Estuarine, Coastal and Shelf Science 149 (2014) 168–177

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

How do demersal fishing fleets interact with aggregate extraction in a congested sea?

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ARTICLE INFO

Article history:
Received 7 April 2014
Accepted 10 August 2014
Available online 19 August 2014

Keywords:
spatial management
spatial planning
demersal fisheries
aggregate extraction
Eastern English Channel

ABSTRACT

The effects of the aggregate extraction intensity and the distance to extraction sites on the distribution of fishing effort were investigated for a broad selection of French and English demersal fleets operating in the Eastern English Channel. The most prominent result was that most fleets fishing near to aggregate extraction sites were not deterred by extraction activities. The fishing effort of dredgers and potters could be greater adjacent to marine aggregates sites than elsewhere, and also positively correlated to extraction intensity with a lag of 0–9 months. The distribution of fishing effort of French netters remained consistent over the study period. However, it is of note that the fishing effort of netters has increased substantially in the impacted area of the Dieppe site (where it is correlated to extraction intensity with a lag of 6 months), while slightly decreasing in the intermediate and reference areas. The attraction of fishing fleets is likely due to a local temporary concentration of their main target species. However, knowledge of their life-history characteristics and habitat preferences suggests that some of these species could be particularly vulnerable to aggregate extractions in the longer term.

1. Introduction

Human use of maritime domains is increasing and diversifying. The pressures are multiple and interacting, including impacts from the exploitation of living and mineral resources, maritime transport, renewable and non-renewable energy production, in a context of changing environmental conditions. Managing ecosystems is primarily managing people and their activities (Leslie and McLeod, 2007), so a key issue for marine management frameworks is to anticipate some of the patterns underlying human behaviour, their interactions, and the pressures they may exert on the marine ecosystems they exploit.

Until recently, marine resources in most countries worldwide were managed on a mono-sectorial basis. However, because of diverse maritime uses and stressors and their spatial distributions, it is evident that the increasing competition for marine space and the cumulative impact of human activities on marine ecosystems requires a more collaborative, integrated approach to management across the different sectors of activity. This has led many countries worldwide to develop marine management policies aiming at managing human activities by adopting new philosophies such as marine spatial planning (MSP), Integrated Coastal Zone Management (ICZM) and ecosystem-based management (EBM). The European Union (EU) is committed towards ecosystem-based management, and as such, the European Commission (EC) has implemented the Marine Strategy Framework Directive (MSFD - EC, 2007; EC, 2008). The MSFD includes a cross-sectorial framework for community action to achieve Good Environmental Status (GES) of the marine environment by 2020 in the context of sustainable development (EC, 2008), with ICZM and MSP providing a spatially-explicit management instrument to both enforce ecosystem conservation and alleviate competition for space and resources between sectors of activity.

Marine scientists from various backgrounds have increasingly been requested to provide integrated advice (i.e. integrating several elements of the ecosystem and several types of human activities) to inform the MSFD, ICZM and MSP. Providing integrated ecosystem-based advice requires overcoming several research challenges. One of the important challenges for research scientists is to understand the spatial interactions between human activities from different sectors, and to anticipate how human activities could be redirected

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http://dx.doi.org/10.1016/j.ecss.2014.08.005

given various scenarios of spatial management, including any 'knock on' effects to the ecosystem. Of particular importance is the issue of how fishers would react (e.g. through a redistribution of fishing effort or by changing métier), if access to traditional fishing grounds was restricted by either management (e.g. Marine Protected Area – MPA) or by spatial competition following the introduction or installation of new sectors of activity.

This study focuses on the Eastern English Channel (henceforth called EEC). The EEC is a productive ecosystem that forms important fishing grounds for a range of commercial species, including herring (*Clupea harengus*), cod (*Gadus morhua*), sole (*Solea solea*), scallops (*Pecten maximus*) and cephalopods and also encompasses some of their spawning and nursery areas and migratory routes. The EEC has also long supported a wide range of sectors of activity. It is considered one of the most intensively used sea areas in the world, including fishing, maritime transport, aggregate extraction, offshore windfarms, aquaculture and tourism (Carpentier et al., 2009).

Of these human activities, fishing and aggregate extractions are probably the most notable in terms of their direct effects on ecosystem structure and functioning (Pauly et al., 1998; Stelzenmüller et al., 2010; de Jong et al., 2014). Marine aggregates have been exploited along the UK coast of the EEC for several decades, and more recently along the French coast (Desprez, 2000; Boyd and Rees, 2003; ICES, 2013). In 2011, UK and French aggregate extraction companies extracted 17 million tonnes and 10 million cubic metres of marine sand and aggregates, respectively, half of which originated from EEC sites (ICES, 2013). This activity has now spread further offshore, to areas also visited by fishermen, where new extraction licenses have most recently been granted. Therefore, while it is essential to get better insights into how developing aggregate extraction activities could affect the EEC ecosystem directly, it is equally important to understand some of their more indirect ecosystem effects, such as those induced by their interferences with fishing activities and the resulting redistribution of fishing effort that may then arise.

