VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors

SP1 - Cooperation

Collaborative Project - Large-scale Integrating Project

FP7 – OCEAN - 2010

Project Number: 266445

Deliverable No: D.2.3.1		Workpackage: WP 2.3	
Date:	31.1.2014	Contract delivery due date	Month 36
Title:	Mechanisms of change in human behaviour		
Lead Partner for Deliverable	IFREMER		
Author(s):	Paul Marchal (IFREMER), Helen Bartelings (DLO-LEI), François Bastardie (DTU-Aqua), Jurgen Batsleer (DLO-IMARES), Alyne Delaney (IFM-AAU), Raphaël Girardin (IFREMER), Pierre Gloaguen (IFREMER), Katell Hamon (VTI-SF), Ellen Hoefnagel (DLO-LEI), Charlène Jouanneau (IFM-AAU), Stéphanie Mahévas (IFREMER), Rasmus Nielsen (DTU-Aqua), Joanna Piwowarczyk (IOPAS), Jan-Jaap Poos (DTU-Aqua), Torsten Schulze (VTI-SF), Etienne Rivot (AGRO), Sarah Simons (VTI-SF), Alex Tidd (CEFAS), Youen Vermard (IFREMER), Mathieu Woillez (IFREMER).		
Dissemination level (PU=public, RE=restricted, CO=confidential)			PU
Report Status (DR = Draft, FI = FINAL)			FI

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. [266445] for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS)

VECTORS Overview

'VECTORS seeks to develop integrated, multidisciplinary research-based understanding that will contribute the information and knowledge required for addressing forthcoming requirements, policies and regulations across multiple sectors.'

Marine life makes a substantial contribution to the economy and society of Europe. In reflection of this VECTORS is a substantial integrated EU funded project of 38 partner institutes and a budget of €16.33 million. It aims to elucidate the drivers, pressures and vectors that cause change in marine life, the mechanisms by which they do so, the impacts that they have on ecosystem structures and functioning, and on the economics of associated marine sectors and society. VECTORS will particularly focus on causes and consequences of invasive alien species, outbreak forming species, and changes in fish distribution and productivity. New and existing knowledge and insight will be synthesized and integrated to project changes in marine life, ecosystems and economies under future scenarios for adaptation and mitigation in the light of new technologies, fishing strategies and policy needs. VECTORS will evaluate current forms and mechanisms of marine governance in relation to the vectors of change. Based on its findings, VECTORS will provide solutions and tools for relevant stakeholders and policymakers, to be available for use during the lifetime of the project.

The project will address a complex array of interests comprising areas of concern for marine life, biodiversity, sectoral interests, regional seas, and academic disciplines and especially the interests of stakeholders. VECTORS will ensure that the links and interactions between all these areas of interest are explored, explained, modeled and communicated effectively to the relevant stakeholders. The VECTORS consortium is extremely experienced and genuinely multidisciplinary. It includes a mixture of natural scientists with knowledge of socio-economic aspects, and social scientists (environmental economists, policy and governance analysts and environmental law specialists) with interests in natural system functioning. VECTORS is therefore fully equipped to deliver the integrated interdisciplinary research required to achieve its objectives with maximal impact in the arenas of science, policy, management and society.

www.marine-vectors.eu

Executive Summary

The scope of this report is to present the science developed within the VECTORS project to improve the understanding of the key processes driving the behaviour of human agents utilising a variety of EU maritime domains. While particular attention has been paid to the spatial interactions between fishing activities and other human uses (e.g., maritime traffic, offshore wind parks, aggregate extractions), the behaviour of non-fishing sectors of activity has also been considered. Various quantitative and semi-qualitative approaches have been pursued to gain better insight into behavioural drivers based on past data, and also forecast how human agents would react if access was constrained by either management (e.g. Marine Protected Areas – MPA), or the installation of a new operator. This report covers the North Sea and Eastern Channel, and also one area of the Baltic Sea: the Gdansk Bay.

Fine-scale catch and effort data by fishing vessel, fishing trip, gear used and ICES rectangle visited have been made available for the French, Dutch, English and German fleets. The VECTORS WP2.3 team has also collected data from the non-fishing sectors of activity, in particular, aggregate extractions and maritime traffic. The objective of collecting data for non-fishing sectors is to produce a Spatial Overlap Metric measuring the constraint exerted by other sectors of activity on fishing. Comprehensive aggregate extraction and shipping intensity metrics could then be derived dynamically at a fine spatial and temporal resolution. For the other sectors potentially competing for space with fishing (e.g., wind farms, oil/gas extractions, aquaculture), and also for protected areas, a static overlap metric has been set to the surface occupied by the plant or area protected. In order to apply common methodologies and codes across different case studies, whilst abiding by confidentiality issues around these data, it has been decided to develop a common exchange format to collate the data used in subsequent analyses; five tables have then been produced.

Two complementary types of approaches have been carried out to analyse and/or model the mechanisms of human behaviour, which are hereby referred to as quantitative and qualitative research. Quantitative research consisted of analysing fishing decision-making processes based on existing data and then making forecasts building on scenarios, while qualitative research consisted of interviewing stakeholders from different sectors of activity to get their views on both their past and likely future behaviour. Different methodological approaches have been pursued by different institutes, and these were applied to several case studies wherever possible.

Modelling the current and past dynamics of fishing vessels

The understanding of the dynamics of fishing vessels is of great interest to define sustainable fishing strategies and to characterize the spatial distribution of the fishing effort. It is also a prerequisite to anticipate changes in fishermen's strategy in reaction to management rules, the economic context or the evolution of exploited resources.

In this context, analysis of individual vessel's trajectories offers promising perspectives to describe behaviour during fishing trips. A hidden Markov model with two behavioural states (steaming and fishing) was developed to infer the sequence of non-observed fishing vessel behaviour along the vessels' trajectory based on GPS records. Conditionally to the behaviour, vessels movements were modelled by a discrete time solution of a (continuous time) stochastic differential equation on vectorial speeds. The model's parameters and the sequence of hidden behavioural states were estimated using an Expectation-Maximization algorithm, coupled with the Viterbi algorithm that captures the most credible joint sequence of hidden states. A simulation approach was performed, that outlined the importance of contrast between the model's parameters as well as the influence of path length to allow good estimation performances. The model was then fitted to four original GPS tracks recorded with a time step of 15 minutes derived from voluntary fishing vessels operating in the Channel within the IFREMER's RECOPESCA project. Results showed differences in parameter estimation depending on the gear used, on both the speeds during fishing operations and the Markovian transitions between behaviours. Results also suggested the benefits of future inclusion of variables such as tidal currents within the ecosystem approach of fisheries.

Hidden Markov models are well suited to describe jointly fishing boat movement and associated fishing activities. They allow us to estimate the sequence of activities (i.e. fishing, travelling) along a trajectory, as well as the movement parameters (speed, turning angle) associated with each activity. Normally, these models are developed to characterize the spatial dynamics of fishing vessels that belong to a specific fishery with a given métier. However, because of the large variability that exists in fishing practices, some

adaptations in the modelling structure are needed when the spatial dynamics of one or several fishing fleets present a mixture of métiers with distinct traits of movement and trajectory. A procedure was developed to capture the variability of fishing practices and associated vessel trajectories. Fishing trips were characterized by their métiers, which were identified for each gear by clustering landing profiles (in value). Fishing boat trajectories were described using movement parameters (speed, acceleration, turning angles, straightness) estimated from GPS positions recorded along the tracks. A principal component analysis was performed to provide a detailed description of the different trajectory patterns in relation with fishing trip specificities (i.e. vessel, gear, métier). Hidden Markov models were then fitted for some selected fishing trips. Two types of models were considered. The basic one was a 2 states model with behavioural activities corresponding to fishing and traveling. The second one presented a number of fishing states depending on the number of métiers identified for the trip. Fitting performance was compared based on DIC and estimated confidence intervals for the parameters. This procedure was applied to a set of volunteer vessels participating in the RECOPESCA project from IFREMER in the Bay of Biscay and the English Channel for years 2011-2012. We show that fishing trip activities, such as métiers, were structuring variables for trajectories, which helped to specify properly hidden Markov models.

Discrete choice models building in a random utility function (RUMs) have also been used to aid understanding and modelling of fleet dynamics and to anticipate how fishing effort is re-allocated following any permanent or seasonal closure of fishing grounds, given the competition for space with other active maritime sectors.

A first Random Utility Model (RUM) was developed and initially applied to determine how fishing effort is allocated spatially and temporally by the French demersal mixed fleet fishing in the Eastern English Channel. The spatial resolution of this investigation was that of an ICES rectangle (30' x 60'). The explanatory variables chosen were past effort i.e. experience or habit, previous catch to represent previous success, % of area occupied by spatial regulation, and by other competing maritime sectors. Results showed that fishers tended to adhere to past annual fishing practices, except for the fleet targeting molluscs which exhibited within year behaviour influenced by seasonality. Furthermore, results indicated generally that maritime traffic may impact negatively on fishing decision. Finally, the model was validated by comparing predicted re-allocation of effort against observed effort, for which there was a close correlation. The method was also applied to the Dutch beam trawl fleet (2008-2010). The Dutch fleets' activity was well captured by the model which included only biological and economic drivers. Predictions were accurate and followed the seasonal patterns well. To predict the long term changes in fishing activity additional factors, such as the competition for space with other marine users, should be included and changes in fish distribution should be linked to the current model.

A second Random Utility Model (RUM) was developed using a finer spatial resolution (15' x 15') and initially applied to analyse the determinants of English and Welsh scallop-dredging fleet behaviour, including competing sectors operating in the eastern English Channel. Results show that aggregate activity, maritime traffic, expected costs, English inshore 6 and French sovereign 12 mile nautical limits negatively impact the choice of fishers, and conversely that past success, expected revenues and fishing within the 12 nautical mile limit have a positive effect on their utility. The model has potential application for Marine Spatial Planning (MSP). This RUM was also used to evaluate the interactions of fishing effort allocation and shipping for the Dutch demersal fleet fishing in the English Channel, this analysis of the French and UK fleets was also undertaken for Dutch seiners operating in the Eastern Channel. The parameters associated with the gross revenue all had positive parameter estimates for the means, as is expected from fishers seeking to maximise net revenues. The parameters associated with costs were also positive, which is striking, given that one would expect a cost minimization. The positive estimates could be caused by the trips to Dutch harbours that are in the data set. The closed area parameters are both negative, reflecting the fact that fishing is not allowed in these areas. The parameters associated with the shipping lanes had negative estimates, as in the French and English case, but these estimates did not differ significantly from zero.

Other spatially-explicit statistical analyses have been conducted to evaluate, separately, the impacts of aggregate extraction and maritime traffic.

In terms of marine aggregate extractions, the effects were investigated of both aggregate extraction intensity and the proximity to dredging sites on the distribution of fishing effort, for a broad selection of French and

English demersal fleets operating in the Eastern Channel. The most striking result was that for most of the fishing fleets and aggregate extraction sites, neither dredging intensity, nor the proximity to the extraction site, had a deterring effect on fishing activities. To the contrary, the fishing effort of dredgers and potters could be larger in the vicinity of marine aggregates sites than in their neighbourhood and also positively correlated to extraction intensity with a lag of 0 to 6 months. The fishing effort distribution of French netters was overall space-invariant over the whole time period under investigation. However, it is important to note that the fishing effort of netters has increased substantially in the impacted area of the Dieppe site (where it is correlated to dredging intensity with a lag of 6 months), whilst remaining almost constant in the intermediate and reference areas. The attraction of fishing fleets is likely due to a local and temporary concentration of their main target species. However, knowledge on the vulnerability and life-history characteristics of these species to aggregate extractions suggests that over-extending the licensed areas would be detrimental to them and to their related fisheries in the longer term.

In relation to maritime traffic, we investigated whether fishermen's effort and catch information could be used to inform on species distributions and if the observed effort (and catches) could be constrained by other activities, such as maritime traffic. In this first attempt to correlate fish distribution observed during a scientific survey and fishing catches via linkage of VMS and logbooks data there was a good correlation between the observed biomass in October by a scientific survey and fishing location targeting the different demersal species in the Eastern Channel. Fleets seem attracted by areas identified to have high abundance densities. For most of the species, maritime traffic seems to be a perturbation for the fishing activities. However, in the case of the red mullet fishery, vessels seem to avoid traffic lanes except when they expect high fish densities. They then may take the risk of fishing inside the traffic lanes or in areas of high marine traffic densities.

Eliciting the perspectives of fishers

To validate the outcomes of fleet dynamics models a survey was undertaken of French and Dutch fishers operating in the Eastern Channel and in the German Bight. In the Eastern Channel, French fishers did not feel constrained in the amount of space they had available for fishing. The one who did, cited Natura2000 and shipping lanes as constraining factors, and said this directly influenced his fishing patterns. Four agreed that they conflicted at times with other fishers (all Dutch purse seiners) over space while one mentioned conflicts with coast guards. One also cited aggregate extraction (when completed) as resulting in no fishing anymore in that area. In the German Bight, Dutch fishers considered that their fishing ground in the German Bight shrank in the past 10 years. They have to fish more intensively now on less available fishing grounds. They have to face sometimes unsafe situations near oil rigs and wind farms. Finally, fishers do not think they have any influence on the increase of competition for space but would like to have more. Closed areas (including real time closures), wind farms and Natura 2000 areas have restricted their activities spatially as well as, to a lesser degree, oil rigs, shipping, and mussel cultures. -German Bight Dutch fishers earn less and catch less targeted species. They have to adapt their fishing pattern. It is crowded now and less safe. Fishers expect more large-area restrictions of a permanent character in the near future in the German Bight but will continue fishing since they feel they have no choice.

Interviews were also conducted with representatives of the main sectors of activity (including fishing but also non-fishing sectors) in the Eastern Channel, the Dogger Bank and the Gdansk Bay. The pressure on spatial usage of European regional seas by various stakeholder groups is intense. In all case study sites, the majority of stakeholders feel this pressure will only increase in the future, primarily due to proposals and plans for offshore wind farms, the newest entrants to these busy seas. In some case study areas, such as the eastern English Channel and Dogger Bank, applications have already been approved with construction planned; in the German Bight wind farms already exist and at least in the Dutch part new proposals have been made[1]. In others, such as the Gulf of Gdansk, such developments are further away, and unlikely to happen soon due to legal constraints, yet the uncertainty of impacts, such as on fishing, is a cause of great concern. Of all the stakeholder groups, the fisheries group was the only one addressed by all surveys and thus can be compared across all case study areas: eastern English Channel, the Dogger Bank, the German Bight, and the Gulf of Gdansk. Fishing is one of the oldest activities in all four of the case study areas and though fishers in each area tend to use different gears

[1] There are, of course, many wind farms throughout the North Sea; there are simply none operational yet in the case study area of the Dogger Bank.

and face different pressures, there are a number of similarities among them. These pressures include: regulatory pressures, competition with other users, and area restrictions.

Modelling the future dynamics of fishing vessels

Having analysed the key determinants of fishers' and other stakeholders' decision-making behaviour, the future effects of increased resource-based competition (resulting from a discard ban combined with restrictive individual fish quotas) or of new area-based constraints (e.g., implementation of new wind farms or enforcement of new legally-binding closed areas) were evaluated in the short- and/or the long-term using bio-economic models.

The short-term economic effect of implementing wind farms in combination with closed areas was studied in the North Sea using an Individual Stress Level Analysis (ISLA). In this study we used the spatial data of the Vessel Monitoring System (VMS) coupled with logbooks to assess the stress potentially caused by closure of fishing areas. The stress was expressed in financial terms as the percentage of current revenue obtained from catch coming from areas to be closed. It is therefore not a loss but more a measure of the level of reallocation of fishing needed to maintain the current revenue.

We used the A2 ("National enterprise" scenario) and B1 ("Global community scenario") VECTORS scenarios to design potential closures due to wind farms, nature conservation areas and maritime traffic in the North Sea and we calculated the stress caused by the closures on the Dutch and German 2010 fishing fleets. The scenarios investigated envisage large closures leading to stress levels of 7 to 15% for the Dutch fleet and 3 to 5% for the German fleet. Almost all of the Dutch vessels would be impacted by the closures (more than 90% of vessels in both cases) while the German fleet would be slightly less impacted (around 55% of vessels impacted for A2 and 65% for B1). All Dutch harbours would have seriously impacted vessels (>15% of revenue) for both scenarios, although the proportion of those vessels would be higher in B1 scenario, especially in the southern harbours. The German harbours would be less impacted with only Büssum showing hosting impacted vessels.

We then examined the longer-term effects of fishers competing for resources and/or space. First, we explored the potential effects of a discard ban in mixed fisheries management using the French mixed fisheries in the Eastern English Channel as a model system (DSVM IBM model). The model evaluates a time series of decisions taken by fishers to maximize profits within management constraints. Compliance to management was tested by applying a tax for exceeding the quota, which was varied in the study. We then evaluated the consequences of individual cod quota in both scenarios, with respect to over-quota discarding, spatial and temporal effort allocation and switching between métiers. Individual quota management without a discard ban hardly influenced fishers' behaviour, as they could fully utilize cod quota and continue fishing other species while discarding cod. In contrast, a discard ban forced fishers to reallocate effort to areas and weeks where cod catch is low, at the expense of lower revenue. In general, a restrictive policy for individual quota for cod needs to be combined with a discard ban and a high tax to reduce over-quota discarding.

