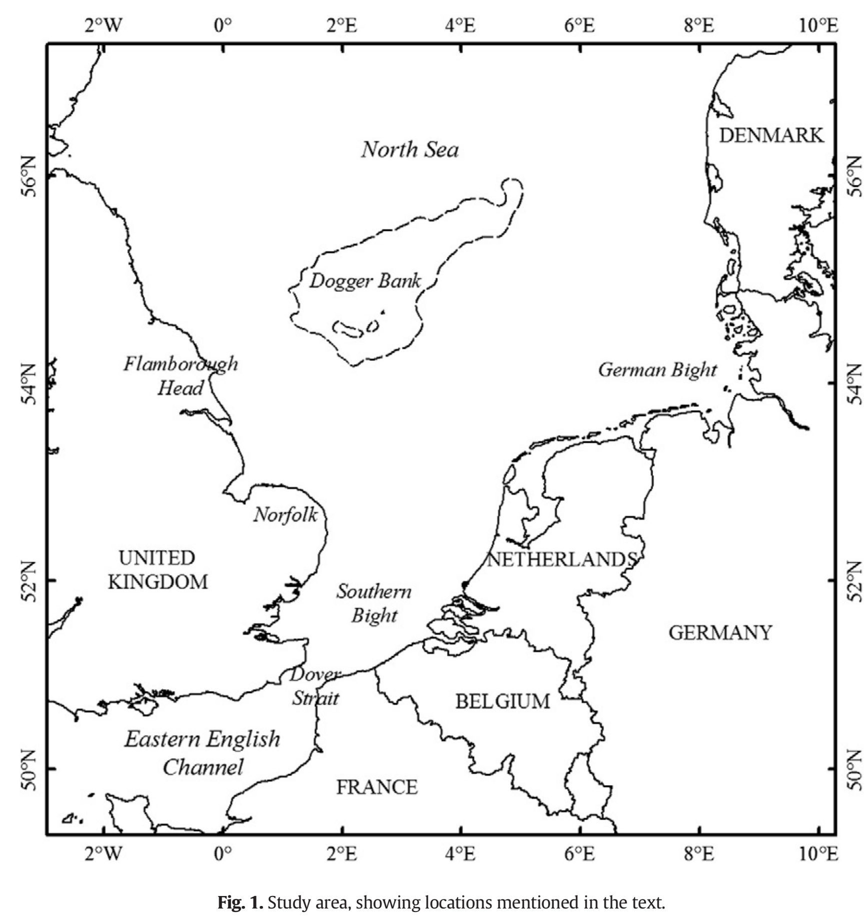

Fig. 1. Study area, showing locations mentioned in the text.