Here the purpose of the study was to investigate how fishers and aggregate extractions interact spatially with one another in the EEC, by analyzing time series of different spatially-explicit metrics of fishing activities and aggregate extractions, and using English and French data from both sectors.

2. Material and methods

2.1. Material

Fisheries information was provided in the same format by IFREMER, the Institut Français pour la Recherche et l'Exploitation de la Mer (French fishing fleets) and CEFAS, the Centre for Environment, Fisheries and Aquaculture Science (English fishing fleets), for the periods 2006–2010 and 2005–2010, respectively. Fishing effort was made available from satellite-based data as hours fished, with a $3' \times 3'$ spatial resolution. Only those vessels larger than 15 m were included, because smaller vessels were not equipped with a Vessel Monitoring System (VMS) until 2012 (EC, 2009). Landings were obtained from fishers' EU mandatory logbooks for each fishing trip at the spatial resolution of an ICES (International Council for the Exploration of the Sea) rectangle [$1^\circ \times 30'$]. The fishing fleets were distinguished based on the gear used per trip. The most important French fleets, in terms of landings, were otter-trawlers (mainly rigged with an 80 mm mesh size), netters (mainly using 90 mm trammel nets), scallop dredgers and potters, while the most important English fleets were scallop dredgers, beam-trawlers (rigged with an 80 mm mesh size) and potters. Fig. 1a and b show the spatial fishing distribution of all French and UK vessels >15 m in the EEC.

Aggregate extraction in the EEC is limited to those areas where deposits of sufficient thickness (sandy gravels and gravelly sands) can be found on the seabed and where water depth does not exceed 50 m (Vanstaen et al., 2010; Desprez et al., 2014). Extraction intensity for all French and English aggregation extraction sites was collated from the different EEC aggregate extraction companies over the same period covered by fisheries data. The format of these data differed between French and English aggregate extraction companies. For the French aggregate extraction sites, the extraction intensity was made available as number of days dredged per month, and the volume of sand and gravel extracted was also made available. For the English aggregate extraction sites, the extraction intensity was provided as number of hours dredged per month. Extraction intensities were binned into $3' \times 3'$ squares (Fig. 1c). Five aggregate extraction sites were defined in the English Exclusive Economic Zone: UK01 (West of Isle of Wight), UK02 (South-East of Isle of Wight), UK03 (East of Isle of Wight), UK04 (Central EEC) and UK05 (South-East England), and these were treated as independent units for later analyses. Three French aggregate extraction sites were identified and treated independently in this study: FR01 (Baie de Seine), FR02 (Le Havre) and FR03 (Dieppe). The intensity of aggregate extraction varied without a trend in four sites (UK01, UK05, FR02 and FR03) and increased in two sites (UK04 and FR01) (Figs. 2–3). Experiments conducted in the sites of Baie de Seine (FR01) and Dieppe (FR03) showed that, in the extraction area, a substantial fraction of the original sandy-gravelly sediment was replaced by pebbles one year after extraction (Desprez et al., 2014). Desprez et al. (2014) also showed that fine sands were deposited in the close neighbourhood of the extraction area (<2 km).

The average fishing effort by fleet in the different aggregate extraction sites is shown in Table 1. We restricted the scope of the later analysis to the main fishing fleets operating in the different aggregate extraction sites (i.e., those fleets the fishing effort of which was, on average, higher than 0.5 h per year, per month, and per $3' \times 3'$ square). There was substantial fishing activity by English scallop dredgers, potters and French otter-trawlers at site UK01 (Fig. 2a,b). English scallop dredgers, French otter-trawlers and French scallop dredgers were the main fleets operating in UK04 (Fig. 2c,d). In aggregate extraction site UK05, English beam-trawlers, English potters and French otter-trawlers were the best represented (Fig. 2e,f). None of the English and French fleets under investigation had substantial fishing activity in sites UK02 and UK03 (not shown here, see Table 1). French otter-trawlers and French scallop dredgers were the main fleets operating around FR01 (Fig. 3a), whilst only French otter-trawlers had a substantial amount of fishing activity around FR03 (Fig. 3d). All French fleets (otter-trawlers, scallop dredgers, potters, netters) had substantial fishing activity around FR03 (Fig. 3b,c). The English fleets hardly operated in sites FR01, FR02 and FR03 (not shown here).

English beam-trawlers primarily landed sole and plaice, and also a quantity of cephalopods (*Loligo* spp. and *Sepia officinalis*) (Table 2). English and French scallop dredgers landed almost exclusively scallops (*Pecten maximus*). French otter-trawlers operate in a true mixed fishery, mainly landing in different quantities cephalopods, whiting (*Merlangius merlangus*), red mullet (*Mullus surmuletus*) and bass (*Dicentrarchus labrax*). Landing information from English and French potters, although more limited than for other fleets, indicated a clear targeting of whelk (*Buccinum undatum*) and substantial catches of cephalopods and crustaceans (edible crab - *Cancer pagurus* and European lobster - *Homarus gammarus*). Finally, French netters primarily landed sole, with a bycatch of cod (*Gadus morhua*).

2.2. Methods

An investigation was conducted to observe whether and to what extent fishing effort was modified in the areas impacted by