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Combining area closures with catch regulations in fisheries with spatio-temporal variation: Bio-economic implications for the North Sea saithe fishery

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ABSTRACT

Although there exists an EU-Norway long-term management plan for North Sea saithe, including a catch regulation, the spawning stock biomass has declined in the last few years, recruitment has been below average since 2006 and growth rates are low. Moreover, catch rates used as a proxy of stock abundance in stock assessment, are believed to decline much more slowly than the actual stock abundance. Thus, a quota-based system may not be sufficient to sustain the stock. A bio-economic simulation and optimisation model was used to explore how various area closures in combination with the quota-system affect levels of by-catch, net profit of individual fleet segments from different ports, and stock development in that fishery. Tested area closures differed in duration, size and location relative to major ports and to seasonal movement patterns of species. These closures were tested under variable recruitment. Area closures that were covering the seasonal migration route of saithe revealed almost two times greater increases in spawning stock biomass than closures that were not covering the migration route. Even area closures where a high dispersal rate of individuals was assumed resulted in increased spawning stock biomass of saithe. Benefits of the tested area closures were distributed heterogeneously among individual fleet segments. Increases of saithe stock size were offset by increases in cod by-catch. The location of an area closure relative to the home port of fleet segments decided if steaming costs increased and catches decreased.

1. Introduction

Saithe (*Pollachius virens*) is of major economic importance for North Sea fisheries, with annual landings values of around 15 million Euros [1]. It is targeted by Norwegian, French, German, English, Danish, and to a small extend Swedish trawlers [2]. There exists an EU-Norway long-term management plan for North Sea saithe. This plan involves a Harvest Control Rule (HCR) with annual Total Allowable Catches (TACs), and reference points. B_{lim} is the reference point for SSB, below which there is a high probability that recruitment is impaired [3,4]. B_{pa} is the precautionary reference point for SSB, below which the stock would be regarded as potentially overfished [3,4]. F_{tar} is the average fishing mortality for age class 3–6 that is set as a target [3,4]. In the long-term management plan for North Sea saithe F_{tar} is set to 0.1 ($F_{tar-low}$), when SSB is estimated to be below the minimum level of 106,000 t (B_{lim}) [5]. Usually the fishing mortality is ~0.4, therefore a F_{tar} of 0.1 is a large reduction to allow SSB to recover. Where SSB is above 200,000 t (B_{pa}), the parties agreed to restrict fishing on the basis of a TAC consistent with a target fishing mortality of 0.3 (F_{tar-up}) [5]. When SSB is estimated to be between B_{pa} and B_{lim} the target fishing mortality rate ($F_{tar-mid}$) is calculated as:

$$F_{tar-mid} = F_{tar-up} - (F_{tar-up} - F_{tar-low}) \times \frac{(B_{pa} - SSB)}{(B_{pa} - B_{lim})} \quad (1)$$

Although, there exists a long-term management plan, spawning stock biomass (SSB) of saithe has declined in the last few years and is currently close to B_{pa} [2]. Besides the declining SSB values, recruitment of saithe has been below average since 2006 [2]. Together with the lower growth rates [2], it indicates a decline in stock productivity. Moreover, there are raising concerns about a potential hyperstability [2], which describes the process when catch rates, which are used as a proxy of stock abundance in stock

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assessment, decline much more slowly than the actual stock abundance [6]. This questions the sustainability of the current management plan for North Sea saithe [7]. Especially, the uncertainty and bias in the estimates of biomass can lead to serious errors in setting excessive quotas, which in turn can result in overexploitation [8,9]. One well-known example for the fatal consequences of hyperstability is Canada's Atlantic groundfish fishery [10], which resulted in the collapse of the stock. In many cases, these uncertainties are serious enough that a single enforcement system, such as a quota-based system, is not enough to ensure a sustainable fishery. Combinations of management measures may therefore provide a mean of buffering against uncertainty and protecting the fish stock in the long-term.

Area closures or Marine Protected Areas (MPAs) have received considerable attention as possible means of replacing or enhancing other management measures to control the utilisation of marine resources. An area closure could provide an insurance against management failures resulting from insufficient knowledge and understanding of the fishery system being managed [11–15]. An area closure may enable the maintenance of significantly higher levels of SSB [16], but it is less certain whether the increase in SSB and its composition within the area closure can provide a net increase to the fishery outside the reserve. From the fishing industry perspective, it may not be enough that a closure increases harvest outside the closure, but rather that the increase will be large enough to compensate for the area removed from fishing. It is important to consider how interactions of humans and biological systems influence the results of alternative area closures [17]. Therefore, it is critical to incorporate integrated and explicitly spatial interactions of the biological and economic component in a fishery system to evaluate if a spatial management policy will work. In particular, it is necessary to understand how the economic response of fishermen in redistributing their fishing effort after closures will impact fish in other areas and the overall productivity of the fishery.

