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Modelling the spatial distribution of plaice (*Pleuronectes platessa*), sole (*Solea solea*) and thornback ray (*Raja clavata*) in UK waters for marine management and planning

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ABSTRACT

Species distribution maps are needed for ecosystem-based marine management including the development of marine spatial plans. If such maps are based on predictive models then modelling procedures should aim to maximise validation success, and any uncertainty in the predictions needs to be made explicit. We developed a predictive modelling approach to produce robust maps of the distributions of selected marine species at a regional scale. We used 14 years of survey data to map the distributions of plaice, sole and thornback ray in three hydrographic regions comprising parts of the Irish Sea, Celtic Sea and the English Channel with the help of the hybrid technique regression kriging, which combines regression models with geostatistical tools. For each species–region combination we constructed logistic Generalized Linear Models (GLMs) based on presence–absence data using the environmental variables: depth, bottom temperature, bed shear stress and sediment type, as predictors. We selected GLMs using the mean squared error of prediction (MSEP) estimated by cross-validation then conducted a geostatistical analysis of the residuals to incorporate spatial structure in the predictions. In general, we found that species occurrence was positively related to shallow areas, a bed shear stress of between 0 and 1.5 N/m^2, and the presence of sandy sediment. Predicted species occurrence probabilities were in good agreement with survey observations. This modelling framework selects environmental models based on predictive ability and considers the effect of spatial autocorrelation on predictions, together with the simultaneous presentation of observations, associated uncertainties, and predictions. The potential benefit of these distribution maps to marine management and planning is discussed.

1. Introduction

Species distribution maps are an important part of marine spatial plans that contribute to sustainable ecosystem-based marine management (Borja et al., 2000; Guisan and Thuiller, 2005; Degraer et al., 2008). Such maps are often based on species distribution modelling, although this is less widespread for marine species than terrestrial systems. The reasons for this are many, with access to environmental sampling data over suitable spatial scales presenting one of the greatest barriers. Distributions of terrestrial plants and animals are invariably better supported by quantitative data than marine species, due to the difficulties and expense of biological sampling in the marine environment. Where data collection programmes exist, they are primarily designed to enumerate the abundance and distribution of commercially exploited species within a predefined geographic region.

Species distributions models estimated from broad-scale fisheries survey data have already proven effective in mapping the distribution and habitat suitability for a range of marine fauna, e.g. Eastwood et al. (2003); Kupschus (2003); Hedger et al. (2004). Complications can arise when predictions of species distributions are needed at regional scales larger than an individual survey, as different sampling gears and survey protocols often lead to differences in catch efficiencies of target species. A further problem is the relative scarcity of marine environmental data. Water depth is routinely recorded, but surface salinity and water temperature are not consistently reported and seabed data are infrequent. Given that large areas of the UK shelf are thermally stratified during the summer months (Elliott et al., 1991), temperature recorded at the surface may not reflect the conditions experienced by demersal fish and benthic fauna. On land, remotely sensed data are often available, e.g. McPherson et al. (2004), while for the marine fauna this data source applies only to the sea surface. Subsea acoustic technologies are beginning to map broad scale coverage of marine seabed features (Kostylev et al., 2001), but in general the availability of basic environmental data over broad spatial scales in the marine environment is poor. However, where data on depth, sediment type and water temperature are available, they have consistently been linked to distribution patterns of demersal marine fish e.g. Abookire

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and Norcross (1998); Kaiser et al. (1999); Eastwood et al. (2003); Stelzenmüller et al. (2005). So, although the literature will reflect the available data, relatively few physical drivers may provide reasonable descriptive power of species distributions.

Common spatial modelling techniques for marine species are regression models (Eastwood et al., 2003; Vaz et al., 2008), geostatistical methods (Stelzenmüller et al., 2004), combinations of both regression and GIS techniques (Pittman et al., 2007) and geostatistics and GIS (Stelzenmüller et al., 2007). Recent work has shown that hybrid techniques such as regression kriging, a combination of regression techniques and geostatistics, have proven to be superior to either single approach, yielding more detailed results and higher accuracy of prediction (Knotters et al., 1995; Carre and Girard, 2002; Stacey et al., 2006; Hengl et al., 2007a). Regression kriging is a two step process which first applies regression on auxiliary information and then uses simple kriging to interpolate the residuals from the regression model (Odeh et al., 1995; Hengl et al., 2007a). The first step, the multivariate statistical modelling, should select a model from a set of candidates and then assesses performance, preferably with independent data. Models are commonly selected by stepwise selection or information–theoretic approaches such as the Akaike's Information Criterion (AIC) (Akaike, 1974) and their predictive performance can be measured with the help of independent test data. The second step fits a covariance function to the regression residuals to account for the effect of spatial autocorrelation in the data (Cressie, 1991). This approach has been successfully applied to estimate soil property distributions (Stacey et al., 2006; Rivero et al., 2007; Sumfleth and Duttmann, 2008), but at present regression kriging is rarely applied in an ecological context and has not yet been applied to predict distribution pattern of marine species.

