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Socio-economic, technological and environmental drivers of spatio-temporal changes in fishing pressure

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ABSTRACT

As part of an ecosystem based approach to fisheries management (EBFM), the heterogeneity of biological communities, key ecological processes and human uses must be understood. Although fishing effort distribution and marine habitat distribution and use are increasingly well understood, little research has quantified spatio-temporal changes in fishing effort or investigated drivers of these changes. Here, a holistic approach was taken to investigate socio-economic, environmental and technological drivers of change in fishing effort distribution of the Northumberland pot-fishery (2004–2014) using Bayesian Belief Network (BBN) analyses. BBNs were populated using large-scale high resolution spatial and temporal fisheries monitoring data, quantitative and qualitative interviews with fishers and expert opinion. Increases in fishing effort over time were explained by a combination of changes in fleet composition and fishers' behaviour. Increasing vessel and engine sizes, combined with an increased uptake of improved fishing technology have resulted in a greater ability for vessels to fish a greater number of pots. This increase in vessel and fishing capability has resulted in fishers' increased ability to fish in harsher weather conditions, as well as target specific areas or habitats quickly and opportunistically. Non-technological factors, such as declines in stocks of finfish and nephrops and the increasing operational costs of participating in these fisheries may have resulted in fishers solely fishing in the less regulated pot-fishery, targeting high value European lobster on a full-time basis. Increasing costs of pot-fishing in Northumberland coupled with stagnating crab and lobster landings prices may have resulted in increased fishing effort to maintain profitability.

1. Introduction

1.1. Background

Fishing provides an important socio-economic function in many parts of the world as a source of food and income [38,53]. Approaches to achieve sustainable management of fisheries have had mixed results but ecosystem-based fisheries management (EBFM) is considered best practice [34,56,61,7]. EBFM requires understanding of the heterogeneity of biological communities, key ecological processes such as population connectivity and interaction webs, as well as the heterogeneity in exploitation practices [19]. In many cases, EBFM requires spatial information [29]; knowledge of fisheries effort distribution and marine habitat usage [38] is a prerequisite for spatial fisheries management, for example, changes in spatial distribution of fishing effort must be taken into account for the interpretation of catch per unit effort (CPUE) trends [21,36,77].

Previous research describing fishing effort distribution and differential use of marine habitats exist [12,41,51,66,76], with the number of studies increasing with the development and use of vessel monitoring scheme (VMS) technologies [23,37,41,55] and surveillance methods [12,22,74]. Fishing spatial patterns can vary over time [39,51], although little research has quantified spatio-temporal changes in fishing effort [66,71] or investigated drivers of these [71]. Yet understanding such drivers is necessary for successful spatial management [19].

1.2. Drivers of fishing effort and distribution

Fishing effort and distribution are determined by fishers' behaviour within the constraints of the fishery and its management system [60]. The majority of spatial fisher behaviour studies are for temperate commercial fisheries [20], where appropriate data are routinely

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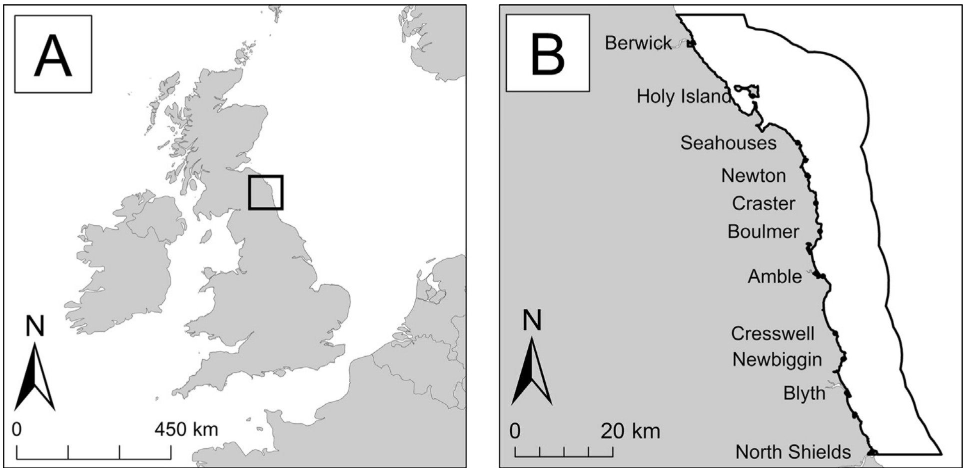

Fig. 1. Location of Northumberland inshore waters (NIFCA district) in Great Britain.