Second, we evaluated the long-term bio-economic effects of a closed area, using the FISHRENT model, for a variety of scenarios. Regulations and changes in market and environmental conditions may change the profitability of one fishery and can lead to reallocation of fishing effort. The extent of this effort displacement will depend on the relative profitability of the alternative options for the fleet segments affected. When fishing areas and fleet segments are heterogeneous, simple aggregate effort models such as those based on the ideal free distribution theory may provide inaccurate predictions. A bio-economic optimization and simulation model was applied to explore how the different conditions of A2 ("National enterprise" scenario) and B1 ("Global community scenario") could impact the fishing effort allocation and the distribution of benefits across fleet segments from different nations. In the model the optimization of net profits determines the effort adjustment and the investment behaviour of fleet segments, which in turn affects the level of catch rates. This tool was applied to the North Sea saithe fishery. For B1 and A2 there was a spatial heterogeneity of the fishing effort observed with shifting effort through the year. As profit was maximized, effort aggregated in those areas where the costs of fishing (e.g. fuel cost) were low. The simulations demonstrate that A2 and B1 will have heterogeneous impacts on individual fleet segments from different nations and home ports. Even when A2 or B1 did result in little change in overall net profits, there were winners and losers, and the distribution of gains and losses may not be intuitively obvious.

FISHRENT was also applied to the Dutch flatfish fisheries using the A2 and B1 scenarios. The same closure scenarios were used as the ones for the individual stress level analysis taking into account wind farms, marine protected areas and shipping closures. In addition, the fuel price and fish prices were increased to match the trend of the A2 and B1 scenarios for 2010-20130. The projections showed that the effects on the fleets were strongly linked to their fuel consumption. The profit of the large beam trawlers that are very dependent on fuel prices decreased because the closures forced them to fish further out to sea.

Finally, an individual-based model (IBM) evaluating the bio-economic efficiency of fishing vessel movements from recent, high spatial resolution fishery data (DISPLACE) was further developed to incorporate the underlying size-based dynamics of the targeted stocks for Danish and German vessels harvesting the North Sea and Baltic Sea fish stocks. The stochastic fishing process is specific to the vessel catching power and proportional to the encountered population abundances, based on disaggregated research survey data. The impact of the fishing effort displacement on the fish stocks and the vessels' economic consequences were evaluated by simulating individual choices of vessel speed, fishing grounds, and ports. All scenarios led to increased energy efficiency, except for the fishing closures due to increased travel distance. On an individual scale, the simulations led to gains and losses due to either the interactions between vessels or to the alteration of individual patterns. We demonstrate that integrating the spatial activity of vessels and fish abundance dynamics allow for more realistic predictions of fishermen behaviour, profits, and stock abundance.

Synthesis of results

The main objectives of the research carried out in the WP2.3 work package were, 1) to identify and quantify the key drivers of fishers' behaviour interacting with other fleets and other sectors of activity operating in the same maritime domain and also, (2) to forecast fishing effort allocation in response to additional spatial or resource-based constraints due to the implementation of a new sector of activity, closed areas, or other management measures.

Models developed and refined in VECTORS indicated that traditions (reflected by past effort allocation) and economic opportunism are driving factors for effort allocation in both the Eastern Channel and the North Sea for the French, English and Dutch fleets investigated, which supported the findings of previous studies applied to other fisheries worldwide. Economics and tradition were still more important in driving effort allocation than spatial interactions/competitions with other fishing fleets, maritime traffic, aggregate extractions, wind farms and closed areas. These model results were largely confirmed by French and Dutch stakeholders interviewed in the English Channel and German Bight respectively.

Fishers interact with other fishers but the nature of the interaction (positive or negative) depends on the metier used. In the Eastern Channel maritime traffic adversely influenced English dredgers. Spatial distribution of Dutch fly-shooters did not appear to be substantially affected by maritime traffic. Many, but not all, of the French fleets under investigation tended to avoid shipping lanes except when stock density was high. In the Eastern Channel and German Bight maritime traffic has been a constraint for fishing activities, but is less so nowadays due to the decrease in the number of trawlers. In other regions (Dogger Bank, Gdansk Bay), maritime traffic did not appear as an important issue to interviewed fishers.

At a broad spatial scale, over the whole Eastern Channel, aggregate extraction restricts English scallop dredgers. However at a more localized level (i.e., for each aggregate extraction site), and for a wider range of English and French fleets, the interactions between aggregate extractions and fishing activities are of a more complex nature. Some fleets (e.g., potters targeting whelks and large crustaceans, netters targeting sole, and even scallop dredgers), were attracted to the vicinity of aggregate extraction sites.

Fishers' interviews indicated that wind farms were seen as a concern in the Eastern Channel, the German Bight and the Gdansk Bay, but less so in the Dogger Bank. Oil and gas platforms are already operating in the North Sea, and these are considered as an issue by some fishers operating in this region.

In some areas, competing stakeholders have found ways to work together for integrated spatial management, such as in the English Channel and the Dogger Bank, in others such as the Gulf of Gdansk, they are just learning to work together. Some stakeholders come together to push for similar aims, alliances can take place even between traditional "competitors." In the English Channel, groups in general seem to compromise and come together, despite differences. The conservationist mandate has been strengthened in recent years, but is being tempered by the UK government's vision for "clean, healthy, safe, productive, and biologically diverse oceans and seas;" consequently pragmatism and compromise is automatically built-in to the system. The UK has also formed statutory bodies whose role is to liaise with industry to help minimize impacts on the environment. In contrast, on the Dogger Bank and in the Gulf of Gdansk, conservationists and other groups appear less willing to compromise, making integrated management much more challenging. In the Dutch situation most consultations are with other federal agencies, major marine industry sectors, and public review of plan documents. The Dutch respondents however don't think they have any influence on these developments.

A range of forecast models with different structures were applied to predict the bioeconomic impact on fishing fleets of (quota-induced) resource competition combined with discard restrictions and of area-based restrictions (inferred by other fleets, other sectors of activity, and/or closed areas) in the short-term and the medium-term These forecast models can be ranked by increased complexity, which also provides indications on how these should be understood and/or used by marine managers. Simple models provide short-term forecast based on historical data only. They could be used by managers to quickly anticipate the stress fishers may experience in the short term as a result of the installation of a new plant overlapping with their fishing ground (e.g., oil rig, wind farm) or the enforcement of a new closed area. However, they cannot be used by mangers to predict the effects on fishing effort spatial displacement or the knock-on pressure exerted on marine ecosystem (and on commercial species in particular). More complex models explicitly build in fleet dynamics in the form of effort allocation but do not build in the dynamics of fish populations. These could be used by managers to evaluate the impact of catch quotas combined with a discard ban or area-based restrictions on fishing effort allocation one year ahead. The most complex of the models investigated account for the dynamics of fishing fleets, fish population, and economics. They could be applied to evaluate the impact of area-based restrictions, in combination with conservation management measures (e.g., catch or effort quotas), on the conservation and economic utilization of fisheries resources in support of marine planning at a fine resolution or to evaluate the impact of economic incentives and right-based management (e.g., Individual Transferable Quotas).

Contents

1 Introduction

Human use of maritime domains is increasing and diversifying. The current and emerging pressures are multiple and interacting including impact from exploitation of living and mineral resources, maritime transport, renewable and non-renewable energy production in a context of climate change. Because managing ecosystems is first managing people (Leslie and McLeod 2007), a key issue for ocean managers is then 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, sea resources were managed on a mono-sectorial basis in most countries worldwide. However, it has become evident that increasing competition for marine space and the cumulative impact of human activities on marine ecosystems requires a more collaborative and integrated approach to management, across the different sectors of activity. This has led many countries worldwide to develop ocean policies aiming at managing human activities that can impact their maritime domain in a cross-sectorial fashion, an approach now referred to as ecosystem-based management (EBM). In the EU, the move towards ecosystem-based management has been materialized by the European Commissions' Marine Strategy Framework Directive - MSFD (EC 2007, EC 2008a), and proposals for effective implementation of Marine Spatial Planning (MSP). The MSFD includes a cross-sectorial framework for Community action to achieve good environmental status of the marine environment in a context of sustainable development, while MSP provides a spatially-explicit management instrument to both enforce ecosystems 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 and MSP. Providing integrated, ecosystem-based advice requires overcoming several research challenges. One of the important challenges for research scientists is to understand spatial interactions between human agents belonging to different sectors of activity, and subsequently to anticipate how human activities could be redirected following various forms of area restrictions, and also how this reallocation could affect the human pressure actually exerted on newly occupied ecosystem compartments. Of particular importance is the issue of how fishers would reallocate their fishing effort if access to their traditional fishing grounds was restricted by either management (e.g. Marine Protected Area – MPA), or the installation of a new sector of activity, and also the extent to which the pressure they exert on marine ecosystems would then be modified.

The scope of this report is to present the science developed within the VECTORS project to improve the understanding of the key processes driving the behaviour of human agents utilising a variety of EU maritime domains. While particular attention has been paid to the spatial interactions between fishing activities and other human uses (e.g., maritime traffic, offshore wind turbine arrays, aggregate extractions), the behaviour of non-fishing sectors of activity has also been considered. Various quantitative and semi-qualitative approaches have been pursued to get better insights into behavioural drivers based on past data, and also forecast how human agents would react if access was constrained by either management (e.g. Marine Protected Area – MPA), or the installation of a new operator.

This report covers the North Sea and Eastern Channel, and also one area of the Baltic Sea: the Gdansk Bay. The expertise and contributions brought about by the different institutes in these case studies is summarised in the table below. For each geographical case study, a selection of sectors of activity to be investigated was made. Protected areas have been considered for all case studies. The sectors of activity and spatial management to be considered across case studies are summarised in the table below.

	North Sea and Eastern Channel			Baltic Sea
	German Bight	Dogger Bank	Eastern Channel	Gdansk Bay
Commercial fishing				
Recreational fishing				
Shipping				
Aggregate extractions				
Windfarms				
Oil/gas extractions				

Aquaculture				
Tourism				
Protected areas				

Codes:

- existing and investigated under VECTORS;
- not existing yet but future projects investigated under VECTORS;
- existing but not investigated under VECTORS;

The report starts with a summary description of the data and methods being used, and of the contribution of the different partners involved. Chapter A describes the different approaches (discrete-choice models, vessel trajectories modelling, time series analyses, semi-qualitative interviews) used to hindcast the behaviour of human agents operating in common maritime domains, based on past data. The objective of Chapter B is to forecast fishers' behaviour in both the short-term (using spatial conflict analyses) and the long-term (using a range of predictive bio-economic models). The report concludes with a comparison of the results obtained with quantitative and stakeholder interview-based approaches, and an opening to the other pieces of research carried out within the VECTORS project.

2 Summary of data available and methods used

Data: Catch and effort data by fishing vessel, fishing trip, gear used and ICES rectangle visited have been made available for the French, Dutch, English and German fleets (IFREMER, CEFAS, IMARES, LEI and vTI-SF). Fine-scale VMS data have also been made available for the Dutch, English, German and French vessels above 15 m. Some complementary satellite-based fishing information was made available for a panel of voluntary French vessels fishing in the Eastern Channel via the RECOPESCA project. The French RECOPESCA project aims to derive fishing effort at a fine time and spatial resolution. Sensors are set on voluntary fishing vessels that measure different parameters of the fishing operations (setting/pulling gear, etc.) and of the environment (temperature, salinity, etc.). Records are registered every 15 minutes. Unlike VMS records, RECOPESCA data do not require a proxy to discriminate between fishing and steaming. However, while VMS data are available for all vessels above 15 m, RECOPESCA data are only available for the panel of voluntary vessels. Finally, both catch and effort data by fishing operation are available from observers on-board voluntary fishing vessels participating in EU discards monitoring programmes.

The VECTORS WP2.3 team also sought data from the non-fishing sectors of activity, and particularly aggregate extraction and maritime traffic. The objective of collecting data for non-fishing sectors was to produce a Spatial Overlap Metric (SOM) measuring the constraint exerted by other sectors of activity on fishing. Comprehensive dredging information (day and area of extraction, volume extracted and/or dredging intensity in hours) was collected by CEFAS, the University of Rouen and IFREMER from English and French aggregate extraction companies operating in the Eastern Channel. In many cases, data mining was not free of charge, and further funding had to be sought outside of the VECTORS project (CEFAS). Access to maritime traffic information was successfully achieved by CEFAS via the AIS programme (ships' positions recorded on average every 30 seconds). Access was then granted by UK coastguards to a wide coverage of the maritime traffic in the Eastern Channel for the period 2005-2011. Similar AIS information has been made available for the North Sea by IMARES and LEI. For the other sectors potentially competing for space with fishing (e.g., wind turbine arrays, oil/gas extractions, aquaculture), the SOM was set to the surface occupied by the plant. A similar approach has been pursued to estimate the SOM resulting from protected areas.

In order to apply common methodologies and codes across different case studies, whilst abiding by outstanding confidentiality issues around these data, it was decided to develop a common exchange format to collate the data presented above for all participating institutes. However, it is stressed that unless specified, the databases could not be exchanged across institutes. Only statistical and modelling packages applicable to those databases were distributed by the responsible work package co-ordinators to data owners. The exchange format including mainly 5 tables is fully detailed on the VECTORS website. These tables are summarized below:

- EFLALO: Vessels' physical attributes, fishing effort and landings, by fishing trip, gear & ICES rectangle (30' x 60')
- EFLALO++: Vessels' physical attributes, fishing effort and landings, by fishing operation & fine-scale area (3' x 3')
- ARBRE-DYN: Protected areas and daily activity of other sectors interacting dynamically with fishing by fine-scale area (3' x 3')
- ARBRE-STAT: Protected areas and daily activity of other sectors interacting statically with fishing by fine-scale area (3' x 3')
- TACSAT: Fishing activity, based on satellite monitoring

The Table below shows data availability per institute and per case study (cells highlighted in yellow).

		EFLALO	EFLALO++	TACSAT	ARBRE-DYN	ARBRE-STAT
CEFAS	E. Channel					
DTU-Aqua	D. Bank					
IFREMER	E. Channel					
LEI/IMARES	D. Bank					
	G. Bight					
TI-SF	D. Bank					
	G. Bight					

Methods development: Two complementary types of approaches have been carried out to analyse and/or model the mechanisms of human behaviour, which are hereby referred to as quantitative and qualitative research. Quantitative research consisted of analysing and modelling fishing decision-making processes based on existing data, while qualitative research consisted of interviewing stakeholders from different sectors of activity to get their views on both their past and likely future behaviour. Different methodological approaches have been pursued by different institutes, and these are summarized below:

- IFREMER and CEFAS focused on the modelling of fishing effort distribution using discrete-choice models building in a RUM (Random Utility Model) function,. The external determinants considered in modelling fishers' decision-making were economics, traditions, spatial management (12-mile zone) and spatial competition with other fishing fleets, maritime traffic and aggregate extractions. Two separate models were developed for the Eastern Channel using R and SAS software, one using an ICES rectangle (30' x 60') observation window, and the other one a 3' x 3' spatial resolution. Both prototype fleet dynamics were applied to the Dutch fleets, operating in the Eastern Channel, the Dogger Bank and the German Bight, using the common exchange format presented above (with contribution of LEI and IMARES).
- Agrocampus-Ouest and IFREMER modelled vessel trajectories using HMC – Hidden Markov Chains, and also methods based on stochastic differential equations. Tools were developed to characterize the fine-scale spatio-temporal dynamics of fishing effort, using VMS data.
- LEI and TI-SF developed a stress level analysis for the German Bight. They calculated in particular a stress level: percentage of fishing effort/catch/revenues of total effort/catch/revenues blocked by competing activities. This index was then be used to analyse the short-term impact of future management on fisheries revenues, and to compare the performances of different management scenarios. A prerequisite to the derivation of this index level was the identification of past revenues in areas which might be closed to fisheries in future.
- LEI, TI-SF, IMARES and DTU-AQUA focused on the development of three bio-economic forecast fisheries models building in fleet dynamics in different ways, FISHRENT, DSVM – Dynamic State Variable Model, and DISPLACE. FISHRENT was initially developed by economists and then expanded within VECTORS to account for spatially-explicit biological and ecological processes, FISHRENT also includes other sectors of activity than fishing, and it builds in long-term behaviour (investment/disinvestments). German and Dutch fleets were already parameterised in FISHRENT for the German Bight. The application was extended to English, French and Danish fleets fishing for saithe in the Northern North Sea. Both DSVM and DISPLACE are Individual-Based Models (IBM). DSVM was used to evaluate competition, among several fishing fleets, for harvesting common fish resources in the Eastern Channel. DSVM builds in demography of fish populations and models both effort allocation and discarding practices. DISPLACE evaluates the bio-economic efficiency of fishing vessel movements from recent high resolution spatial fishery data. DISPLACE considers the underlying size-based dynamics of the targeted stocks for Danish and German vessels harvesting the North Sea and Baltic Sea fish stocks. The stochastic fishing process is specific to the vessel catching power and proportional to the encountered population abundances, based on disaggregated research survey data. The impact of the fishing effort displacement on the fish stocks and the vessels' economic consequences were evaluated by simulating individual choices of vessel speed, fishing grounds, and ports.
- IFM, LEI and IOPAS led the qualitative research part of WP2.3. Qualitative research, consisting of semi-structured and structured surveys, was conducted to investigate competition between the different users of the marine environment. A comparative questionnaire was developed to be used in support of qualitative semi-structured stakeholder interviews. Interviews were undertaken with 2-3 representatives of each stakeholder group. The interviews with marine users sought information on, (1) which competition for space (and/or species) they already experience from each other, (2) their expectations on future competition, (3) the influence of restriction/temporary area closures and how they (would) deal with those and, (4) the motivations underlying their decision-making. The goal was to provide results from qualitative research as inputs to model developments and to also validate the simulation results obtained with the (quantitative) modelling approach. Of particular importance was the identification of the determinants of fishing behaviour, the design of realistic scenarios to be simulated, and the likely impact of new forms of area restriction on future fishers' behaviour.