Distribution models need to be constructed using transparent methods that yield outputs which maximise predictive success. In order to demonstrate a model's performance, confidence in the predictions also needs to be made explicit, and predictions should be used to complement rather than replace empirical observations (Burgman et al., 2005).

Employing the hybrid modelling technique regression kriging enabled us to select models with good predictive performance and to account for the effect of spatial autocorrelation on the predictions. We assessed the models' predictive ability with the mean squared error of prediction (MSEP) via cross-validation (Mosteller and Tukey, 1968), a measure widely used for model validation, e.g. Roche et al. (1999); Francis (2006). Estimating MSEP via cross-validation is a relatively simple approach to assessing model performance and so has the advantage of being easily interpreted by non-experts.

In this study we developed species distribution models for UK waters using 14 years of observations of plaice (*Pleuronectes platessa*), sole (*Solea solea*) and thornback ray (*Raja clavata*) from different beam trawl surveys. Fish population size and range fluctuate over time and many fish populations show density-dependent habitat selection, with range contracting to areas of optimal habitat as abundance falls (Myers and Stokes, 1989; Marshall and Frank, 1995; Blanchard et al., 2005). Therefore, by using multiple years of data, we aim to capture

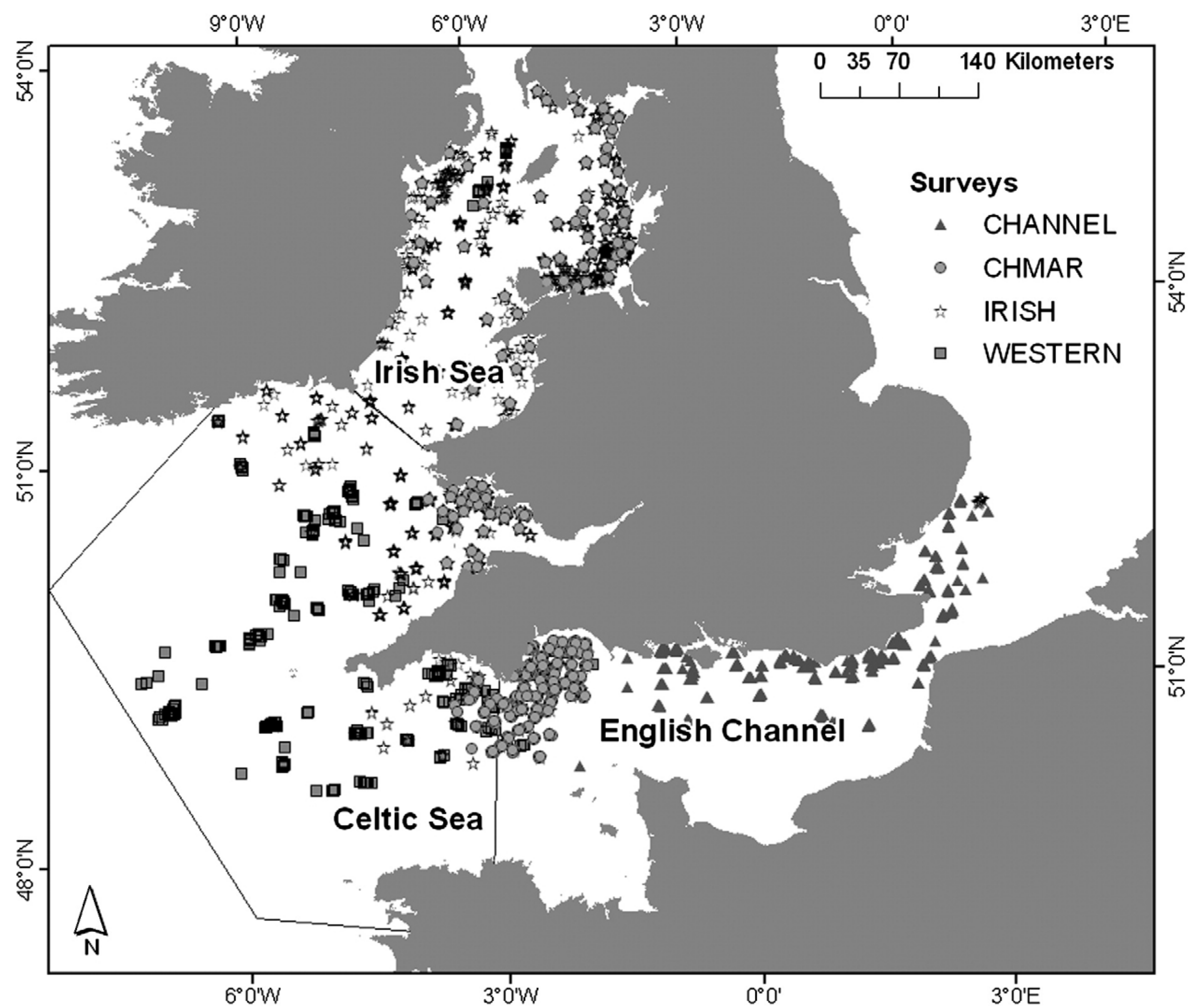

Fig. 1. Sampling stations by survey in relation to the hydrographical regions defined.