In the present study both economic and biological consequences of imposing various area closures on top of an existing fisheries management system that limits catches by setting annual TACs were explored. As a part of this study it was investigated how interactions of fleet segments and fish stocks influence the results of alternative area closures. A bio-economic simulation and optimisation model was used to explore how area closures in combination with catch regulations might affect by-catch of cod, net profits, and the spawning stock biomass of saithe. Area closures were tested under variable levels of recruitment. The simulations of area closures of different duration, size and location relative to major ports and its orientation relative to seasonal movement patterns of fish stocks were run and their effectiveness and the distribution of benefits across fleet segments from different ports analysed.

2. Material and methods

2.1. Model settings

The North Sea and Skagerrak were subdivided by the grid of ICES rectangles (30×30 nm²) (Fig. 1). All ICES rectangles of the North Sea and Skagerrak were included in the model, but to highlight the main results a focus was laid on four zones (Fig. 1).

The model accounted for four fleet segments with North Sea saithe as main target and cod as a by-catch species, covering vessels from Denmark, England, France and Germany (see main home ports Fig. 2). According to the Data Collection Framework (DCF) fleet

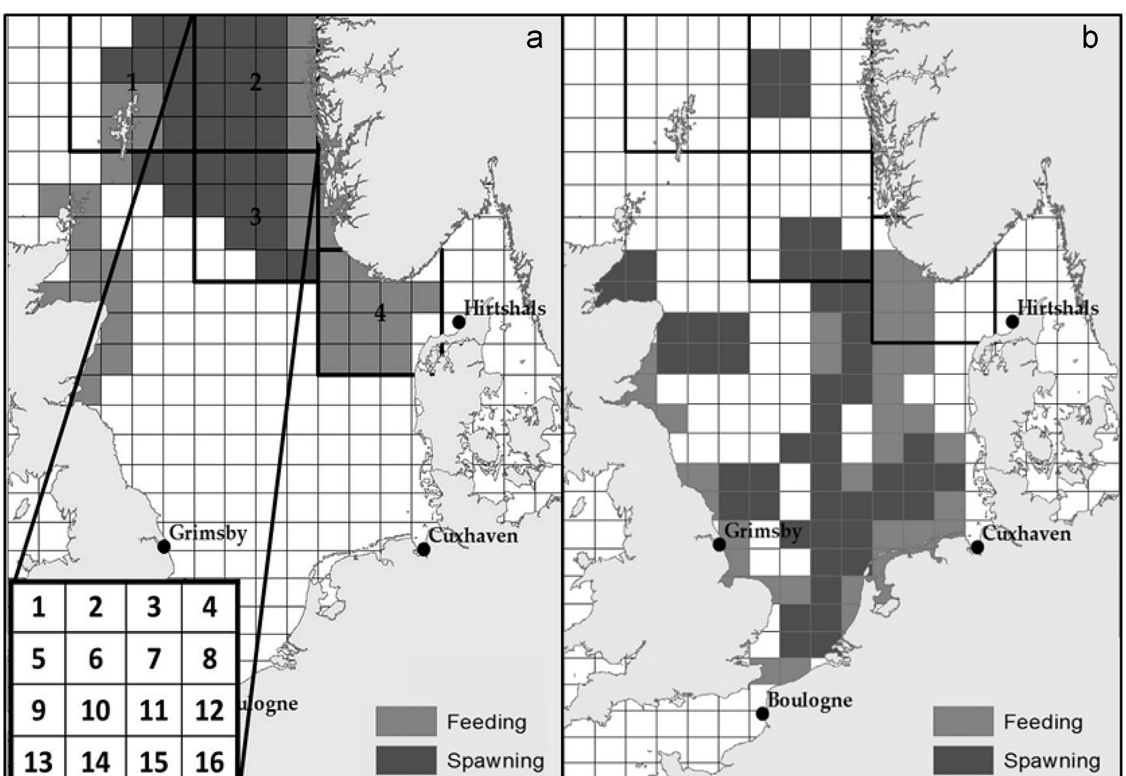

Fig. 1. The spatial layout for simulations of the North Sea saithe fishery. The North Sea is subdivided by the grid of ICES rectangles with a focus on four zones. Zone 2 is zoomed out and the individual ICES rectangles are numbered to explain individual area closures. Main home port for the Danish (Hirtshals), English (Grimsby), French (Boulogne) and German (Cuxhaven) fleet segment are shown. Feeding (grey) and spawning grounds (black) of North Sea saithe (a) and North Sea cod (b) are shown.