In short, all participating institutes presented a variety of approaches to fleet dynamics modeling and the results they obtained. These methods were applied to alternative case studies. These different approaches and their case study applications are summarized in the Table below.

		Eastern Channel			Dogger Bank				G. Bight		Saithe fishery			
		FRA	GBR	NLD	DEN	GBR	GER	NLD	GER	NLD	FRA	GER	GBR	DEN
CEFAS	Random Utility Model		■	■										
IFREMER	Random Utility Model	■						■						
	Other spatial approaches	■	■					■						
DTU-Aqua	Individual-Based Model				■									
IMARES	Individual-Based Model	■												
LEI / TI-SF	FISHRENT					■	■	■	■	■	■	■	■	■
	Spatial Conflict Analysis								■	■				
AGRO/IFREMER	Trajectory Models	■												

A. Hindcasting the behaviour of human agents operating in a common maritime domain

1 Modelling the spatial dynamics of fishing effort

1.1 Modelling vessels trajectories using Hidden Markov Chains

1.1.1 An autoregressive model to describe fishing vessel movement and activity

The following report is due to be published as a paper with the following reference:
Gloaguen, P., Mahévas, S., Rivot, E., Woillez, M., Guitton, J., Vermard, Y., and Etienne, M. An autoregressive model to describe fishing vessel movement and activity. Submitted to Environmetrics, under review.

Section Abstract
The understanding of the dynamics of fishing vessels is of great interest to define sustainable fishing strategies and to characterize the spatial distribution of the fishing effort. It is also a prerequisite to anticipate changes in fishermen's strategy in reaction to management rules, the economic context or the evolution of exploited resources. In this context, analysing individual vessel's trajectories offers promising perspectives to describe the behaviour during fishing trips.

A hidden Markov model with two behavioural states (steaming and fishing) is developed to infer the sequence of non-observed fishing vessel behaviour along the vessels' trajectory based on GPS records. Conditionally to the behaviour, vessels movements are modelled by a discrete time solution of a (continuous time) stochastic differential equation on vectorial speeds. The model's parameters and the sequence of hidden behavioural states were estimated using an Expectation-Maximization algorithm, coupled with the Viterbi algorithm that captures the most credible joint sequence of hidden states.

A simulation approach was performed, that outlined the importance of contrast between the model's parameters as well as the influence of path length to allow good estimation performances. The model was then fitted to four original GPS tracks recorded with a time step of 15 minutes derived from volunteer fishing vessels operating in the Channel within IFREMER's RECOPESCA project. Results showed differences on parameters estimation depending on the gear used, on both the speeds during fishing operations and the Markovian transitions between behaviours. Results also suggested future inclusion of variables such as tide currents within the ecosystem approach of fisheries.

Introduction

The understanding of the dynamics of fishing vessels is essential to estimate the impact of fishing pressure on the marine ecosystem. It is widely accepted that spatial and seasonal variability of many factors, such as the species assemblage (targeted or accessory), the economy, the environment, fishing regulations and individual preferences, influence fishermen's decisions and induce an heterogeneous distribution of the fishing effort. Therefore, characterizing spatial distribution of fishing effort on a fine spatial scale is crucial to assess fishing mortalities accurately (Smith and Wilen 2003; Poos and Rijnsdorp 2007a; Mills et al. 2007). Recently, some statistical models of fishermen's behaviour have been developed to understand fishermen's reactions to management measures (Vermard et al. 2008) and improve the assessment of the impact of management plans (Lehuta et al. 2013). Another key issue addressed with such models of fishing vessel dynamics concerns the understanding of the population dynamics derived from the spatio-temporal distribution of vessels targeting fish populations (Bertrand et al. 2004; Poos and Rijnsdorp 2007a).

Modelling the dynamics of fishing vessels is classically approached by statistical analyses of landing declarations with a low spatial resolution (ICES statistical rectangle) (Hutton et al. 2004; Pelletier and Ferraris 2000). Recent technological progress has led to massive acquisition of fishing vessels' movement data, which offer new means of studying the spatio-temporal dynamic of fishermen. Since 2005, vessels bigger than 15 meters have been equipped with Vessel Monitoring System (VMS), for legal controls and safety (Kourti et al. 2005). Since 2012, the regulation has been extended to all fishing vessels larger than 12 meters. VMS data consists in geographical positions recorded at a more or less regular time step (less than two hours for mandatory VMS data) with low positioning errors. In addition to this, IFREMER developed the RECOPESCA project with volunteer fishermen, whose vessels positions were recorded at a 15 minute time step.

Concerning the statistical modelling approach, mechanistic mathematical models have long been used in ecological sciences to analyse movements and behaviour of different tracked animals (Bovet and Benhamou 1988; Mills Flemming et al. 2006). A key issue in behavioural ecology is the identification of the sequence of hidden (non-observed) behaviours from the analysis of the trajectory, such as foraging, research, migration. Similar questions are investigated in fisheries science, where the identification of different behaviours adopted by fishing vessels during a fishing trip (route towards fishing zone, fishing activity...) is of interest to understand what drives fishing activities and fishing effort dynamics. The associated mathematical models are hierarchically structured. They first describe a non-observed time-behavioural process based on different behavioural states adopted by the individual and rules for switching from one to the other. The continuous path is then modelled considering movement characteristics such as direction or speed for instance, conditionally to the behavioural state. These models are commonly called State Space Models (SSM) and Hidden Markov Models (HMM) and have proved their usefulness for both ecology and fisheries science (Patterson et al. 2009). In animal ecology, Morales et al. (2004) described the path of elks with a mixture of discrete time random walks, considering Weibull and Wrapped Cauchy distributions for scalar speeds and turning angles, with an underlying switching process between different behaviours. Similar kinds of models were used in fisheries science by Vermard et al. (2010) and Walker and Bez (2010) who describe fishing vessel movement with a mixture of discrete time random walks, considering respectively normal and beta distributions for scalar speeds and wrapped Cauchy distributions for turning angles, both using a hidden Markov process to rule the behaviour. Jonsen et al. (2007) and Gurarie et al. (2009) modelled movements of leather back turtles and fur seals with mixed correlated discrete time random walks over vectorial speed. Beyond the wide range of case studies, models in all those applications are based on the principle of a linear interpolation of the movement between two successive records. However, such linear interpolations may be a crude approximation of the real movement. For instance, when the time step between two successive observations is long, it may under-estimate the distance (and therefore the speed) between two points (Skaar et al. 2011).

The primary goal of this study is to investigate the possibility of moving towards a model of fishing vessel movement in continuous time whereby a HMM captures the sequence of behavioural states along the fishing trip. Stochastic differential equations (SDE) appear as an appealing tool to describe continuous time processes (Protter 2004). However, estimating parameters of a SDE driven by a HMM still remains an unsolved statistical issue. In this study, this difficulty was overcome using a specific vessel movement model with good mathematical properties. We propose to describe the vessel's path using the Ornstein Ulhenbeck process (OUP). This model is well adapted as it is an exact solution of the considered SDE, and is equivalent, when considered at discrete and regular time steps, to a Gaussian Auto-Regressive (AR) process. Considering a HMM coupled with an AR of order 1 process largely facilitates inferences by comparison with a SDE in its native form. The OUP has already been used by Johnson et al. (2008) to describe the movement of fur seals. To the best of our knowledge, the strengths and limitations of this approach have never been investigated to model fishing vessel movement.

Unlike most applications of HMM in fisheries science that used a Bayesian framework to estimate model parameters (e.g., Vermard et al. 2010; Walker and Bez 2010), we considered a maximum likelihood approach based on a combination of the Baum Welch algorithm and the Viterbi algorithm. The former is a derivation of the Expectation Maximization (EM) algorithm for HMMs, while the Viterbi algorithm is used to rebuild the most probable (behavioural) hidden state sequence. This latter algorithm showed reliable inferences on HMM as it accounts for the serial dependencies in the Markovian sequence instead of considering each time step marginally (Rabiner 1989).

We illustrate the strength and limitations of the approach by fitting the model to GPS records issued from the RECOPESCA project (Leblond et al. 2010), implemented by IFREMER to improve the assessment of the spatial distribution of catches and fishing. A sample of voluntary fishing vessels, equipped with GPS systems together with a suite of sensors for studying fishing effort, take part in this project. Although they concern a rather restricted number of fishing vessels, RECOPESCA data offer several advantages by comparison with mandatory

VMS data. First, these data are recorded with a shorter time step than VMS data (a position every 15 minutes instead of 1 hour). Second, they are recorded with a highly regular time step (15 min +/- 1 min). The finer time scale allows for a more accurate reconstruction of fishing vessel trajectories than VMS data. In particular, bias induced by interpolating the trajectory with a straight line between two records would be lower than with an hour time step between two points (Skaar et al. 2011). Furthermore, the regularity of recording offers an interesting opportunity to reformulate the Ornstein Ulhenbeck as an autoregressive process.

This article is structured in the following way. In the Material and Methods, we detail the RECOPESCA* data set, followed by the theoretical and methodological framework including the model's description, the inference algorithm and the simulation approach to assess the performance of the method. Results are then presented and the ending section proposes a discussion on the adequacy of this modelling approach and some recommendations for future modelling of fleet dynamics.

Material and Methods

RECOPESCA data

Four trajectories associated with four different fishing vessels operating in the Channel with different fishing gears were considered as examples to illustrate our modelling approach (see Figure 1). These four trajectories were extracted from the RECOPESCA data base. For each trajectory, GPS positions in port and at sea were available. As the analysis only focus on fishing vessel movement during fishing trips, we first removed positions in port based on logbooks (landings declarations). The positions were recorded at a regular time step (plus or minus 1 minute). Selected trips last more than 12 hours, ensuring enough observed positions for parameters identification. These four vessels belong to the demersal fishery for which the research of fish aggregations observed in pelagic fisheries does not exist. Hence only two behaviours are assumed along their path, 'steaming' for cruising and 'fishing' when they operate their gear.

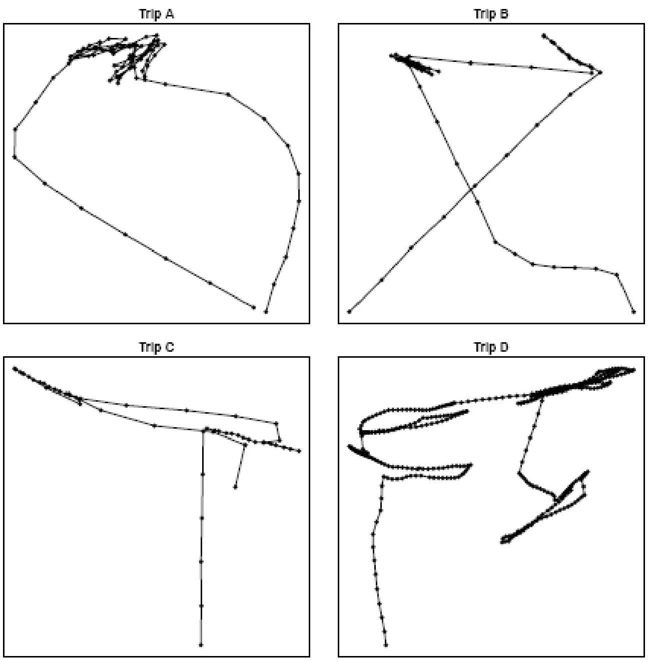


Figure 1. Four fishing trips considered to illustrate the strengths and limitations of the approach. Trip A is a 22 hour trip of a 12 meter vessel using dredges. Trip B is a 14 hour trip of a 12 meter vessel using otter trawl. Trip C is a 13 hour trip of a 13 meter vessel using trammel nets. Trip D is a 107 hour trip of a 22 meter vessel using otter trawl.

* http://archimer.ifremer.fr/doc/00024/13500/

Despite their differences, common characteristics can be noticed for these trajectories: 1) movement is mainly in a straight line with no turning direction privileged; 2) when cruising, vessel goes faster than when fishing; 3) at a 15 minutes time step, there is mainly persistence in a state (states occur in sequence). While animals usually show a more erratic movement when foraging than when cruising (Morales et al. 2004), for fishing vessels, the fishing phase can be either erratic or not depending on the operated gear. For instance, it is sometimes erratic for dredging whereas it is more linear for trammelling or otter trawling. Therefore, this erratic behaviour might not be appropriate to distinguish between fishing and cruising states.

An SDE for a continuous movement process considered as an AR1 in regular discrete time

The vessel movement is considered via a decomposition of vectorial speed process on its two dimensions *V p* and *V r*.

V p is called the “persistence” speed, and corresponds to the tendency to maintain previous direction. *V r* is called the “rotational” speed, and corresponds to the tendency to turn. These two quantities are derived as follows:

$$V_j^p = V_j \cos(\psi_j) \quad (1)$$
$$V_j^r = V_j \sin(\psi_j) \quad (2)$$

where *Vj* is the average speed derived from positions *Xj* and *Xj* recorded at times *tj*1 and *tj* , and *ψj* is the turning angle derived from *XjXj* and *Xj*1*Xj* , with *ψ*1 = 0 (see figure 2).

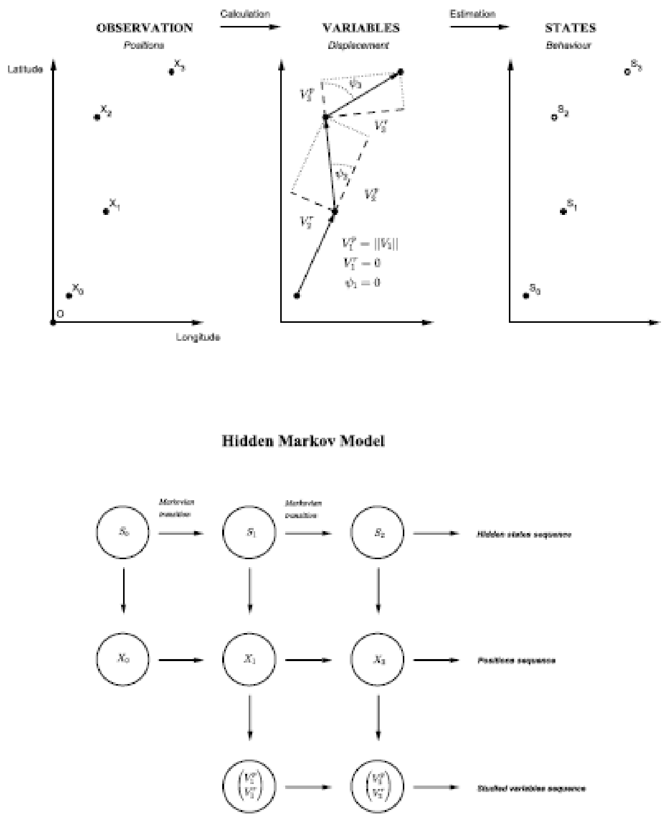


Figure 2. Graphical representation of the Hidden Marlov Process for behavioural states of the autoregressive speed movement. Above: from observed positions to modelled displacement variables considered to estimate behavioural states. In third column, empty dots would be for instance state 2, and plain dots state 1. Below: HMM structure with a sequence of hidden states ruled by a Markovian transition matrix determining a sequence of observations.

