Fisheries Research 193 (2017) 21–32

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

A temporal race-for-fish: The interplay between local hotspots of flatfish and exploitation competition between beam trawlers after a seasonal spawning closure

Klaas Sys[a,b,c,*], Jef Van Meensel[c], Hans Polet[b], Jeroen Buysse[a]

[a] Department of Agricultural Economics, Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium
[b] Flanders Research Institute for Agriculture, Fisheries and Food, Animal Sciences Unit – Fisheries and Aquatic Production, Ankerstraat 1, 8400 Oostende, Belgium
[c] Flanders Research Institute for Agriculture, Fisheries and Food, Social Sciences Unit, Burg. van Gansberghelaan 115 bus 2, 9820 Merelbeke, Belgium

ARTICLE INFO

Article history:
Received 23 December 2016
Received in revised form 8 March 2017
Accepted 25 March 2017
Handled by George A. Rose
Available online 3 April 2017

Keywords:
Fleet dynamics
Beam trawling
Catch per unit effort
Fishery closure

ABSTRACT

In this paper we examine the response of the Belgian beam trawl fishery after the implementation of a spawning closure in the Celtic Sea. It was observed that fishing effort was mainly reallocated in time, resulting in a short-term "race for fish" immediately after re-opening of the fishery. The rationale of this behavior was examined by analyzing the landing rate of the target species (sole) in a generalized additive mixed model. Results showed that daily sole landings were up to twice as high just after re-opening of the fishery and dropped within 3 weeks to a reference level. This pattern of landing rate per unit (lpue) of sole was strongly related to the spatial distribution of fishing effort in the closed area during the month of re-opening. During the first week, fishing effort was very patchy, with increasing dispersal toward the end of the month. These results give indirect evidence for the occurrence of high local concentration of sole as a result of the closure, and the occurrence of exploitation competition when the fishery restarted.

1. Introduction

One of the critical steps towards an effective implementation of an ecosystem based fisheries management (EBFM) is to improve understanding of how ecosystems function, including the interactions between the various subsystems (Crowder and Norse, 2008; Link, 2002; Pikitch et al., 2004). Therefore, understanding the relationship between a fishery and its resource remains a major research topic of fisheries science (Branch et al., 2006). Improved understanding of the underlying mechanisms and interactions that shape this relationship may reduce the uncertainty of fisher behavior (Fulton et al., 2011), and consequently increase the effectiveness of fisheries management and enhance the sustainable exploitation of marine resources. This relationship is often expressed as catch-per-unit-effort (cpue), and is known to have a positive linkage with the density of the resource, making it an important parameter in the various models used to design fisheries management (Harley et al., 2001). Nevertheless, cpue is affected by many factors (see Gillis and Peterman (1998) for an overview). Correct interpretation and use of cpue depends largely on both spatial distribution of the fish resource and the allocation of fishing effort (Paloheimo and Dickie, 1964).

Spatiotemporal management tools such as temporary fishery closures are commonly used in fisheries management. The success of these interventions depends strongly on the response of the fishery in terms of spatial and temporal reallocation of fishing effort (Dinmore et al., 2003). Spatial reallocation of fishing effort, often resulting in the strategy called "*fishing the line*" which is characterized by intensive fishing close to the borders of the closed area, has been extensively described (Van Der Lee et al., 2013; Murawski et al., 2005) and explained through the mechanisms of *spill-over* and *export* of eggs and larvae and juveniles (Gell and Roberts, 2003). In contrast, the underlying mechanisms and effects of a temporal reallocation of fishing effort are not. Trawl fisheries are particularly relevant to this line of inquiry, as this type of fishery has a strong linkage with the flatfish resource due to seafloor disturbance. The heavy trawl gear penetrates the upper layer of the seabed, damaging benthic life and altering the composition of benthic communities (Jennings and Kaiser, 1998). Hiddink et al. (2008) and Van Denderen et al. (2014) proved that both the trawling frequency and the temporal aggregation of fishing effort are

* Corresponding author at: Department of Agricultural Economics, Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium.
E-mail address: klaas.sys@ilvo.vlaanderen.be (K. Sys).

http://dx.doi.org/10.1016/j.fishres.2017.03.018
0165-7836/

important parameters for the impact of bottom trawling on the structure of benthic communities. Ignoring this feedback mechanism may result in unforeseen management outcomes, such as the increase of discards of juvenile plaice (*Pleuronectes platessa*) in the Dutch beam trawl fishery after implementation of the Plaice Box (Beare et al., 2013).

The objective of this paper is to assess how a reallocation of fishing effort in time influences the relationship between fishers and their resource, and thus affects the link between catch and effort (cpue) and fisher behavior. Therefore, we use the Belgian beam trawl fishery in the Celtic Sea, in which a remarkable short-term race for fish after re-opening of the fishery in the Trevose Box in April was observed. First, we explain the rationale of this short term race for fish through analysis of cpue of the target species sole (*Solea solea*). In addition, we explore the underlying mechanisms of this distortion through analysis of the micro distribution of fishing effort, as this may reflect the small scale dynamics of the fish resource (Rijnsdorp et al., 1998). The objective of this paper is to increase knowledge about the interaction and feedback mechanisms between beam trawling and the flatfish resource at a high temporal resolution, with the aim of improving fisheries management outcomes.

