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Recent experience with effort management in Europe: Implications for mixed fisheries

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ABSTRACT

This study addresses a common assumption in fisheries science: that partial fishing mortality is directly proportional to fishing effort. It is important to challenge this *a priori* sensible assumption, as it is also built into many models and tools used by the International Council for the Exploration of the Sea (ICES) to help provide advice and conserve fish stocks. Here we test this assumption at scales relevant to management using catch and effort data from the EC Scientific, Technical and Economic Committee for Fisheries (STECF), together with mean fishing mortality estimates from ICES. We focus on the eight predominant fishing gear types in the North Sea, and for each gear, test how effort is related to partial fishing mortality exerted by each gear on their main target species. For many gear types, the relationships found were not inconsistent with the assumption being tested, although in many cases there was also no significant pattern between fishing mortality and effort. Fishing mortality-effort relationships can be complex, as exemplified by the frequent lack of significant relationships in mixed demersal fisheries. The relationship between fishing mortality and effort can also vary over time, particularly in response to changes in catchability, producing patterns that can be difficult to uncover. These factors may significantly affect the impact management strategies may have on stocks and fleets. As tools are developed to provide mixed fisheries advice, we encourage efforts that help understand the implications of assumptions made for management strategies.

1. Introduction

There is a growing recognition of the complexities of many of the North Sea fisheries, and together with legislative changes taking place, there is an increasing demand for tools with which to explore potential management strategies. While there is an understanding that these tools need to have a strong fleet-based perspective, many still assume that fishing mortality is proportional to fishing effort (e.g., Ulrich et al., 2011). Similarly, the outcomes of effort management strategies currently implemented in the North Sea (EC Scientific, Technical and Economic Committee for Fisheries (STECF) (STECF, 2012a)) are predicated on this assumption. In this study we explore the relationships between fishing mortality and fishing effort for fleet segments (aggregated to the same scale used in management) operating in the North Sea, to better understand under what circumstances the assumption of proportionality is justified, and in what cases there are discrepancies.

The recent reform of the European Union's Common Fisheries Policy (CFP) introduced significant changes to how fisheries are to be managed, including a landings obligation, a legal requirement to fish at levels consistent with the maximum sustainable yield (MSY), and management plans that take account of biological (i.e., predator-prey) and technical (i.e., simultaneous exploitation of several fish stocks) interactions (European Union, 2013). In order to meet these needs, models have been developed to explore different management strategies, lay bare the potential trade-offs between objectives, and provide advice; examples of such models include the Stochastic Multispecies Model (SMS; Lewy and Vinther, 2004) for interactions between species; FCube (Ulrich et al., 2011) and ISIS-Fish (Mahévas and Pelletier, 2004) for technical interactions; and Ecopath with Ecosim (EwE; Mackinson and Daskalov, 2007; Plagányi, 2007) for ecosystem effects. For the advice to be valuable, however, the models need to accurately reflect the link between an input that can be managed (the fishing effort or activity) and the

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response (e.g., the quantity of fish caught), and therefore require a strong fleet-based underpinning.

Several EU fisheries management plans have included measures intended to reduce mortality, F, on the species managed by reducing fishing effort, E (e.g., North Sea cod: Council Regulation 1342/2008; and flatfish: Council Regulation 676/2007), implicitly assuming that fishing mortality is proportional to effort. The assumption, often expressed in the literature as $F = qE$, where q is the constant catchability parameter for a given fleet, is *a priori* reasonable (a fishing vessel that spends more time fishing is likely to catch proportionately more fish), but has been questioned in the past (Cooke and Beddington, 1984; Hilborn and Walters, 1992). Indeed, recent experience shows that reductions in effort need not lead to the expected decrease in fishing mortality (ICES, 2013d; Kraak et al., 2013), equally implying that reductions in F can occur without reductions in effort (via, for instance, avoidance behaviours). Any deviations from the assumption that F is proportional to fishing effort will have implications for the management of fleets and realised management outcomes for the stocks (Kraak et al., 2008; Thøgersen et al., 2012). Studies have shown that the relationship between fishing mortality and effort can be complex (e.g., Rijnsdorp et al., 2006; Thøgersen et al., 2012; Ulrich et al., 2012) and influenced by such factors as the heterogeneous distribution of stocks and fleets (e.g., Rose and Kulka, 1999), targeting behaviour of fleets (Quirijns et al., 2008), interactions between vessels (Poos and Rijnsdorp, 2007), non-random behaviour of fishermen (Walters and Martell, 2004; Tidd, 2013) due to, for instance, changes in fuel costs or market value of the targeted stocks, and gear improvements (Arreguín-Sánchez, 1996). These factors have led experts to hypothesise that current effort management strategies are applied to fleet segments that are too broad (STECF, 2011, 2012a,b; Kraak et al., 2013). However, the relationship between fishing mortality and effort has so far not been quantified systematically at the scale used by management.