Modelling the movement with variables 1 and 2 requires less assumptions than models using scalar speed and turning angles separately. The former can be approached using a Gaussian structure (Gurarie et al. 2009), whereas the latter requires two different distributions (Vermard et al. 2010; Walker and Bez 2010). The speed process in a given activity is assumed to solve a SDE

$$dV_t = \rho(\gamma - V_t)dt + \zeta dW_t \quad (3)$$

where *γ* is the asymptotic mean of the process, *ζ* is the variance, *ρ* is an autocorrelation parameter, and *Wt* is the standard Wiener process (see 28, for instance). The Ornstein Ulhenbeck Process is known to be the solution of equation 3 (Uhlenbeck and Ornstein 1930). Considering discrete time observation (*Vt*1 , . . . , *VtJ*) and using stochastic calculus, one can show that for each increment of time Δ*j* between observations *Vtj* and *Vtj*+1, a solution of equation 3 has the following exact discrete form :

$$V_{t+\Delta_j} = \gamma(1 - \mathrm{e}^{-\rho\Delta_j}) + \mathrm{e}^{-\rho\Delta_j}V_t + \zeta\sqrt{\frac{1 - e^{-2\rho\Delta_j}}{2\rho}}\epsilon_t \quad (4)$$

Thus, assuming a regular time step Δ*j* = Δ the process in equation 4 is equivalent to an autoregressive process:

$$V_{t+1} = \eta + \mu V_t + \sigma\epsilon_t \quad (5)$$

Consequently, the vectorial speed process is modelled by a mixture of two dimensional AR processes (with respect to its decomposition 1 and 2), and, following Vermard et al. (2010), the vessel's behaviour is modelled by a hidden stochastic discrete time process noted *St* 0 = *S*0*, ..., St* = (*St*)*t*_0, where *Sj* is the state at time *t* = *j*, *Sj 2 S* = *f*1*, . . . , lg*, and *S* is the set of behavioural states. This process is assumed to be a homogeneous Markov chain of first order with a transition matrix Π = (Π*ik*)*i;k*=1*;:::;l* :

$$\mathbb{P}(S_t = k|S_0^{t-1}) = \mathbb{P}(S_t = k|S_{t-1} = i) = \Pi_{ik}$$

The first state is supposed to be known and set to 1 with P(*S*0 = 1) = 1. In our specific study, we only considered two states, *S* = 1*,* 2*,* 1 standing for steaming, 2 for fishing.
Therefore the model can be summarized as follows :

$$V_{t+1}^p|(S_{t+1} = i) = \eta_{p,i} + \mu_{p,i}V_t^p + \sigma_{p,i}\epsilon_{p,t} \quad (6)$$

$$V_{t+1}^r|(S_{t+1} = i) = \eta_{r,i} + \mu_{r,i}V_t^r + \sigma_{r,i}\epsilon_{r,t} \quad (7)$$

$$V_1^p = V_1, \quad V_1^r = 0, \quad \epsilon_{\cdot,t} \sim \mathcal{N}(0,1) \quad (8)$$

As in Gurarie et al. (2009), processes 6 and 7 are assumed to be independent. Even if this assumption seems unrealistic, data reveal a weak empirical correlation between those two variables. Both components of the speed *V p t* and *V r t* at each time step *t* were considered as observed without error. It is known that an AR process as in 6 and 7 is stationary if *jµj* < 1 (Shumway and Stoffer 2000). In this case the expectation and the variance of a process *V* satisfy asymptotically:

$$\mathbb{E}(V) = \frac{\eta}{1-\mu} \quad (9)$$

$$\mathbb{V}(V) = \frac{\sigma^2}{1-\mu^2} \quad (10)$$

These asymptotic equalities can be useful in order to interpret parameters variation. For instance, if the vessel stays long enough in state 1, the expectation for *V p* and *V r* could be derived from equations 9 and 10.
Moreover, parameters in processes 6 and 7 have some intuitive interpretations.
– *η* can be seen as a level parameter (if *µ* is equal to 0, then it's the mean of a normal distribution).
– *µ* is an autocorrelation parameter. Its existence and variability is justified considering data from the four different trips (autocorrelation plots not shown). It's important to note that its uniqueness only makes sense because of the regularity of time-step.
-- σ^2 is a shape parameter, it is the noise of the process.

Inference

The inference procedure consists in the estimation of both parameters and the sequence of hidden states from observed positions. It requires two steps 1) performing parameter estimation using the Baum Welch algorithm, 2) estimating the most likely sequence of states using the Viterbi algorithm. Considering *J* states, the set of parameters to be estimated for this model is

$$\Theta = \{\Pi_{i\cdot},\ \eta_{p,i},\ \eta_{r,i},\ \mu_{p,i},\ \mu_{r,i}\ \sigma_{p,i},\ \sigma_{r,i}\ \}_{i=1,\ldots,J}$$

When *J* = 2, 14 parameters are estimated (2 for the transition matrix, and 3_2_2 for AR processes parameters). Computing the likelihood function in this case is too time consuming as the number of terms grows exponentially with observations. A classical approach is to find Maximum Likelihood Estimators (MLE) Θ via the Baum Welch algorithm, the Expectation Maximization (EM) algorithm for Hidden Markov Models (Rabiner 1989; McLachlan and Krishnan 1997). Considering the model described above, both the Expectation (E) step and the Maximization (M) step can be computed directly and without optimization techniques (R Core Team 2013). The convergence is assumed when the log likelihood increase is less than 0.01. A known problem of the EM algorithm is that, given a starting point, one can converge towards a local maximum of the likelihood. To ensure a global maximum is found, the algorithm was performed from 100 different starting points, keeping the result with the largest likelihood as Θ. A bootstrap is used to assess the variance of Θ. The MLE is used to simulate *M* bootstrap samples on which MLE (ˆΘ*m*)1_*m_M* are re-estimated, given these *M* re-estimations, empirical 95 % confidence intervals are obtained for each parameter (getting 95% central values, McLachlan and Krishnan 1997; Efron and Tibshirani 1993). The bootstrap is the most time consuming part of this first estimation step. Once the MLE step is performed, the Viterbi algorithm is used to derive the most probable sequence of states (Rabiner 1989). Formally, for a MLE ˆΘ*m* the Viterbi algorithm computes

$$\hat{S}^m = \operatorname{argmax}_{s_0 \ldots s_T} \left(p(s_0 \ldots s_T,\ X_0 \ldots X_T | \hat{\Theta}_m) \right) \qquad (11)$$

The state at time *t* is therefore dependent on the sequence of states from *t* = 0 to *T -1* accounting for Markovian transition properties of the whole hidden sequence. In order to estimate uncertainty of state attribution, the Viterbi algorithm is performed for each bootstrap sample. The empirical probability of being in state 2 at time *t* is then computed. Working on real data, state 2 (standing for ”fishing”) is attributed to the estimated state with the lowest mean for scalar speed, due to the fact that the vessel goes slower in that case.

Simulations

The performance of the estimation method is assessed through simulations of trajectories based on various scenarios mimicking different levels of contrast in the movement characteristics of the two behavioural states. For the model with two different states (14 parameters), parameters used for simulation are restricted to values consistent with characteristics of the observed trajectories. For instance, we noticed that
1) *ηr;*1 = *ηr;*2 = 0 : the movement of vessels is mainly in a straight line, both while steaming and fishing, and does not privilege any turning direction ;
2) The asymptotic persistent component of speed should be greater when steaming than when fishing ;
3) diagonal terms Π11 and Π22 of the transition matrix Π are large. This matrix is common to all scenarios and diagonal terms are fixed at Π11=Π22=0.9/ Trips are simulated following nine scenarios with various degrees of mixture between states and with different lengths (number of time steps) (see Table 1 for detailed values).

Scenario 1 is the baseline scenario. The difference between $\eta_{p;1}$ (= 6) and $\eta_{p;2}$ (= 1) is large, as well as difference in autocorrelation parameters (”Steaming” state is uncorrelated while ”Fishing” state is positively correlated).

Scenario 2-3 $\eta_{p;2}$ increases from 1 (scenario 1) to 2 (scenario 2) and 3 (scenario 3), resulting in an increase of the asymptotic expectation of V_p in state 2. Therefore the contrast in the expected asymptotic speed between state 1 and 2 decreases.

Scenario 4-5 $\mu_{p;2}$ increases from 0.5 (scenario 1) to 0.6 (scenario 4) and 0.8 (scenario 5), resulting in an increase of the asymptotic expectation of V_p in state 2. Therefore the contrast in the expected asymptotic speed between state 1 and 2 decreases. Moreover, the asymptotic variance of process V_p increase in state 2.

Scenario 6-7 In scenario 6, $\sigma^2_{p;1}$ and $\sigma^2_{r;1}$ increase from 1 and 0.5 (scenario 1) to 2 and 1 respectively, resulting to a higher asymptotic variance in state 1. In scenario 7 $\sigma^2_{p;2}$ and $\sigma^2_{r;2}$ increase from 0.5 and 0.1 (scenario 1) to 1 and 0.5 respectively, resulting to a higher asymptotic variance in state 2.

Scenario 8-9 The length of the observation is shortened from 400 points (scenario 1) to 100 points in scenario 8 and 50 points in scenario 9. Lengths of 400 and 50 points would represent respectively 100 and 12 hours data considered and were the maximal and the minimal length of trajectories considered.

		η (1 2)	μ (1 2)	σ^2 (1 2)	$\mathbb{E}$ (1 2)	$\mathbb{V}$ (1 2)	n
1	p	6 1			6 2		
	r	0 0			0 0		
2	p	6 2	0 0.5	1 0.5	6 4	1 0.7	400
	r	0 0	0 0.2	0.5 0.1	0 0	0.5 0.1	
3	p	6 3			6 6		
	r	0 0			0 0		
4	p	6 1	0 0.6	1 0.5	6 2.5	1 0.8	400
	r	0 0	0 0.2	0.5 0.1	0 0	0.5 0.1	
5	p		0 0.8		6 5	1 1.4	
	r		0 0.2		0 0	0.5 0.1	
6	p	6 1	0 0.5	2 0.5	6 2	2 0.7	400
	r	0 0	0 0.2	1 0.1	0 0	1 0.1	
7	p			1 1		1 1.3	
	r			0.5 0.5		0.5 0.5	
8	p	6 1	0 0.5	1 0.5	6 2	1 0.7	100
	r	0 0	0 0.2	0.5 0.1	0 0	0.5 0.1	
9	p						50
	r						

Table 1. Simulation scenarios: The matrix II is identical for all scenarios. Expectation and variance indicated are calculated from equations 8 and 9 and rounded to the first digit. They are asymptotic and must be considered as indicators of how the parameters affect the different processes.

Results of Simulations

For each set of parameters, 100 trajectories are simulated, thus providing 100 parameter estimates. Examples of simulated trajectories obtained with parameters of scenarios 1, 3, 4 and 7 are presented on figure 3.

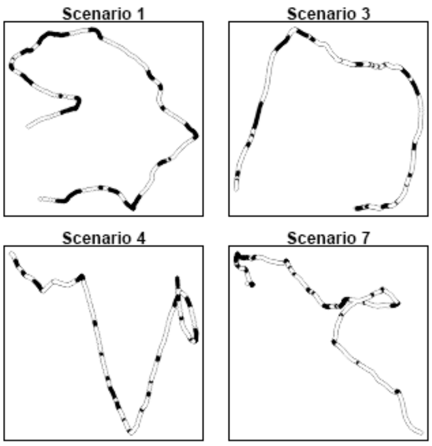


Figure 3. Examples of simulated trajectory for scenario 1, 3 4 and 7. Black dots are for fishing, white dots for steaming.

Vectorial speeds associated to trajectories of figure 3 are represented using scatter plots on figure 4. These scatter plots highlight the different degrees of mixture between the two states, depending on the scenario.

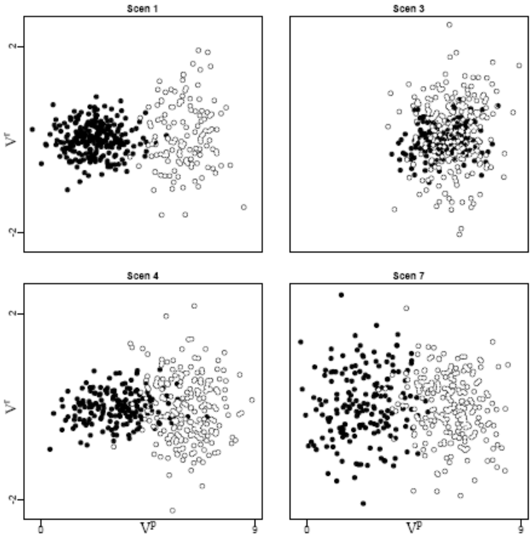


Figure 4. Simulated vectorial speed processes for scenarios 1,3,4 and 7 (see Table 1). Black dots are for fishing, white dots for steaming.

Knowing the true value of each parameter, estimation errors are computed and summarized using box plots (figure 5). Results are shown only for process V_p, as trends are similar on process V_r.

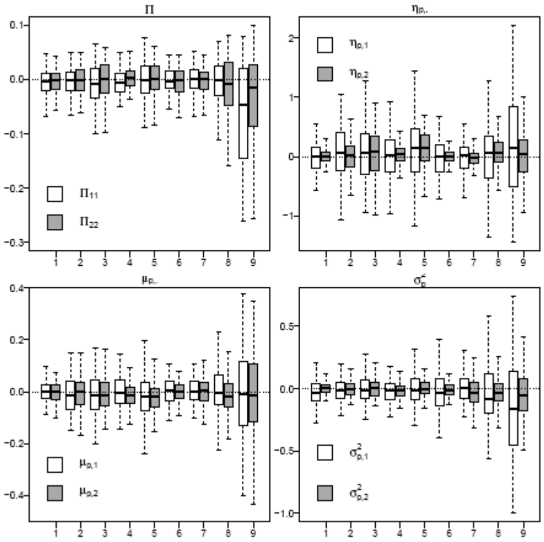


Figure 5. Box plots of estimation errors (estimated value 0 the true value) obtained for simulation scenarios presented in Table 1. Only estimation errors for process V^p are presented, white and grey box plots are for parameter estimates in steaming and fishing respectively. The whiskers represent 1.5 time the interquartile range at most. Outliers are plotted.

Moreover, as the true sequence of behavioural states is known, a misclassification rate is also computed and displayed using box plots (figure 6). Box plots results highlight performances of the parameters estimation method and the Viterbi algorithm, which are now detailed for the different simulation scenarios:

Scenario 1-3 For all parameters, the width of the box plots increases from scenarios 1 to 3, revealing that an increase proximity between $\eta_{p;1}$ and $\eta_{p;2}$ has a negative impact on the estimation of all parameters (Figure 5). Moreover, the misclassification rate of the states estimation is also increased. Even if it remains low for scenarios 1 and 2, it increases for scenario 3 (more than 50% of state estimations have a misclassification rate greater than 0.15, Figure 6). Looking at figure 4, this large misclassification rate can be explained by the large degree of mixture between states in scenario 3.

Scenario 1, 4-5 When $\eta_{p;1}$ and $\eta_{p;2}$ are not changed, the increase of $\mu_{p;2}$ increases estimation's uncertainty over level and autocorrelation parameters η and μ (Figure 5). The misclassification rate also increases, with a low increase for scenario 4, and a larger one for scenario 5 (figure 6). Indeed, there is an increase in the degree of mixture between states from scenario 1 to scenarios 4 and 5 (Figure 4).

Scenario 1, 6-7 In scenario 6, increasing of noise parameters $\sigma^2_{p;1}$ in state 1 increases lightly the uncertainty for the estimations of level and noise parameters $\eta_{p;1}$ and $\sigma^2_{p;1}$. The same trend can be noticed in scenario 7 when noise parameters in state 2 increase (Figure 5). The misclassification rate remains stable between scenario 1 and 6, but increases for scenario 7 as the processes in both states have in this case the same noise parameters (Figure 6). Indeed, there is an increase in the degree of mixture between states from scenario 1 to scenario 7 (Figure 4).

Scenario 1,8-9 When the length is shortened, estimation's uncertainty increases for all parameters, the increase becomes larger from scenario 8 (100 points) to scenario 9 (50 points) (Figure 5). Moreover, the misclassification rate is also impacted, getting worse as the observation gets shorter (Figure 6). Looking at the empirical distribution function of Π_{22} (for instance, the same can happen for Π_{11}), it is worth noting that in scenario 9, this parameter is sometimes estimated close to 0 (Figure 7). This results in the identification of only one behavioural state, and then a large misclassification rate.

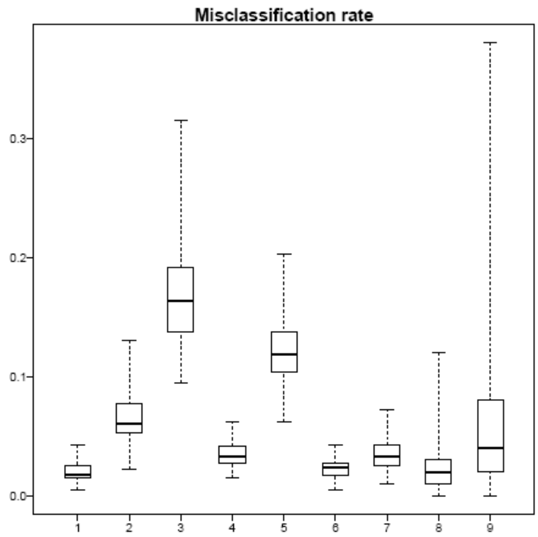


Figure 6. Box plot of misclassification rate from the Viterbi algorithm for simulation scenarios presented in Table 1, the whiskers height is at most 2 times the interquartile range. Outliers are not plotted.

More generally, it is worth noting that for all scenarios, estimations are unbiased. Moreover, except for scenario 7 where the noise parameters are equal in both states, the variance of estimators is greater for state 1 parameters than for state 2 parameters, as the noise parameter is larger in the first state ($\sigma^2_{p;1} > \sigma^2_{p;2}$).

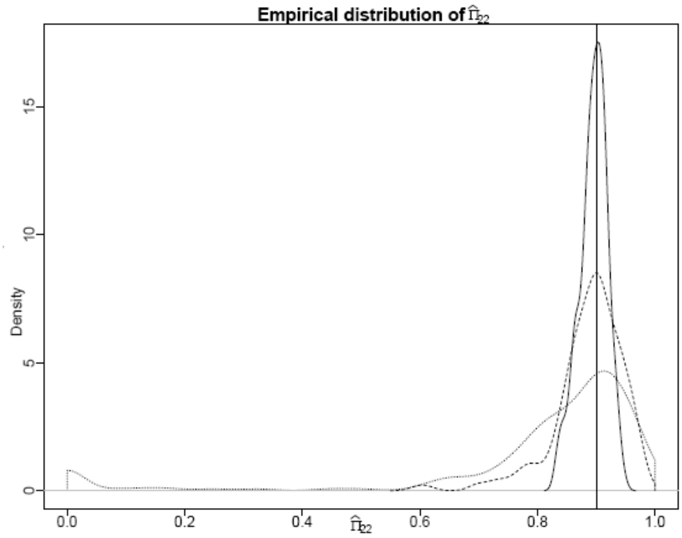


Figure 7. Empirical distribution functions of estimated values for Π_{22}, depending on the observation length for scenario 1 (n = 400, solid line), scenario 8 (n = 100, dashed line) and scenario 9 (n = 50, dotted line). The true value of Π (=0.9) is represented by a vertical line. When one of the Π_{22} is estimated close to 0 only one state is identified.

