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Dynamic prediction of effort reallocation in mixed fisheries

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ABSTRACT

A discrete choice model is applied to determine how fishing effort is allocated spatially and temporally by the English and Welsh North Sea beam trawl fleet. Individual vessels can fish in five distinct areas, and the utility of fishing in an area depends on expected revenue measured as previous success (value per unit effort) and experience (past fishing effort allocation), as well as perceived costs (measured as distance to landing port weighted by fuel price). The model predicts fisher location choice, and the predictions are evaluated using iterative partial cross validation by fitting the model over a series of separate time-periods (nine separate time-periods). Results show the relative importance of the different drivers that change over time. They indicate that there are three main drivers throughout the study, past annual effort, past monthly effort in the year of fishing, and fuel price, largely reflecting the fact that previous practices where success was gained are learned (i.e. experience) and become habitual, and that seasonal variations also dominate behaviour in terms of the strong monthly trends and variable costs. In order to provide an indication of the model's predictive capabilities, a simulated closure of one of the study areas was undertaken (an area that mapped reasonably well with the North Sea cod 2001 partial closure of the North Sea for 10 weeks of that year). The predicted reallocation of effort was compared against realized/observed reallocation of effort, and there was good correlation at the trip level, with a maximum 10% misallocation of predicted effort for that year.

1. Introduction

It is becoming increasingly evident that fisheries management is not solely a biological issue. Fisheries science is an interdisciplinary field, and combining social, economic, and ecological information has proven to be increasingly important in achieving sustainable fisheries management (Mumford et al., 2009). Of increasing importance to fisheries science and management is the ability to anticipate fisher behaviour in response to management regulation, in order to reduce implementation error, i.e. where the effects of management differ from that intended. An example of implementation error is where fishing effort is redistributed following a spatial closure to protect a stock (or cohort) in a way that was not anticipated by management.

Many factors influence a fisher's decision where and when to fish, including fish distribution, fuel price, regulations, their habits and experience, previous catch rates, market prices, and the proximity to landing ports. These factors can lead to differences in observed individual fisher behaviour and the way a group of fishers (a fleet) allocate their effort in time and space. Several studies have looked at behavioural aspects of the way fishers spatially allocate their effort (Rijnsdorp et al., 2000; Hilborn et al., 2005; Smith et al., 2009). An important element influencing fisher behaviour is stock density, because fishers tend to have prior knowledge (Begossi, 2001) of resource distribution and habitat (Hilborn and Ledbetter, 1979; Gillis et al., 1993; Pet-Soede et al., 2001). Catch rates are related to stock density and will have a large impact on fisher behaviour (Eales and Wilen, 1986; Marchal et al., 2006). This means that fishers will gravitate towards areas where catch rate is greatest, and gravity models have been specified and applied to model fishing vessel spatial distribution (e.g. Walters and Bonfil, 1999). Economic factors and management measures in the form of technical measures (size restrictions or gear restrictions; Bene and Tewfik, 2001), marine protected areas (MPAs), and spatial closures may also force fishers to search for new fishing grounds (Hutton et al., 2004).

Over the past few years, much attention has been paid to predicting fisher location choice by applying random utility methodology and discrete choice models (Andersen et al., 2010). Predicting fisher behaviour using discrete choice models has

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increased in popularity with the increasing availability of appropriate data (vessel-by-vessel trip data), because such models offer an opportunity to study individual behaviour at finer resolutions of time and space than other techniques (Coglan et al., 2004; Hutton et al., 2004). These models can be applied to theoretical policy scenarios, which can also be simulated. The key characteristics of discrete choice models or random utility models (RUMs) are that they model discrete decisions, and the assumption of homogeneity among individuals does not need to hold. As with other economics-based choice models, utility drives individual choice with a deterministic component and a stochastic error component (hence the name "random" utility model). Prior to implementation in fisheries behaviour models, discrete choice models were used in the travel industry to analyse the behaviour of consumers of transportation services and facilities (McFadden, 1974; Ben-Akiva and Lerman, 1985).

The behaviour of fishers can be studied in the short term (their tactics), for example on a trip-by-trip basis in terms of decisions where to fish and which species to target, or the long term (their strategies), i.e. choices made year by year where the availability of decommissioning grants, stock status, catch quotas, investment, and other key factors play a critical role in the decision of a fisher to invest in the fishing operation (Tidd et al., 2011). Models prior to the application of discrete choice models assumed the ocean to be a homogenous space in which fish are distributed uniformly and fishing locations are identical (e.g. Holland and Brazee, 1996; Smith and Wilen, 2003). Sanchirico and Wilen (1999) modelled behavioural dynamics, including both spatial and temporal aspects, under conditions of open access. The results of their analysis suggested that fishing effort across a system of interconnected spatial patches is driven by the bio-economic conditions in each patch, and the biological dispersal rates between patches. In patches where costs are high or the catchability and prices low (mix of low price species and/or cohorts), effort is driven away, and as it relocates, it affects the distribution and density of stocks (i.e. the local density and the potential for dispersal to nearest-neighbour patches) of other patches directly and indirectly. Incorporating economic variables (such as revenue and travel costs) into decision-maker behaviour is therefore important when analysing a resource that is distributed heterogeneously in space.