As multi-stock management plans are developed, it is important to consider what role effort management has to play in addressing technical interactions in mixed fisheries. Furthermore, an understanding of the link between F and effort can inform parameterisation of fleet and fishery forecasting tools such as the Fcube model (e.g., Ulrich et al., 2011; Iriondo et al., 2012) and other bioeconomic models (Gröger et al., 2007; Gourguet et al., 2013) developed to provide mixed fisheries advice (ICES, 2012, 2013a,c). STECF (2012a) recently made data on catch and effort available for all EU fleets operating in the North Sea, providing time series from 2003 onwards. This data allows us to study the relationships between mortality and effort for a wide range of fisheries where effort management is seen as a viable alternative or complement to current management strategies (Ulrich et al., 2011).

In this study we explore the relationships between fishing mortality and effort for fleets in the North Sea, with the fleet definitions used in management plans. We test whether (i) there is a pattern, and (ii) the pattern is consistent with the assumption of proportionality. We provide plausible explanations for the patterns found, and discuss their potential implications. The results can inform future management choices, bearing in mind not only the impact of management strategies on stocks, but also the economic implications for fleets.

2. Methods

2.1. Data sources

Two datasets are used: the data appendix to the report by the Evaluation of Fishing Effort Regimes in European Waters working group of the STECF (henceforth "STECF data"), and the ICES stock assessment database.

The STECF dataset is publicly available at http://stecf.jrc.ec.europa.eu/data-reports, and consists of data submitted by Member States in response to the current Data Collection Framework (DCF, previously the Data Collection Regulation; STECF, 2012a) data calls. The data provided include landings and discards per species and métier, and effort (as measured by kilowatt days fished) per métier for the period 2003–2012. Métiers are defined by the predominant fishing gear type used (in some cases disaggregated by mesh size – see Supplementary Table S1; STECF, 2012a).

The STECF data were subset to keep the areas relative to Annex IIa, Area 3b, which correspond to ICES subdivisions VIId, IV, and part of IIIa. Fleets for which no effort data were available were removed. The data were further subset to only include species present in the ICES database (cod, haddock, herring, plaice, saithe, sandeel, sole, sprat, and whiting).

The ICES stock assessment database was downloaded in 06/2014 using the ICES web services (ICES, 2014). We used data for the North Sea ecoregion.

2.2. Fishing mortality and statistical analyses

We use the instantaneous rate of partial fishing mortality (F_{par}) as the measure of fishing mortality. It is defined as

$$F_{\text{par}}(s, x, y) = \frac{C(s, x, y)}{C(s, y)} \bar{F}(s, y), \quad (1)$$

where $C(s, x, y)$ is the catch (landings plus discards) of stock s by fleet category or métier x in year y, $C(s, y)$ is the catch of stock s in year y across all fleet categories, and $\bar{F}$ is the fishing mortality averaged over the age classes typically selected by the fishery; the range of age classes was specific to each stock (e.g., ages 2–4 years for North Sea cod) and in agreement with those used in stock assessments (ICES, 2013b,d). We estimated F_{par} using the proportions of the total catch weight by each fleet segment. This method of estimating F_{par} is common (Ulrich et al., 2011; Tidd, 2013), and is considered a reasonable approximation of the contribution of the fleet to total fishing mortality. However, the method also assumes that the size-selection pattern is the same for all fleet segments, which is unlikely to be the case in reality. The selection patterns of different gears can differ, potentially biasing the relative contribution of a gear to the total F of a stock. However, in the context of the relationship between F and E, it is the relative changes in F_{par} that are of interest. We are therefore making the more important but reasonable assumption that the selection patterns have not changed considerably over the study period. Carefully testing this assumption to understand its impact on the relationships analysed in the present study, and on management strategies more generally, would warrant and deserve a separate study, and would require more reliable catch-at-age data than is currently available.

Fishing gears are developed to selectively target specific stocks; management strategies are therefore likely to target vessels grouped by the predominant type of gear used. For similar reasons, current ecosystem models characterise fleets by their gear type (Mackinson and Daskalov, 2007). We therefore investigate the relationship between fishing mortality and effort for fleets grouped by the main gear type used, i.e., catch and effort for a fishing gear catching a stock were added across all Member States. The number of gear types per stock was reduced by ranking them in descending order using the mean F_{par} between 2003 and 2012, and keeping the gear types that accounted for the top 95% of the overall fishing mortality. Both fishing mortality and effort were ln-transformed to approximate normal distributions.

We used generalised least squares (GLS; Pinheiro et al., 2013; R Core Team, 2013) to fit linear regressions between $\ln F_{\text{par}}$ and $\ln E$