Discussions and perspectives

This study provides a first application of an autoregressive model coupled to a hidden Markov chain to describe the movement of fishing vessels. The vessel's speed is modelled using an Ornstein Ulhenbeck process formulated as a solution of a stochastic differential equation. Assuming a regular time step, we investigate the potential of using an AR process. Studying the speed process with an AR allows one to include autocorrelation during the movement of the vessel as it was done for several animals (Jonsen et al. 2007; Johnson et al. 2008; Gurarie et al. 2009) but, to the best of our knowledge, it has never been investigated in fisheries studies yet. This modelling approach has two advantages compared to previous similar studies (e.g., Vermard et al. 2010; Walker and Bez 2010). First, the model formulation is simpler and required less assumptions. Vessel dynamics is described using only the speed process formulation considering the Gaussian structure of its vectorial decomposition, while traditionally travelled distance and angular displacement were jointly used. Second, it accounts for the continuous property of vessel's travelling and not only the discrete feature of the observations of their displacement.

The inference was performed by likelihood maximisation using the Baum Welch algorithm. In the case of autoregressive processes, this iterative method has explicit equations and maximization solutions, allowing a certain simplicity in parameters estimation. Confidence intervals of parameters estimates were derived using a bootstrap method. The EM approach has also the advantage of allowing the use of the Viterbi algorithm to estimate the hidden states sequence. This algorithm accounts for the whole sequence of states and not only the probability of a state at each time step. In a two-state model, this would not make a major difference but this would be more efficient than classical methods considering three states or more (Rabiner 1989). Results obtained were compared with the Bayesian approach (not shown here), which is commonly used for such modelling (Vermard et al. 2008). The Bayesian approach would use Monte-Carlo-Markov-Chain algorithms instead of EM. A loss in this case would be the potentiality of using the Viterbi algorithm, but, on the other hand, the uncertainty of the estimation is directly computed, and there is no need for bootstrap methods, which is the most time consuming step in our method. The Bayesian approach also needs to deal with prior distributions, which allows us to integrate a priori knowledge, but raises the problem of sensitivity. On the other hand, the EM approach requires different starting points to ensure the convergence towards the global maximum of the likelihood and not a local maximum. Results in both approaches are similar as MLE corresponds to the mode of posterior distribution in Bayesian estimation, and the same difficulties are encountered in disentangling states when parameters are not contrasted enough. Computational times are hard to compare, given that both techniques demand calibration and convergence criteria that can be discussed.

A simulation approach is performed to assess the performance of the model and the accuracy of the estimation for various realistic sets of parameter values (called scenarios). The simulation highlights the importance of the heterogeneity on level (η parameters) and/or autocorrelation (μ parameters) of processes in each state in order to have good estimation of both parameters and the sequence of hidden states. Simulation results also outline the influence of the noise parameter, as a large σ in a given state increases the estimation's uncertainty for all parameters. Finally, the importance of the duration of observation is also established: the longer the trajectory, the better the estimation.

The model is applied to four vessels involved in IFREMER's RECOPESCA project, involving volunteer fishermen. The quality of this data set provides several advantages over VMS data. First, the time step of observations is more regular. This property of regularity is essential in our model and previous studies based on VMS data have shown weakness because of the lack of regularity in records [34]. Second, geographical positions of RECOPESCA vessels are recorded with a higher frequency (15 minutes instead of 1 hour for VMS) which makes the hypothesis of a steady course between recorded positions more reasonable, and reduces the chance of an unobserved fishing operation (Vermard et al. 2008).

Estimations reveal contrasted behaviours along the vessels' trajectory. A first trip shows 2 states neatly separated, corresponding to an erratic and low speed fishing pattern, and a higher speed steaming pattern, whereas two other trips show fishing activity characterized by a (almost) constant value for vectorial speeds, traducing a steady course and constant scalar speed fishing pattern. A fourth example is presented where the interpretation in fishing/non fishing is questionable. Looking at the scalar speed process, it is unrealistic to declare that one of the two states is fishing or steaming. The differentiation between states is made over auto correlated and noisy patterns on $V\ p$ process. Actually, the scalar speed process shows sine wave patterns that are identified as state 2, while patterns of noise are for state 1. The sine wave patterns could indicate fishermen's adaptation to tide currents, fishing with the currents is indeed a possible behaviour in order to minimize fuel costs, or change the gear behaviour and target other fish assemblage. If it is so, it would be of interest in the future to couple the vessel dynamics model with tidal streams models to remove the trend due to this force. The results over the four studied vessel's trajectories show different sets of parameters obtained for different types of vessels and fishing activities (Biseau 1998), and a relative small uncertainty over state estimation.

The model considered here has two states, steaming and fishing, that could be similar to a "migrating"/"foraging" pattern adopted for animals (Jonsen et al. 2007). For simplicity reasons, we privileged a two-states model rather than a three states one (as in Vermard et al. (2010) or Walker and Bez (2010)). This was made possible thanks to a pre-treatment of the data that consists in removing positions in port but also because each studied fishing vessel operates only one gear and one métier Woillez et al. (unpublished data). If a two-states model is realistic here it could be more relevant in other cases to adopt a three or more states for trips during which several gears can be operated or several métiers can be practised. A model with "transition" states can also be adopted to deal with problems due to time step acquisition, and specifying different parameters for each fishery (Peel and Good 2011). A challenging alternative to these choices would be to consider a state space model where the number of states is a parameter to infer, which would increase the computing time.

More generally, choosing a model raises several issues. Given a set of trajectories, the models' hypothesis have to be compared with the observations using some expert or statistical criterion, then, among satisfying models, the best one has to be selected on some criterion (best fitting to the data, good estimation properties...).

In order to increase realism, it would be of interest to investigate the potential of an inhomogeneous Markov chain to model the change of states. Indeed, in the model presented here, the Markovian transition matrix is constant through time. However the "fishing" probability would decrease with time during the fishing trip. Another challenging issue would be to model behaviours with a hidden Markov chain which is not synchronous with the observations. Indeed change of state can occur between two observations of a vessel's geographical position. Assuming that change of state and observations are synchronous, the number of confounding factors in the estimates of states would be increased (Vermard et al. 2010). One could consider a continuous time Markov process to rule the observations. This hypothesis, although more natural, makes the inference a lot harder.

Conclusions

This work applies the discrete version of the Ornstein Ulhenbeck process, solution of a stochastic differential equation, which was used to describe fur seal movements in Johnson et al. (2008). Adopting stochastic differential equations to describe dynamics of individuals is still a major challenge. To our knowledge this mathematical framework has already been used for some animals (Brillinger 2010; Haiganoush et al. 2004), though without a state space model, but has never been used in fisheries science. However Bertrand et al. (2007) showed that Peruvian anchovy fishermen's foraging strategy is close to natural predators. Therefore, it would be interesting to assess the relevance of this continuous time approach for fishing vessels. A comparison of estimates derived from both a continuous and discrete time framework would allow determining of when the linear interpolation of trajectory is a good approximation to 1) conveniently describe a vessel's dynamics and 2) to allocate a vessel's fishing effort. Indeed, using stochastic differential equations formalism might be time-consuming and more complex.

This study shows the efficiency of fleet dynamics models to understand the mechanisms of fishing vessels' movements and activities. The outputs of this analysis can then benefit paramatisation of the fleet dynamics models for existing bio-economic models to improve the understanding of fisheries dynamics and to anticipate the adaptation of fishermen to ecosystemic and management changes (Mahévas and Pelletier 2004; Pelletier et al. 2009; Lehuta et al. 2013).

1.1.2 Accounting for the variability of activities to improve modelling of fishing vessel behaviour with hidden Markov models

The following study is due to be published as a paper with the following reference:
Woillez, M., Gloaguen, P., Mahévas, S., Rivot, E., Vermard, Y., and Guitton, J. Accounting for the variability of activities to improve modeling of fishing vessel behavior with hidden Markov models. In preparation.

Section Abstract
Hidden Markov models are well suited to describe jointly fishing boat movement and associated fishing activities. They allow us to estimate the sequence of activities (i.e. fishing, traveling) along a trajectory, as well as the movement parameters (speed, turning angle) associated to each activity. Most of the time these models are developed to characterize the spatial dynamics of fishing vessels that belong to a specific fishery with a given métier. However, because of the large variability that exists in fishing practices, some adaptations in the modeling structure are needed when the spatial dynamics of one or several fishing fleets present a mixture of métiers with distinct traits of movement and trajectory. A procedure was developed to capture the variability of fishing practices and associated vessel trajectories. Fishing trips were characterized by their métiers, which were identified for each gear by clustering landing profiles (in value). Fishing boat trajectories were described using movement parameters (speed, acceleration, turning angles, straightness) estimated from GPS positions recorded along the tracks. A principal component analysis was performed to provide a detailed description of the different trajectory patterns in relation with fishing trip specificities (i.e. vessel, gear, métier). Hidden Markov models were then fitted for some selected fishing trips. Two types of models were considered. The basic one was a 2 states model with behavioural activities corresponding to fishing and traveling. The second one presented a number of fishing states depending on the number of métiers identified for the trip. Fitting performance was compared based on DIC and estimated confidence intervals for the parameters. This procedure was applied to a set of volunteer vessels participating to the RECOPESCA project from IFREMER in the Bay of Biscay and the English Channel for years 2011-2012. We show that fishing trip activities, such as métiers, were structuring variables for trajectories, which helped to specify properly hidden Markov models.

Introduction

The implementation of a spatially explicit management in fisheries sciences will require a better understanding and modelling of the spatial dynamics of fishing boats and derived efforts. Therefore much research has recently focused on developing individual-based models of fishing boat using geolocation data with high spatial and

temporal resolution. Mostly inspired from animal movement ecology, models that have been implemented, aimed at estimating jointly the fishing boat movement and its behaviours along the trips.
Hidden Markov models (HMM) have proven to be well suited for this purpose. Several types of Hidden Markov models have been developed until now (Vermard et al., 2010; Walker and Bez, 2010; Joo et al., 2013, Gloaguen et al., submitted). Hidden states are defined to describe the unobserved behaviour (e.g. fishing, traveling, stopping, and searching). The sequence of hidden states is ruled by a Markov chain or a semi-Markov chain (Joo et al., 2013). The movement is modelled conditionally to hidden states, usually either by a correlated random walk (Vermard et al., 2010; Walker and Bez, 2010) or by an autoregressive process on vectorial speeds (Gloaguen et al., submitted). Observation process errors with re-interpolation are sometimes performed (Vermard et al., 2010).

However, all the modelled movements correspond to a single type of object. For instance, in animal movement ecology, HMM were applied to elks (Morales et al., 2004), seals (Jonsen et al., 2005) leatherback turtles (Jonsen, 2006; Jonsen et al., 2007) or southern bluefin tuna (Patterson et al., 2009). Same finding can be done in fishery sciences. HMM were applied to a specific fishery with a given métier, such as the purse-seine French tropical tuna Fishery (Walker and Bez, 2010), the pelagic trawl French anchovy fishery (Vermard et al., 2010), or the purse-seine Peruvian anchoveta fishery (Joo et al., 2013). Even though it is recognized widely that fishing practices are heterogeneous.

Therefore, our aim was to demonstrate that modelling approaches need to be adapted to the heterogeneity of the fishing practices. In effect, when the spatial dynamics of one or several fishing fleets present a mixture of métiers with distinct traits of movement and trajectory, some adaptations might be naturally expected in the modelling structure. To guide practitioners, we proposed a procedure that will allow us (i) to identify species-based métiers, (ii), to analyse trajectory data and (iii) to investigate relationships existing between trajectories and fishing activities, such as vessels, gears and métiers. From the latter exploration, different structural types of HMM models were developed in the aim of testing if the knowledge of the fishing activities can improve the estimation performance of the sequence of behaviours. The application of the procedure was illustrated on a subset of voluntary vessels operating along the French coasts and presenting a mixture of métiers.

Materials and methods

Trajectory data

Since 2005, IFREMER, the French Research Institute for Exploitation of the Sea (partner 15), has coordinated a network of fishing vessels that volunteered to provide scientific observations. This project, named RECOPESCA[2], aims at using fishing vessels as scientific platforms to sample fishing activities and environmental conditions during fishing trips. Various non-intrusive sensors were used. A Global Positioning System (GPS) monitored the vessel's positions at a regular time step of ~15 minutes. Depth sensors mounted on fishing gears provide non-exhaustive information about fishing operations (not all gears are equipped and recording can fail).

For this study, the dataset considered is a subset of the RECOPESCA database. It corresponds to data collected on-board 39 fishing vessels operating in the Bay of Biscay, the Channel, the Celtic Sea and the southern North Sea for years 2011-2012 (Figure 8). The fishing vessels range from 8.3 to 24 m for a power comprised between 44 and 657 kW (Table 1).

[2] http://archimer.ifremer.fr/doc/00024/13500/

Table 2**.** Technical characteristics of the 39 fishing vessels selected from the RECOPESCA database for years 2011-2012.

Vessel code number	Length (m)	Tonnage (t)	Power (kW)
1	14,3	3718	165
2	18,6	4058	221
3	12,0	1300	110
4	9,1	1041	83
5	11,8	1018	81
6	16,4	3772	272
7	11,1	400	70
8	15,6	3919	157
9	14,4	3515	140
10	19,5	10925	316
11	10,3	813	106
12	12,0	2553	162
13	13,3	3012	242
14	16,1	5865	261
15	15,8	7284	258
16	21,0	13056	442
17	10,2	994	113
18	23,3	15596	511
19	23,9	16365	657
20	19,4	10500	336
21	8,3	567	84
22	18,4	4900	397
23	12,0	983	283
24	15,9	6475	316
25	20,6	12142	355
26	24,0	15255	453
27	22,4	14576	392
28	15,9	6502	256
29	12,0	1682	155
30	17,3	3815	216
31	19,1	9036	294
32	24,0	16280	499
33	11,7	900	44
34	12,0	3091	103
35	22,5	15094	371
36	22,5	16963	365
37	12,0	1839	215
38	15,0	4097	323
39	13,0	2792	161

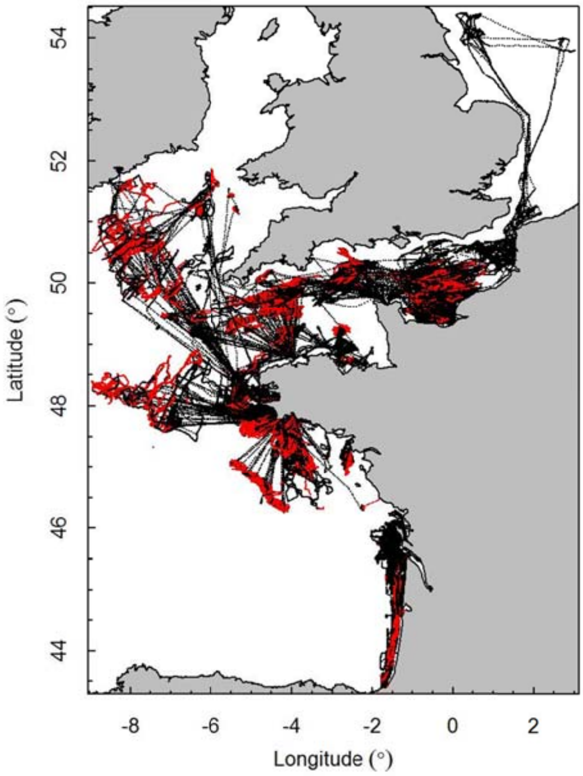


Figure 8. Map of trajectories from RECOPESCA fishing vessels for years 2011-2012. GPS points where fishing operations were detected using depth sensors are in red, while others are in black.

Only fishing trips presenting average speeds lower than 14 nmi/h and time steps equal to 15min +/- 1.5min, were considered to insure that a clean dataset is used for the following statistical analyses.

Catch and sales data

A project named SACROIS[3] has been developed at IFREMER to produce a coherent and validated dataset about French production and fishing effort. Practically it links various data types coming from vessel monitoring systems, logbooks, and sales. This database was used to extract sales data and characterize each log event by their landing profiles in value (i.e. in euro).

To do so, some pre-processing were realized, first to get rid of any lines containing NA's values, then to remove any duplicate lines qualifying the same log events due, for instance, to incoherence between the various data sources, last to spatially aggregate sales data of log events, that were allocating to several ICES rectangles in proportion of fishing effort derived from thresholding the speed from VMS data (4.5 nmi/h).