2. Material and methods

2.1. The Trevose Box closure in the Celtic Sea as natural experiment

During the study period (2003–2014), the Celtic Sea (International Council of Exploration of the Sea – ICES divisions VIIg and VIIf) was predominantly exploited by French, Irish, British and Belgian trawlers targeting demersal fish species (Rijnsdorp et al., 1998; ICES, 2015). Most vessels were French, Irish and British otter trawlers targeting gadoids, with cod (*Gadus morhua*) being the most important species in terms of landed weight and value (ICES, 2007). The remainder of the fleet consisted mainly of Belgian and British beam trawlers targeting flatfish species, with sole being the most important species in terms of landed value (>60%).

This fishery was dominated by Belgian vessels (>60% of the annual Celtic Sea sole landings) with the shallow waters of the Bristol Channel estuary (ICES division VIIf) being the main fishing grounds in terms of annual sole landings as well as fishing effort (Fig. 1) (ICES, 2007, 2015). Belgian beam trawlers were active in the Celtic Sea throughout the year, but effort showed a seasonal pattern. Most effort was concentrated from December to April in the Bristol Channel, with ICES statistical rectangle 30E4 (1° longitude x 0.5° latitude, ca. 30 × 30 nautical miles) being the most frequently exploited. As part of the Celtic Sea cod recovery plan, the Trevose Box (ICES statistical rectangles 30E4, 31E4 and 32E3) (Fig. 1), one of the three spawning grounds of the Celtic Sea cod stock, was closed for fishing during January – February 2005, with subsequent annual closures during February – March since 2006. The aim of excluding fishing activities during the spawning season is to reduce fishing mortality of cod, as these fish aggregate during the spawning season and are therefore more vulnerable to fishing. Derogation was given to vessels using pots and creels, or nets with mesh size <55 mm, and, in March 2005, to beam trawlers as well (ICES, 2007). The Trevose Box closure caused Belgian beam trawlers to adjust their exploitation patterns in the Celtic Sea.

2.2. Data

Logbook data from 2003 to 2014 of Belgian beam trawlers with engine powers >221 kW using beam trawls with mesh size 80 mm were used for analysis of the landing rates per unit effort (lpue) of sole (Table 1). Along with the daily estimated weights (kg) of the landings of commercial species, logbooks contain daily information about the fishing activity in terms of gear type, mesh size and location (by ICES statistical rectangle). Trip (departure and arrival date and harbor of departure and embarking) and vessel (reference number, length, engine power and gross tonnage) information was added to the logbooks. No information about discards was available, thus the analysis was restricted to the landings per unit effort. Nevertheless, sole discards are considered very small (discard ratio <5%) causing lpue to be very close to cpue (ICES, 2015). Due to missing logbook data, 2005 was excluded from the analysis.

To examine the micro-distribution of fishing effort, data from the vessel monitoring system (vms) were used. This dataset contains the vessel's geographical position (latitude, longitude), heading direction (0–360°) and speed (knots) at regular time intervals (approximately every 2 h; Table 2). As vessel monitoring systems are only mandatory for larger vessels (length > 12 m) in the EU since 2006, analysis was restricted to the period 2006–2014. Vessels activities were distinguished based on analysis of their speed profiles (Hintzen et al., 2012). Only data representing vessels during the fishing state were retained for analysis of fishing effort. The spatial analysis was restricted to the most heavily exploited ICES statistical rectangle 30E4.

2.3. Effect of the Trevose Box closure on the landing rate of sole

To quantify the effect of re-opening of the Trevose Box on the landing rates of sole, a generalized additive mixed model (GAMM) was fitted to the daily sole landings. In GAMMs, nonparametric effects and random effects are included. Nonparametric effects allow for inclusion of predictor variables of which the predetermined form is not known; random effects account for sources of specific, individual variation and correct for the bias caused by repeated observations. The effect of re-opening the Trevose Box on lpue of sole was examined by comparing different models, without and with the effects of interest. Due to the similarity of the fleet, a null model [Eq. (1)], without explanatory variables about the re-opening effect of the Trevose Box, was specified according to Sys et al. (2016):

$$\log(lpue) = \beta_0 + \beta_{1_i} year + \beta_2 \log(engine) + \mathrm{f}(tripday) + \mathrm{f}(month)_{rect} + \epsilon + \mu_v. \quad (1)$$

In this model, the inter-annual variation, for example caused by different year-class strengths of sole or technical modifications, is captured by a categorical variable (*year*) with the first year of analysis (2003) included in the intercept β_0. Hence, the coefficient of β_{1_i} represents the change of every year ($i \in 2004,\ldots,2014$) relative to 2003. The value β_2 is the slope of the log-linear relationship between the landing rates and the beam trawler's engine power ($\log(engine)$) (Rijnsdorp et al., 2000a,b). Two nonparametric effects were included in the null model; these terms are smoothed to the data using regression splines (Wood, 2006). To capture the intra-annual, spatiotemporal variation caused by migration of adult sole from and to feeding and spawning grounds, a seasonal effect for each ICES statistical rectangle ($f(month)_{rect}$) of the study area was specified. An extra restriction (cyclic cubic regression splines) was imposed to assure continuity of lpue at the end points (Zuur et al., 2009). An intra-trip effect ($f(tripday)$) was included for the variation caused by the searching and exploitation phases of beam trawlers during a fishing trip (Rijnsdorp et al., 2011). This *tripday* effect was expressed as the number of days before the end of a trip, with a value 0 as the last day of the fishing trip. To account for the occurrence of zero catches and over-dispersion, a negative binomial distribution was specified for the error term (ε) by includ-