In this study, we investigate whether tactical behaviour by fishers is influenced by expected revenues, habitual seasonal fishing patterns, effort fluctuations, and changes in fuel costs, and whether there are dynamic changes in the relative importance of these drivers through time. Focus is on the English and Welsh North Sea beam trawl fleet, where there have been changes in both ownership and spatial management; as such, this study provides an opportunity to investigate the dynamics and drivers of fisher behaviour. Also of interest to this study is the fact that, during 2001, the European Commission implemented a temporary closure or MPA in the North Sea between mid-February and the end of April, to conserve spawning of North Sea cod (EC, 2001). As a regulatory management measure that impacted fishing effort, the 2001 closure of the North Sea covered most of Roundfish area 7, which beam trawlers frequent, and the remainder of which included a plaice box preventing trawlers >300 hp from entering (Fig. 1). This allowed us to evaluate the predictive power of the model and analysis, and among other factors the response of the fleet to a management measure.

An earlier study also applied a discrete choice model to the same fleet using individual fishing trip data over the years 1999–2000. Previous knowledge or experience of fishing grounds (in 1999) was found to have a bearing on the decision to fish in a given area in 2000, and this information was then used to construct a simple effort redistribution model to simulate the implications of the 2001 closure (Hutton et al., 2004). Although that study investigated detailed spatial location choice, there are limitations to such work for considering temporal changes in fisher behaviour. This is because of the short time-period of data and the type of discrete choice model used. Hutton et al. (2004) used a conditional logit model, a model often criticized when used for spatial policy analysis because of the Independence of Irrelevant Alternatives (IIA) it imposes, i.e. choices are assumed to be independent, and a change in one choice would not affect the relative choice set, which could have serious implications if used for a spatial policy analysis (Wilen et al., 2002).

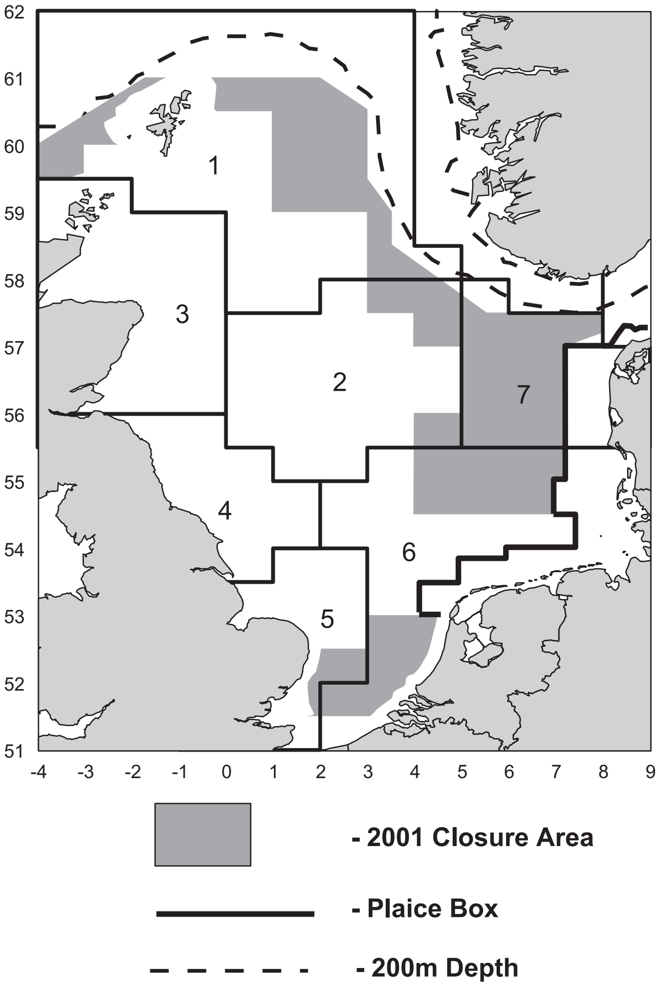

Fig. 1. The study area and Roundfish areas, including the 2001 closure areas and the plaice box.

Here, focus is on the dynamic changes in tactical behaviour over a 12-year period. We introduce the use of a mixed model (relaxing the IIA assumption) and extend the set of explanatory variables investigated to a wider range of potential drivers (such as distance to landing port and separation of catch into their targeted components, plaice and sole). To understand better the drivers and dynamics of fisher location choice over space and time, we fit discrete choice models over different periods and investigate the effects of the various explanatory variables (which are proxies of expected revenue and costs perceived by fishers from past experience on monthly and annual time-scales). We then predict fisher location choice over separate periods to evaluate the model predictions, along with the versatility and robustness to potential changes in tactics. Finally, we develop a framework for investigating fisher location choice that can be used to reduce potential implementation error and scientific uncertainty and allow for the management system to be adjusted or adapted to what is learned.