Trajectory descriptors

Characteristics of fishing vessel trajectories were captured using various movement parameters (Dodge et al., 2009). They were computed at each GPS position along trajectories. The movement parameters considered were:

- The speed, which measures the rate of change of the fishing vessel position. It is computed by taking the ratio between the travelled distance and the time needed to travel this distance.
- The acceleration, which is the rate of change of the fishing vessel speed. It is calculated by taking the ratio between the variation of speed over the travelled distance and the time needed to travel this distance.

[3] http://sih.ifremer.fr/Description-des-donnees/Les-donnees-estimees/SACROIS

- The turning angle, which is the direction of change of the movement.
- The straightness index (Batschelet, 1981), which is the ratio between the displacement and the travelled path.
- The displacement is the initial beeline distance to the goal, while the travelled path is the path length travelled to reach it. Computed at the order *k* and for a given GPS position x_i, the initial position is the position x_{i-k}, and the goal position is the position x_{i+k}. Conveniently, the straightness index ranges from 0 when the travelled path is much larger than the beeline distance, to 1 when the travelled path is the straight line. Here, the considered index was averaged over the first four orders.

Then, mean and standard deviation were computed for the various movement parameters for each trajectory, as well as a Gini index. This index measures the inequality among values of a frequency distribution. It equals zero if there is perfect equality (i.e. all values are the same), and it equals one if there is a maximal inequality among values. Practically, the Gini index is derived from the Lorenz curve, which represents the cumulative share of time from lowest to highest speed, for instance, versus the cumulative share of total speed.

Additional descriptors, such as the trip duration, the inertia, and the isotropy, were computed over the entire trajectories. The inertia describes the dispersion of the GPS positions around their mean location, while the isotropy quantifies that the distribution of the GPS positions do not show any preferential direction in the geographical space (Woillez et al., 2007; 2009).

Métiers identification

The métier reflect the fishing intention at the start of a fishing trip (Marchal, 2008). This information is rarely available, unless direct interviews are made with fishermen (Neis et al., 1999; Christensen and Raakjer, 2006). Alternatively, métiers can be defined retrospectively using effort information (e.g. gear, mesh size, fishing ground visited, season) recorded in fishermen's logbooks (Ulrich et al., 2001; Marchal et al., 2006). Other methods assume that catch or landing profile, with or without effort information, reflect the fishing intention. Several multivariate-based methods have been applied: Principal Component Analysis (PCA; Jabeur et al., 2000), Multiple Correspondence Analysis (MCA; Pelletier and Ferraris, 2000), and cluster analysis (Lewy and Vinther, 1994).

Here our methodology consisted in a quantitative analysis of landing profiles using a methodology developed within an R package 'vmstools' (Hintzen et al., 2011; Deporte et al., 2012). It consisted in 3 steps: (i) identification of the main species, and reduction of the dataset to these key species only; (ii) reduction of the dimensionality of the dataset by running a PCA; (iii) running a selection of clustering methods and defining the species-based métier level 7 classifications. However some adaptations were needed, as this methodology was applied on a subset of logbooks/vessels. The PCA step was skipped, because there was no need to reduce the dimension of this dataset as it concerns only logbooks from a few vessels. Then, among the proposed clustering methods, the Hierarchical Agglomerative Clustering (HAC) was chosen. It allowed an objective determination of the number of clusters thanks to a scree-test (Cattel, 1966). On the opposite, the k-means method was not able to do so. Thus, it was rejected. The CLARA method, which was developed to handle clustering on a large dataset, was not appropriate either. For the HAC, the scree-test was adapted to the size of the dataset. The dendrogram was cut after the first largest gain in the clustering variance ratio (variance between clusters/total variance of the dataset). Deporte et al. (2012) were less conservative as they considered the second or the third threshold allowing for more clusters to be found, which may not be appropriate in a smaller dataset like ours.

Exploring activities and trajectories

A Principal Component Analysis (PCA) (Lebart et al., 1984) was used to explore trajectories in relation to activities. PCA consists in a eigenvalue decomposition of the covariance (or correlation) matrix after centering (or normalizing) the data matrix for each variable. Here the data matrix is organized as follows; columns correspond to 18 continuous variables (the 15 trajectory descriptors and 3 technical descriptors) and 3 categorical variables (the gear, the métier and the number of métier per fishing trips), rows correspond to individual fishing trips. The eigenvalue decomposition was performed on the normalized data matrix made of the 15 trajectory descriptors. It allowed us to build uncorrelated factors (i.e. the principal components), which are linear combination of the original variables. The first principal component has the largest possible variance and each succeeding component in turn has the highest possible variance under the constraint of being orthogonal to the preceding components. The original high-dimensional dataset was then projected into a lower-dimensional space defined by the most informative factors. Practically the 2 first plans made of the factors 1-2 and 1-3 were considered. To help the interpretation of these factorial plans, correlations between the original variables and the principal components (i.e. the factors) were represented into correlation circles. Thus the PCA allows describing a dataset by revealing the internal structure of the data in a way that best explains the variance in the data. It allows us to summarize the dataset and to reduce its dimensionality. Supplementary variables were considered to help the interpretation of the PCA. They were the 3 technical descriptors (continuous variables) and the 3 activities variables (categorical variables). These variables did not take part to the eigenvalue decomposition. Supplementary continuous variables were plotted on the correlation circles, while supplementary categorical variables were represented by categorizing individuals with distinct colours in the factorial plans.

Adapting hidden Markov models to activities

Here we adopted a simple approach to model movement to estimate the unobserved behaviour of the fishing vessels. The movement was assumed to be generated by a mixture of random walks with stationary switching probabilities. Conditionally to the behavioural state (noted S) at a given time step t, the observation was assumed to be independently drawn from a normal distribution with parameters μ_S and σ_S for mean speeds V_t, and a wrapped Cauchy distribution with parameters μ_θ and ρ_θ for turning angles θ_t.

$$V_t | S_t \sim N(\mu_s, \sigma_s)$$
$$\theta_t | S_t \sim WC(\rho_\theta, \mu_\theta)$$

Parameters in each state and transition probabilities were estimated within a Bayesian framework using the R package 'RStan'. Most priors were non informative, except for the mean parameter μ_S of the normal distribution of scalar speeds, where an order constraint was set. The priors indeed impose that $\mu_1 > \mu_2 > \mu_3$, with μ_1 drawn in a uniform prior over [1,15].

Two cases study were considered: a fishing trip of a vessel performing 2 different métiers due to the use of 2 different gears, and a fishing trip of a vessel performing 2 different métiers with a similar gear (different landing profiles in value). For each trip, two hidden Markov models were fitted. The first presented 2 states, that could correspond to 'fishing' and 'traveling', while the second had 3 states, that could correspond to 'fishing for métier 1', 'fishing for métier 2' and 'traveling'. Fitting performance were compared using a Deviance Information Criterion penalized for the model complexity. And when available, observed fishing operations were used for validation.

Results

Clustering landing profiles to evidence species-based métiers

The analysis to determine the species-based métiers was run for each gear and for each region. Logbook/sales data showed that 14 distinct gears were used by the 19 vessels from the Bay of Biscay, and 11 for the 12 vessels from the Eastern Channel. However, because the number of fishing trips associated to each gear was variable, only the ones that showed a good sampling coverage (i.e. >100 fishing trips) were considered. The detailed procedure is first illustrated on an example gear, and then results are summarized for all the other gears. The procedure was run over all of the recorded logbook/sales data referenced in SACROIS for the 31 boats considered for years 2011-2012.

For the example gear bottom otter trawls in the Channel - North Sea region, the métier analysis allowed first to extract the main species from all of the log events of the vessels using this gear. The HAC method retained 44 species out of 196 from the initial dataset (Figure 9). The 'perTotal' method was less selective: given the strong dominance of few species in the total value of the dataset, the incremental slope was very low and 24 species, representing 95% of the total value, were retained. The 'perLogevent' method returned 17 species for the recommended threshold of 100% (number of species representing at least this proportion of the value of at least one log event). Combining these three sets of species led to a reduced dataset of 44 main species, i.e. 98.9% of the total value.

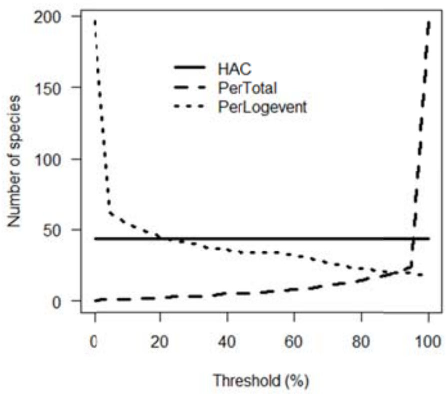


Figure 9. Number of key species to retain depending on methods and thresholds. Species considered here come from log events from vessels operating in the Channel - North Sea region and using bottom otter trawls as gear.

The PCA step was skipped and the HAC method was run on landing profiles of the bottom otter trawls while considering only these 44 main species. The dendogram was cut at the first threshold. 4 clusters were identified (Figure 10). Target species were identified from the species composition of each cluster. Target species should belong to the first 75% of the cumulated catch proportion, have a test value of above 3 and be present in more than 30% of the log events. The target species of the first cluster were, in order of value, whiting, inshore squids, haddock, Atlantic mackerel, lemon sole. For the second cluster, it was cod, thornback ray, red gurnard, black seabream, pouting, nursehound. It was common sole and European plaice for the third, and common cuttlefish, monkfishes for the fourth.

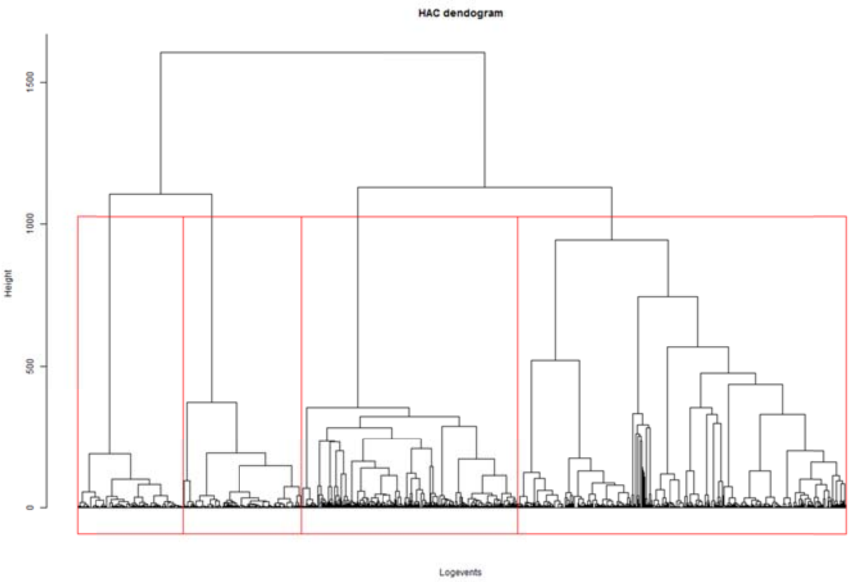


Figure 10. Landing profiles in value (i.e. euro) per clusters for fishing vessels using bottom otter trawls (OTB) in the Channel - North Sea region.

Such analysis was run for each gear and each region. 11 gears were treated with a total of 60 metiers identified. 43 métiers from 10 gears were identified in the Bay of Biscay - Celtic Sea region, while 24 métiers from 6 gears were identified in the Channel - North Sea region. Such analyses allowed identification of métiers based on landing profiles, which provide a valuable knowledge about fishing activities by determining a posteriori the fishing intention at the start of a trip. Such fishing activities characteristics may have consequences on the trajectories patterns of fishing boats

Exploring activities and trajectories

Trajectory descriptors were computed for the 31 fishing vessels operating in the Bay of Biscay - Celtic Sea and in the Channel - North Sea regions for years 2011-2012. First, two separate PCA were done for the two regions. They were performed on trajectory descriptors using gear as a supplementary variable and fishing trips with only one gear and one métier. The idea was to evidence trajectories difference according to gear. Then, two other separate PCA were performed for the two regions, but on trajectory descriptors for fishing trips using the same gear, e.g. bottom otter trawls. This time, vessel references and species-based métiers were used as supplementary variables.

For the PCA run for the Bay of Biscay - Celtic Sea region (Figure 11), the first three axes explained 67% of the total variance; 38% for axis 1, 17% for axis 2, and 12% for axis 3. The first axis is explained positively by the standard deviation of the turning angle and the acceleration, and the Gini index and the standard deviation of the straightness index and the speed. The first axis is negatively explained by the mean acceleration and straightness index and the fishing trip duration. The second axis is only explained negatively by the mean speed and straightness index, and by the Gini index of the acceleration. The third axis is explained positively by the inertia and negatively by the isotropy index. This allowed quantifying of how trajectories differ depending on the gear used during the fishing trip. Trips using fishing pots aggregate tightly in the factorial plan. They are characterized by a short trip duration, low mean acceleration and sinuosity, in opposition to a high variability in turning angle, acceleration, speed and sinuosity. Trips using gillnets, dredges and longlines are quite similar to the ones with fishing pots. Trips using otter twin trawls and bottom otter trawls show similar trajectory characteristics; a long trip duration, high mean acceleration and sinuosity, a low variance in turning angles, acceleration, speed and sinuosity. Trajectory patterns for trawls do not show preferential direction (isotropic) on the contrary to other gears. Trips using pureseine or Scottish seine differ mainly in terms of average speed and straightness index, and of the inequality in the distribution of the acceleration values. Technical characteristics, i.e. vessel length, tonnage and power, were projected on the correlation circle as supplementary variables. All three variables were positively correlated with the mean acceleration and the trip duration on axes 1-2, and with the second order straightness index on axis 3.

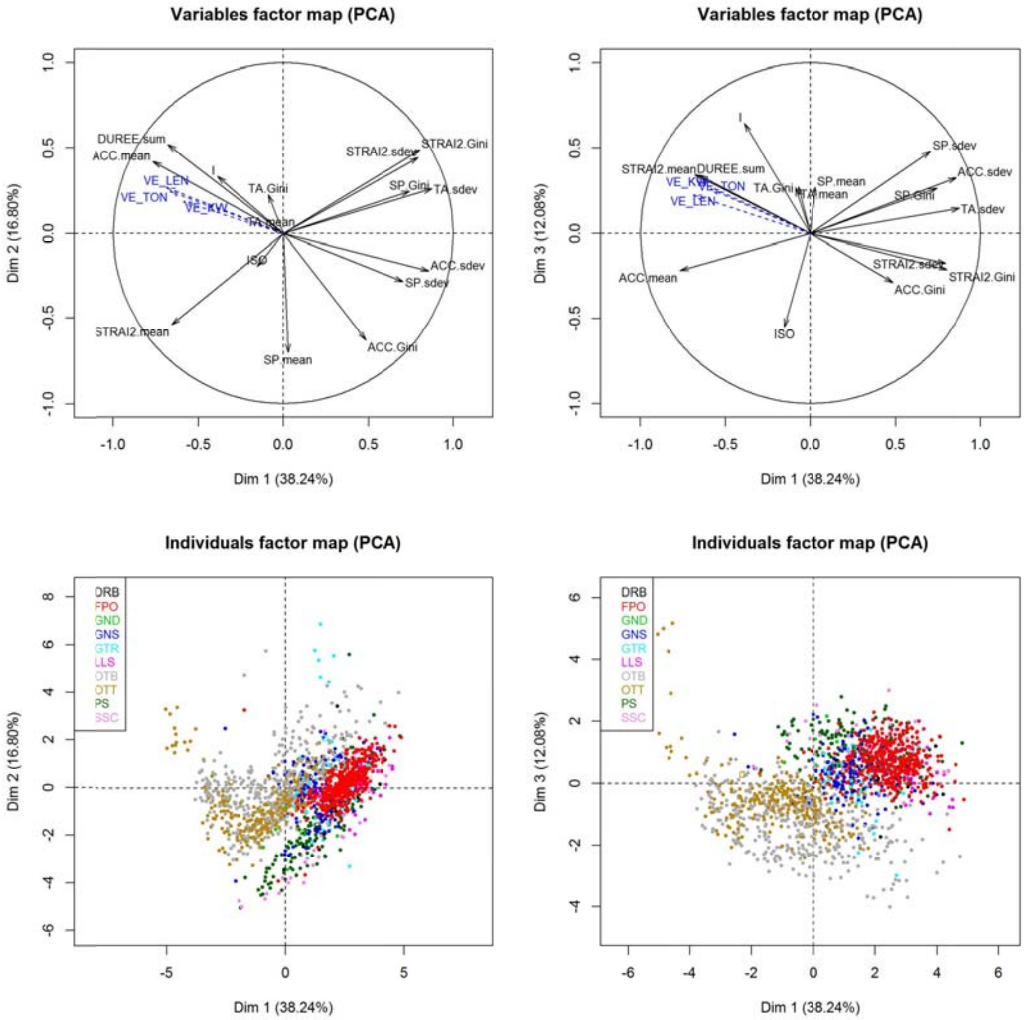


Figure 11. Principal component analysis (Bay of Biscay - Celtic Sea region): Top row: correlation circles for the variables projected in the factorial plan represented by axes 1-2 (left), and axes 1-3 (right). Among all the variables, three were treated as supplementary; the vessel tonnage (VE_TON), length (VE_LEN) and horse power (VE_KW). Bottom row: Projected individuals (i.e. fishing trips) on the factorial plan defined by the axes 1-2 (left), and axes 1-3 (right). Individuals were coloured according to gears they are using.