collected (see Branch et al. [11] for a review). Many of these data-rich economic modelling studies use a profit maximisation approach to study fisher behaviour [75], however, the underlying assumptions of this approach are debated since the heterogeneity of fisher behaviour is not always captured [60] (see Table A1 in Supplementary materials for further information). A qualitative approach may be more appropriate in order to understand the complexity and context-specific behaviour of fishers [20,60]. Several studies have used both quantitative and qualitative data to investigate drivers of fishing effort and distribution, concluding that a combination of socio-economic, environmental, technological and biological drivers can influence these [31,6,60,8]. For example, environmental drivers such as climatic conditions can affect the choice of fishing location [21] and fishing activity [16] (i.e. target species). Adverse weather conditions can stop fishers from fishing or restrict them to sheltered areas, for example, sheltered inshore reefs [72]. However, drivers of fishing often do not affect behaviour in isolation. The decision to fish in various climatic conditions may also be dependent on economic drivers such as fishers' technological resources (i.e. vessels size and capability) [20,79,80] and social drivers such as the degree of risk fishers are willing to operate in [24,64]. The importance of individual drivers of fishing behaviour may vary geographically because of differing target species, technological availability and fishers' social and cultural norms. Table A1 (Supplementary materials) summarises some of the current understanding of drivers affecting fishing behaviour and possible interactions among these in temperate climates.

Multidisciplinary studies have examined the influence of multiple drivers on fisher behaviour [5,6,18,30,45,59,78] but we are aware of no studies that aim to understand how drivers of fisher behaviour change over time and the subsequent impacts on fishing effort and distribution. The large multidisciplinary data sets required and the different scales and formats in which these data are collected make modelling multiple drivers of fisher behaviour challenging [21,6,78].

BBNs are a flexible modelling tool that can combine causal expert knowledge and empirical evidence-based data [49] to challenge assumptions and investigate scenarios. Differently from null-hypothesis testing, BBNs address a problem in a systemic way, addressing the net changes in the outcome (i.e. the variable) of interest, rather than arbitrary levels of statistical significance (i.e. there is no test of statistical significance). Importantly, BBNs (and other decision-theoretic approaches) explicitly (and mathematically) incorporate uncertainty, which highly characterizes the data used to underpin the decisions on natural resources. BBNs are graphical representations of a network of variables (whereby related variables are joined by an arc, or arrow), and of a set of conditional probabilities (where the state of a variable is conditional on the states of *n* others) [10]. The graphical nature of these models conveys complex information in an intuitive manner that is easily interpreted by non-technical managers [14,17,9]. Thus these modelling tools can be used to effectively bridge the gap between scientific investigation and management implementation [17,26]. BBNs have successfully been used for a range of natural resource management problems [42,46,47,52,58] and they are increasingly used to investigate spatial processes, e.g. marine spatial planning [49,65,67], fisheries habitat suitability [26] and mapping ecosystem services trade-offs [28].

This study investigates socio-economic, environmental and technological drivers of change in inshore pot-fishing effort distribution in Northumberland, UK. Declines in stocks of finfish may have resulted in increasing pot-fishing in the UK [3,48,70,73] yet little is known about spatio-temporal patterns in potting effort and associated drivers [71]. The lobster fishery in Maine has evolved over time due to fishers' responses to market forces [68], informal rules amongst fishers [13,3], lobster population responses to changes in oceanographic conditions [32,35,69,81] and to harvesting practices within the fishery [13,2,3]. Fishers in the UK are likely to adapt and evolve their practices in response to similar ecological and behavioural drivers [74] but to improve decision making, context specific drivers must be understood.

The present study site in Northumberland was selected because of the availability of large-scale high-resolution spatial and temporal multidisciplinary data sets (see Methods). There has been significant change in fishing effort and spatial distribution between 2004 and 2014 [71]. Here the unique combination of these temporal fisheries effort distribution data with fishers' local ecological knowledge in a BBN analysis allowed identification of the relative importance of different drivers. We contextualise the socio-ecological results of the BBN using fisher interview data, and highlight often-overlooked social and technological drivers of fishing effort distribution.

2. Methods

2.1. Description of case study area

The waters of the Northumberland Inshore Fisheries & Conservation Authority (NIFCA) extend 6 nautical miles (NM) offshore, from the River Tyne in the South to the Scottish border in the North (Fig. 1). The fishery is mixed [27], largely operating close to shore (< 6NM) and primarily composed of < 10 m fishing vessels n = 70 ± 9% between 2003 and 2014; [71]. The majority of Northumberland fishers target crustaceans: European lobster (*Homarus gammarus*), edible crab (*Cancer pagurus*) and to a lesser extent, velvet crab (*Necora puber*), using baited pots (which are also referred to as traps). Only the pot-fishery was investigated in this study.

Pot-fishing effort and distribution vary seasonally in Northumberland – primarily due to changes in weather as well as