For the PCA run for the Channel - North Sea region (Figure 12), the first three axes explained 61% of the total variance; 31% for axis 1, 19% for axis 2, and 11% for axis 3. The first axis is explained by the same set of variables as the axis 1 of the previous PCA, except for the standard deviation and the Gini index of the speed. The second axis is explained positively by the mean and standard deviation of the speed, while axis 3 is explained negatively by the Gini of the acceleration. Trips using fishing pots aggregate separately from other trips on the first factorial plan. These trips differ from others in terms of higher mean and variance of the speed. Trips using dredges, trawls or gillnets aggregate together, but differences can be detected. Trips using dredges show the lowest mean and variance of the speed, while trips using gillnets and trawls show intermediate values. Trips using gillnets and trawls differ from each other along the first axis. Trips using trawls show longer trip duration with higher mean acceleration and straightness index than trips using gillnets. The latter shows higher variability of the turning angles, the straightness index and the acceleration than trips using trawls. Technical characteristics were again projected on the correlation circle as supplementary variables. All three were positively correlated with the trip duration and the mean acceleration and on axes 1-3, and with the second order straightness index on axis 1. It is worth noting that the PCA over the 2 regions show a lot of similarities.

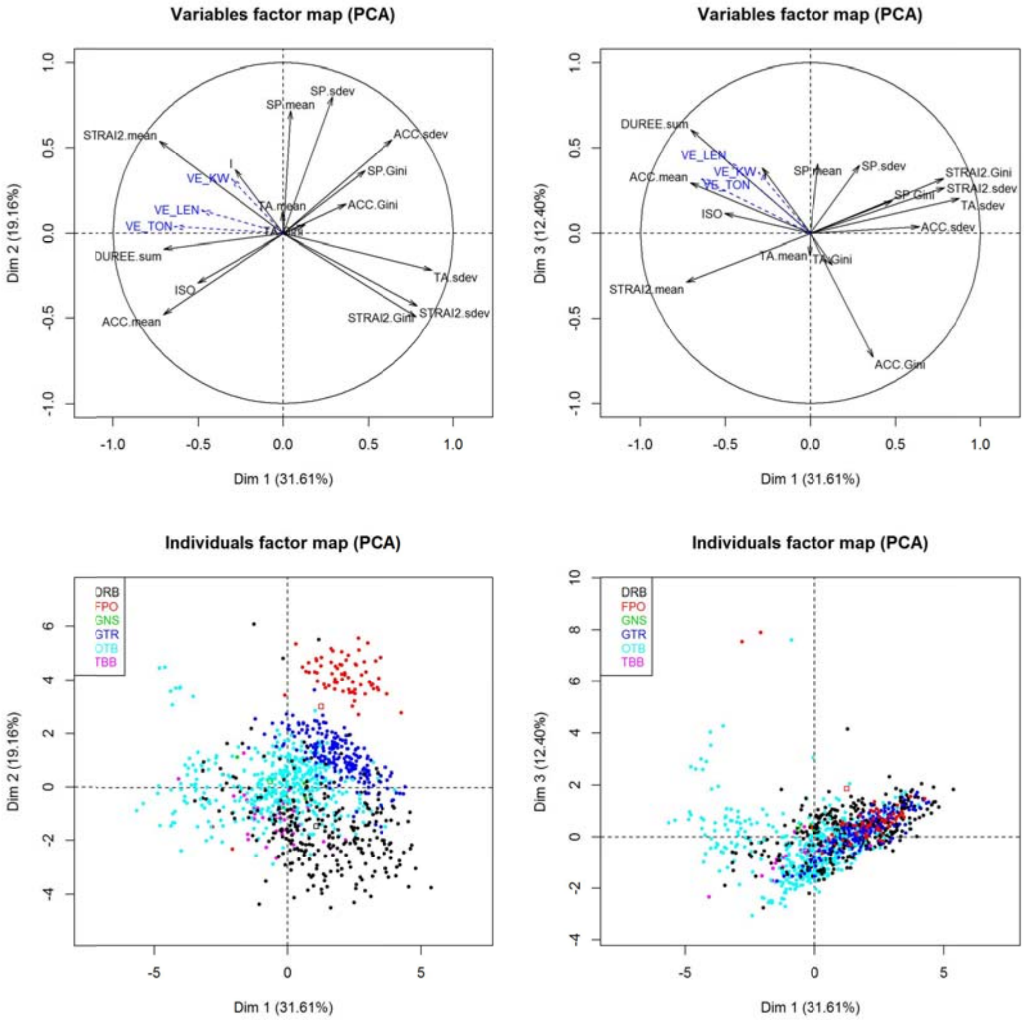


Figure 12. Principal component analysis (Channel - North Sea region): Top row: correlation circles for the variables projected in the factorial plan represented by axes 1-2 (left), and axes 1-3 (right). Among all the variables, three were treated as supplementary; the vessel tonnage (VE_TON), length (VE_LEN) and horse power (VE_KW). Bottom row: Projected individuals (i.e. fishing trips) on the factorial plan defined by the axes 1-2 (left), and axes 1-3 (right). Individuals were coloured according to gears they are using.

A PCA was run on trajectory descriptors from fishing trips using only bottom otter trawls in the Bay of Biscay (Figure 13). By using vessel reference and species-based métier as supplementary variables, one can evidence that, in such a small dataset, some métier are specific to a vessel. For instance, métier corresponding to cluster 3 (inshore squids, surmullet, common octopus, greater weever) is mainly performed by the vessel #6. Common expectation should rather be that métiers are not specific to a vessel. For instance, métier corresponding to cluster 6 (common sole and wedge sole) is practiced by vessels #3, #5, #33 and #38. More interestingly, for a given vessel, for instance, the vessel #33, several métiers are undertaken during distinct fishing trips, and these métiers exhibit different trajectory patterns as illustrated through the PCA. Thus trips of métiers corresponding to cluster 2 and 6 differ mainly in terms of mean speed (positively correlated to axis 2) and standard deviation of the turning angles and the straightness index (positively correlated to axis 1, and negatively to axis 2).

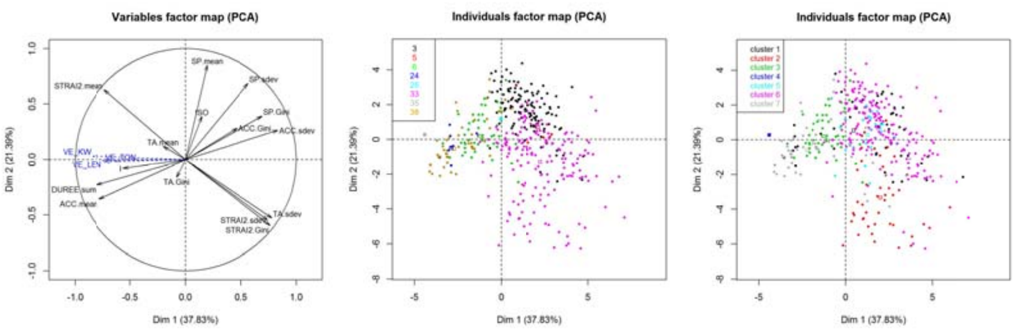


Figure 13. Principal component analysis on movement parameters computed for trajectories of fishing vessels using otter bottom trawl (OTB) in the Bay of Biscay - Celtic Sea region. a) Correlation circle of the variables. Projection of individuals trajectories on the factorial plan (axes 1 and 2) with colours indicating b) the vessel reference, c) the métiers and d) the number of métiers.

The same remarks could be made for the PCA run for trips using bottom otter trawls in the Channel - North Sea region (Figure 14). Trajectories are structured in function of activities characteristics (i.e. vessel characteristics, gears, and species-based métiers).

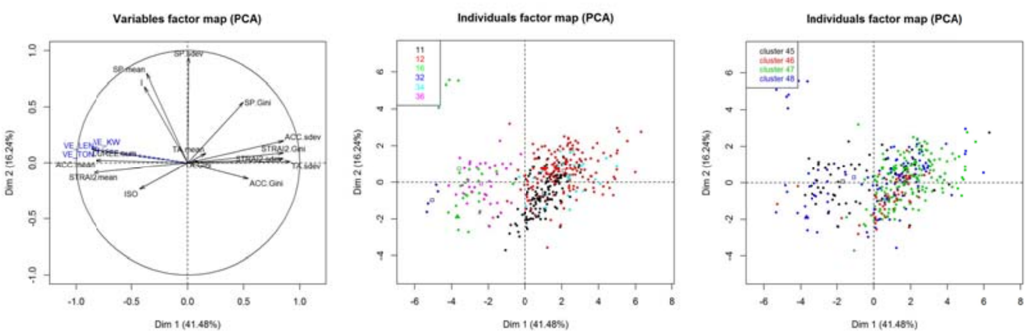


Figure 14. Principal component analysis on movement parameters computed for trajectories of fishing vessels using otter bottom trawl (OTB) in the Channel - North Sea region. a) Correlation circle of the variables. Projection of individuals trajectories on the factorial plan (axes 1 and 2) with colours indicating b) the vessel reference, c) the métiers and d) the number of métiers.

Adapting hidden Markov models to activities

From the conclusions of the previous analysis, one can expect to see a difference in the fishing state characteristics (in terms of speed and turning angles for instance) of 2 distinct métiers when fitting a hidden Markov model. Here we focus on fishing trips where 2 métiers were practiced; one trip with 2 distinct métiers due to the use of 2 distinct gears (case study 1) and another trip with 2 distinct métiers while using the same gear (case study 2). The idea was to see if the addition of a second fishing state (three states total for the HMM) improve the model fit for such multi-métiers fishing trips.

In the first case study, the fit was improved (Figure 26). The penalized deviance information criterion decreased from 932.4 to 877.4. Posterior distributions of the speed for fishing splits into two narrower distributions; one with a higher speed and another with a lower speed. Unfortunately, no observation data were available for this trip for validation.

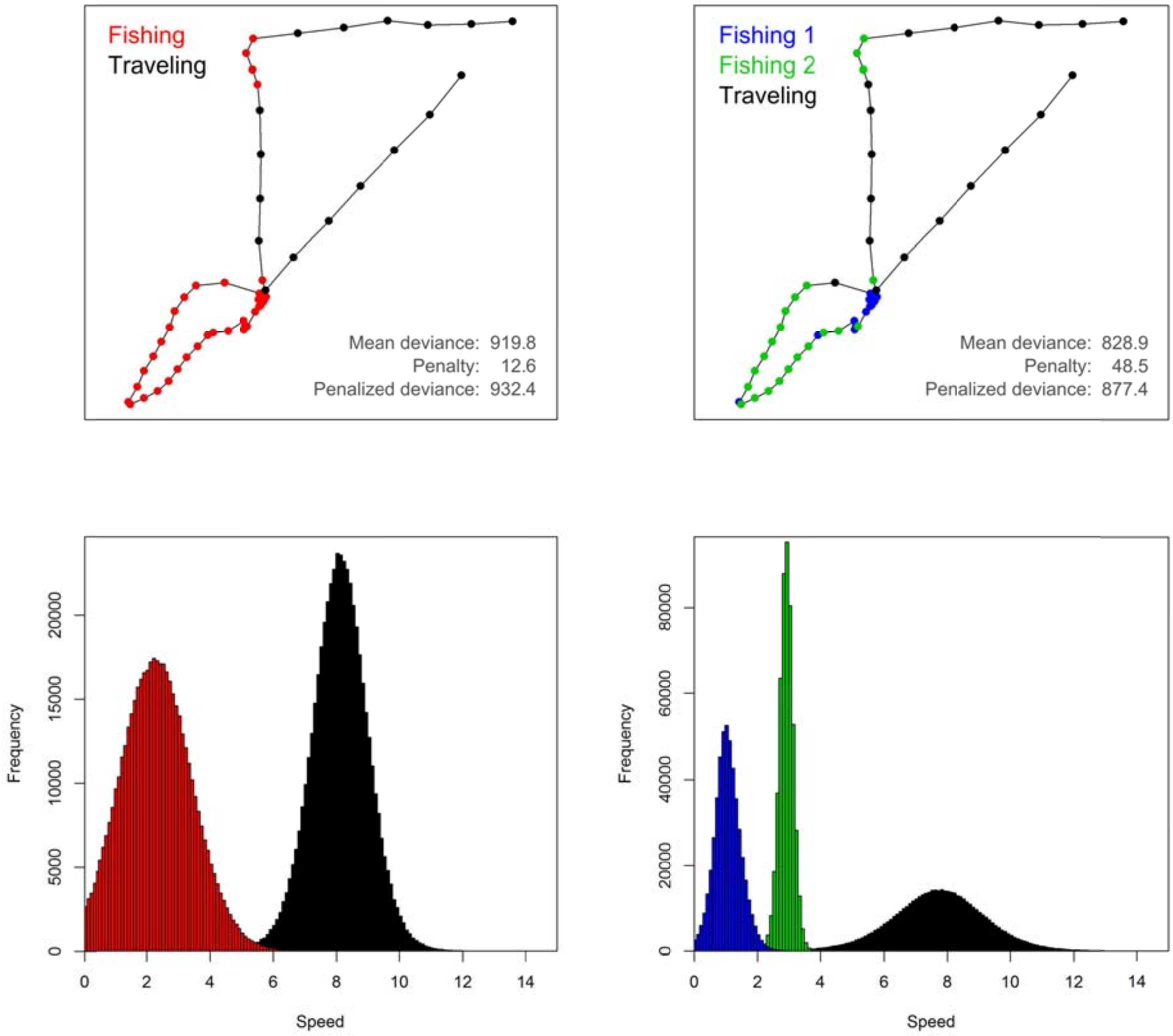


Figure 15. Top: Fitting a correlated random walk model with 2 or 3 states for a vessel (#3) using trawls and gillnets. Bottom: Posterior distributions of speed for states 'fishing' and 'traveling'.

In the second case study, although the fit is also improved (decrease of the penalized deviance information criterion), validation data show that the supplementary state must be interpreted as 'traveling between fishing zones' rather than 'fishing'. Actually, when looking at the posterior distribution of the speed for fishing, the distribution did not change between both model fits. It was the distribution of the speed for traveling which changed. This supported our conclusions concerning the interpretation of the first case study. For these 2 cases studies, results show that 2 métiers, due to 2 different gears, are better estimated (using 2 fishing states) than 2 métiers practiced with the same gear.

Discussion

The results of our study indicate that fishing boat trajectories show movement parameters and patterns in space that depend on the type of fishing activities. Three effects were quantitatively described in a PCA-based exploratory approach; the vessel characteristics (vessel length, tonnage and power), the type of fishing gears (e.g. trawls, gillnets, longlines or pots), and the species-based métiers (sets of target species determined from the landing profiles in value). A set of descriptors were proposed to quantify fishing boat movement (speed, turning angle, acceleration, and sinuosity) and patterns in space (inertia and isotropy). This set was used for describing trajectory pattern in the PCA. However it is not exhaustive and could be enhanced. This exploratory approach succeeded in illustrating the high variability due to fishing activities in the trajectory patterns.

Consequently, hidden Markov models were adapted to account for such variability. This was evidenced on 2 fishing trips using a mixture of métiers either due to different type of gears or not. A Hidden Markov model with 2 fishing states was performing better than a model with 1 fishing state in the case of the trip with 2 métiers due to the use of 2 different fishing gears. In the case of the trip with 2 métiers using the same gear, the third state has a better interpretation as a transition between fishing and steaming, thus the 2 métiers cannot be disentangled. In such cases, covariates describing the environment, such as the time of the day, the season, the habitat, might be better to distinguish the métiers properly.

This analysis was applied on a restricted dataset. Such a procedure could be applied to the complete French fisheries, or at least to vessels above 12m (the ones equipped with VMS). The métier would be defined in the same condition as in Deporte et al. (2012). The number of fishing trips presenting a mixture of métiers due to gear is expected to be different. In the dataset that has been used for this study, most of the fishing trips (>90%) presented a single gear. A lower proportion is expected for the complete French fisheries. Accounting for the gears in the HMM may not make a huge difference when estimating the fishing effort but would increase model's adequacy to reality. Moreover, the allocation of captures to fishing locations may be improved by the estimation of the fishing states corresponding to each gear.

This required that gears are known with confidence. However gears can be incorrectly declared in logbooks affecting the captures allocation, but also the identification of the métiers. Trajectory classification based on the same movement parameters used for the PCA could be undertaken to estimate the accuracy of such information. In addition, the PCA-based exploratory approach could also be used to validate displacement models by comparing simulated and observed movement characteristics.

1.2 Modelling effort distribution using Random Utility Models

1.2.1 Eastern Channel: Spatial effort allocation of French vessels interacting with other fleets, maritime traffic and coastal management

The following study is due to be published as a paper with the following reference:
Girardin, R., Vermard, Y., Thébaud, O., Tidd, A., and Marchal, P. Predicting fisher response to competition for space and resources in a mixed demersal fishery. Submitted to Ocean and Coastal Management. In review.

Section Abstract

Understanding and modelling fleet dynamics and their response to spatial constraints is a prerequisite to anticipating the performance of marine ecosystem management plans. A major challenge for fisheries managers is to be able to anticipate how fishing effort is re-allocated following any permanent or seasonal closure of fishing grounds, given the competition for space with other active maritime sectors. In this study, a Random Utility Model (RUM) was applied to determine how fishing effort is allocated spatially and temporally by the French demersal mixed fleet fishing in the Eastern English Channel. The explanatory variables chosen were past effort i.e. experience or habit, previous catch to represent previous success, % of area occupied by spatial regulation, and by other competing maritime sectors. Results showed that fishers tended to adhere to past annual fishing practices, except the fleet targeting molluscs which exhibited within year behaviour influenced by seasonality. Furthermore, results indicated French and English scallop fishers share the same fishing grounds, and maritime traffic may impact on fishing decision. Finally, the model was validated by comparing predicted re-allocation of effort against observed effort, for which there was a close correlation.

Abbreviations:
DCF: Data Collection Framework

DPMA: Directorate for Marine Fisheries and Aquaculture
EAFM: Ecosystem Approach to Fisheries Management
IBM: Individual-Based Modelling
IFD: Ideal Free Distribution
IIA: Independence of Irrelevant Alternatives
LRI: likelihood ratio index
MSFD: Marine Strategy Framework Directive
RUMs: Random Utility Models
VSS: Vessel Separation System

Introduction

According to the FAO (2012) most fisheries resources are already fully exploited or over-exploited due in part to excess fishing capacity and fishing power. Fishing activities can also have adverse effects on the structure and functioning of marine ecosystems (Buchen, 2009; FAO, 2012). To address that challenge, many fisheries management agencies have adopted an Ecosystem Approach to Fisheries Management (EAFM) (Browman and Stergiou, 2004), by implementing management plans. This approach aims at maintaining or restoring fisheries resources to sustainable levels, while mitigating the adverse ecological impacts of fishing (Pauly et al., 2002). To accurately assess and evaluate fisheries management performances, it is essential to better understand the processes driving the dynamics of the marine ecosystems and the fishing fleets that impact upon them (Fulton et al., 2011; van Putten et al., 2011; Wilen et al., 2002).

Understanding and predicting the complex interactions between resource users and ecosystem dynamics is essential to reduce the risk of management failure (Hilborn, 2004). A founding principle of ecosystem-based management is that humans are fully part of ecosystems (Leslie and McLeod, 2007), and one of the main challenges for decision-makers is to better understand the factors that influence human behaviour (Wilson and McCay, 2001). This is of particular importance to fisheries managers who need to better understand the mechanisms of fishing effort allocation, so as to better anticipate fishers' reactions to management.

Fishers' decision-making can be cast in terms of short- versus long-term choices (Van Putten et al., 2011). For example long-term choices include decisions about capital investment, or about whether to enter or exit a particular fishery (Nostbakken et al., 2011). Conversely short-term decisions may consist of immediate actions, such as choosing a fishing area and/or a type of fishing activity (referred to in this deliverable as a "métier") at the beginning of, or during a fishing trip, and also includes actions, such as discarding fish (Andersen et al., 2012; Hilborn, 1985; Hutton et al., 2004). In this study we concentrated on short-term behaviour, and in particular the factors that determined fishing effort allocation both spatially and across métiers. An increasing number of studies have investigated and modelled short-term fishers' behaviour using both conceptual and data driven approaches. Conceptual approaches include applications of the Ideal Free Distribution (IFD) theory (Gillis, 2003; Rijnsdorp et al., 2000), optimal foraging theory (Dorn, 2001), Individual-Based Modelling (IBM) (Millischer and Gascuel, 2006; Soulié and Thébaud, 2006) or vessel trajectory analysis (Bertrand et al., 2005; Vermard et al., 2010). Many data-driven approaches to fishers' behaviour modelling have built in Random Utility Models (RUMs). RUMs provide an appropriate and functional approach to describe how fishers make a choice among a panel of finite alternatives (Wilen et al., 2002). Such a discrete-choice modelling approach has been applied to analyse fishers' choice of fishing ground (Hutton et al., 2004; Wilen et al., 2002), target species (Pradhan and Leung, 2004a; Vermard et al., 2008), and gear type (Andersen et al., 2012; Holland and Sutinen, 1999; Marchal et al., 2009).

Fishers do not necessarily know all of the surrounding environmental factors and so may only have partial information about the precise position and availability of their target species. In most fleet dynamics studies, skippers have been assumed to choose their fishing ground, gear and/or target species, based on their own experience (e.g. their past choices/activity) and on their economic expectations for a given choice (e.g. past profit achieved). For example, fishers' behaviour can be influenced by fish price fluctuations, which are often seasonal and are an important factor to take into account when evaluating the expected profitability of alternative potential choices (Dupont, 1993; Loannides and Whitmarsh, 1987). Anecdotal evidence suggests that other factors which have seldom been considered in past empirical studies could determine fishers' behaviour. These factors include communication between fishers, or radar-screening of concurrent vessels which may indicate the presence of target species in a specific area. By contrast, skippers compete for space and resources, not only with other fishers, but importantly also with other sectors of activity operating in the same maritime areas. Exploitation of marine resources, for example aggregate extraction, offshore wind farms and maritime traffic can impact the choice of fishing grounds by restricting access or decreasing the availability of fish resources. In EU waters, the Marine Strategy Framework Directive (MFSD) of the European Union (EC, 2008a) requires that the different sectors of activity operating on the same maritime domain be managed jointly rather than in isolation. A key issue for fisheries managers then becomes understanding how fishers operate their activities and adjust their tactics in area-constrained environments.

To assess spatial constraint impact, this study aimed to identify and quantify the determinants of fishing fleet dynamics in one of the most congested maritime area in the world, the Eastern English Channel (ICES Division VIId) (Figure 16).

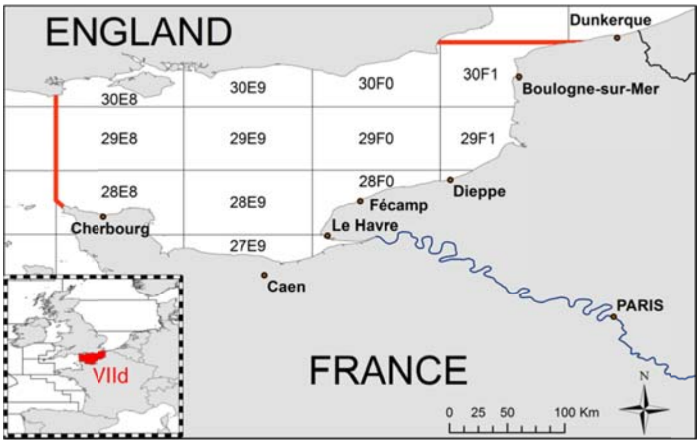


Figure 16. Statistical rectangles and main fishing harbours in the Eastern English Channel (ICES Sub-Divisions VIId).

The analysis focused on French fleets catching flatfish species, sole (*Solea solea*) and plaice (*Pleuronectes platessa*). The flatfish species represent an important source of revenue for fishers in this area, however this fishery has important impacts on the marine ecosystem (Riou et al., 2001). Random utility modelling is used to gain insights into how fishers choose a métier and/or an area, at the scale of a trip, whilst interacting with other fishing fleets, maritime activities and spatial management (regulations). Maritime traffic in the Channel is thought to interact substantially with fishing activities due to it being one of the world's busiest shipping lanes encompassing a large proportion of the Channel (Figure 16 and Figure 17). The main form of spatial regulation for commercial fishing activities in the Channel is the coastal area within twelve nautical miles from the coastline (hereafter called the "12-mile zone") where trawling is prohibited to vessels with an engine power exceeding 221 kW or an overall length exceeding 24 meters. Finally we tested the predictive capability of the model to forecast effort re-allocation one year ahead using two different predictors, and then predicted re-allocation of effort was compared against realised/observed re-allocation of effort.

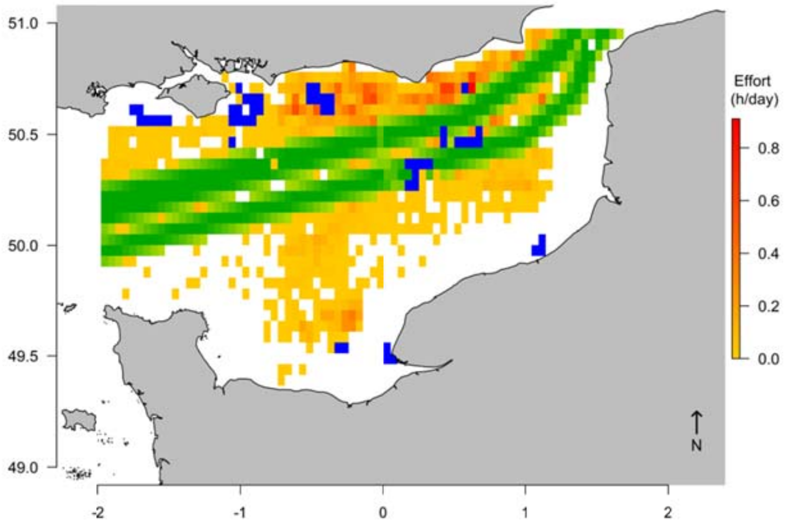


Figure 17. Intensity of the other human uses of the maritime area in the Eastern English Channel per ICES pixel (0.05°. of longitude x 0.05°. of latitude) in 2008. The maritime traffic is represented in green. The aggregate extraction is in blue and the daily average cumulated effort of the English fishery is represented in a shade of red (data derived from VMS data in 2008).

Materials and methods

Data

French fishing fleets

French landings (in both weight and value) and fishing effort data are collected by the French Directorate for Marine Fisheries and Aquaculture (DPMA) from mandatory fishers' logbooks combined with sales slips information. They are available on the "Harmonie" database of the Fisheries Information System managed by IFREMER. Landings in weight and value as well as fishing effort (in hours fished) are available by vessel, fishing trip, gear type and statistical rectangle (ICES rectangle with a surface of 1° longitude × 0.5° latitude,Figure 16). Price per species and per month was derived from the average monthly value of landings. Fishing vessels were categorised into Data Collection Framework fleets (EC, 2008b, 2010; DCF) based on the IFREMER national fleet register and trips were categorised into métiers based on monthly activity calendars (Marchal, 2008). Consistent with EC (2008b), a fleet represents hereby a group of fishing vessels sharing similar attributes in terms of technical characteristics (length class, horse power, capacity) and/or major activity (e.g., main gear used, main species targeted) during a particular year. Vessels belonging to a fleet group may still operate different fishing activities (hereby referred to as métiers) during the year. A métier is defined as a group of fishing trips targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area, and are characterised by a similar exploitation pattern. The different fleet and métier groups considered in this study are shown in Table 3.

Table 3. Description of the fleets (a) and métiers (b) investigated in this study, as defined in the Data Collection Framework (DCF) of the European Union (EC, 2008b). The fleets and métiers coding are specific to this study.

a)

Gear type	Main gear	Vessels length (m)	Fleet code
Active gears	**Demersal Trawlers**	<10	**FL07**
		10-11.99	**FL08**
		12-17.99	**FL09**
		18-23.99	**FL10**
		24-39.99	**FL11**
	Dredgers	10-11.99	**FL26**
		12-17.99	**FL27**
	Vessels using Polyvalent 'active' gears only	10-11.99	**FL38**
		12-17.99	**FL39**
Passive gears	**ALL**	<10	**FL43**
		10-11.99	**FL44**
	Fixed nets	12-17.99	**FL49**
Other fleet		ALL	**FLZZ**

b)

Gear	Fishing activity	Métier code
Boat dredge	Molluscs	**NOS01**
Bottom otter Trawl	Demersal fish	**NOS05**
	Mixed cephalopods and demersal fish	**NOS07**
Beam trawl	Demersal fish	**NOS22**
Mid water otter Trawl	Small pelagic fish	**NOS24**
Trammel net	Demersal fish	**NOS34**
Others		**NOSZZ**

We analysed fisheries data per vessel and fishing trip for the period 2007-2009. During a trip, vessels can operate in multiple ICES (International Council for the Exploration of the Sea) rectangles (Figure 16). Where a vessel visited several ICES rectangles in the same trip, the rectangle wherein it spent most of its fishing effort was attributed to the trip under consideration. The French vessels selected were those registered in the main Channel maritime districts (ICES Division VIId), i.e., Boulogne sur Mer, Cherbourg, Caen, Dieppe, Fécamp, Le Havre and Dunkerque (Figure 16). Those vessels, which had never fished in VIId during the period 2007-2009, were excluded from the analyses. Furthermore, analysis of the landing profiles of each fleet allowed us to determine the flatfish fishery by selecting flatfish landings which represented more than 2% of the total flatfish landings by weight in this area.

Allocation of the fleets' effort across métiers varied intra-annually. Figure 18 illustrates for all demersal trawlers smaller than 18 m (FL07, FL08 and FL09), polyvalent active gear fleets (FL38 and FL39), and for the dredger fleets (FL26 and FL27), the seasonal shift between dredging for molluscs (mainly performed in the winter) and bottom otter-trawling for demersal fish (mainly performed in the summer), or also midwater otter trawl for fleets polyvalent active gear fleets. In addition, an important part of the activity of the smallest trawlers and smallest dredgers (respectively <10 m, FL07, 10-12m, FL26) was composed of the “other métiers” (NOSZZ). In contrast, demersal trawlers larger than 18 m (FL10 and FL11) almost exclusively used bottom otter-trawl for demersal fish (NOS05) throughout the year. Polyvalent passive gear fleets (FL43 and FL44) showed a more constant pattern of activity throughout the year, which was mainly dominated by trammel-netting (NOS34) for the larger vessels, and by the “other métier” group (NOSZZ) for the smallest vessels. A seasonal shift to dredging was observed for the 12-18 m fixed nets fleet (FL49), similar to that observed for the towed gear fleets (Figure 3).

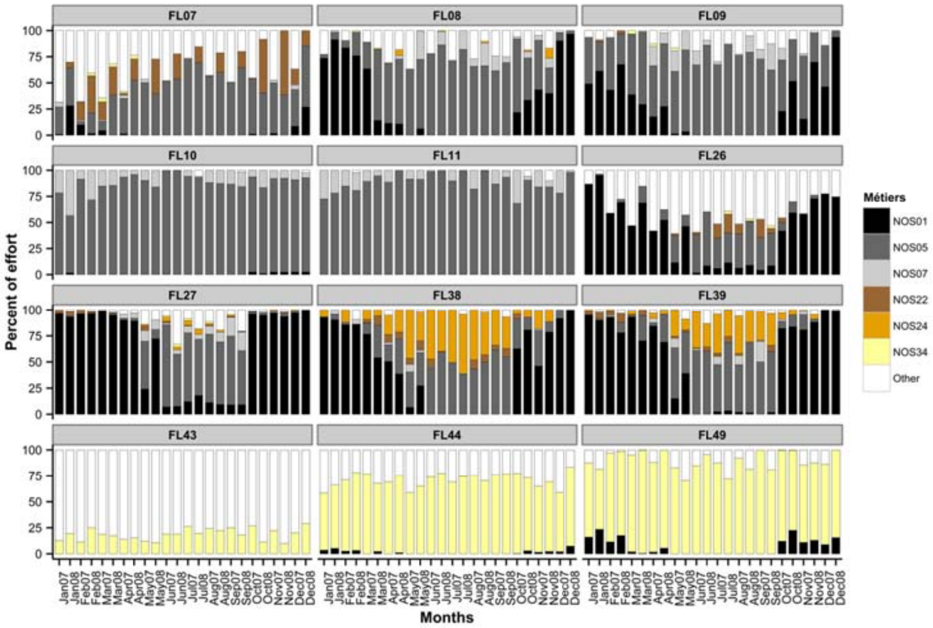


Figure 18. Proportion of métiers used by each selected fleet per month in 2007 and 2008, in percentage of trip chosen (Data used derived from French logbooks and monthly activity calendars).

<u>Other sectors of activity and spatial restrictions</u>

The interactions between each of the French fleets were examined in relation to (i) other French and English fishing fleets, (ii) maritime traffic, and (iii) spatial management. The fishing activity of English vessels (mainly beam trawlers) was represented by their aggregate effort (in hours fished) per day and per ICES statistical rectangle. Most of the large-scale maritime traffic in the Channel occurs through a corridor referred to as the extended Vessel Separation System (VSS; Figure 2). For the purpose of this study, we assumed the pressure exerted by maritime traffic on fishing activities to be represented by the percentage of an overlap of VSS on the ICES statistical rectangle. The 12-mile management zone was represented by the percentage of spatial overlap between this zone and each statistical rectangle. The spatial overlaps described above were calculated using a Geographic Information System (GIS) and then normalized with the surface of each statistical rectangle using R statistical software (R Core Team, 2012).

Fleet dynamics modelling

In order to understand and forecast fishing behaviour, we developed a discrete-choice model using a random utility function. Such models have been widely applied to analyse and model human behaviour and activities (Earnhart, 2002; Holland and Sutinen, 1999; McFadden, 1974; Sammer and Wüstenhagen, 2006). The main assumption of RUM is that individuals seek to maximize their utility (Pascoe and Robinson, 1998; Robinson and Pascoe, 1997; Wilen et al., 2002). Different explanatory variables were tested in order to identify the best model by running the RUM with different sets of explanatory variable (Table 4). A model was parameterized for each of the fleets shown in Table 3.

Several RUM types building on different probability distributions have been used to model fishing choice behaviour. In the present case, two distributions have been considered. First, a conditional logit model (McFadden, 1974 ; Vermard et al., 2008) was used. This is the simplest sort of distribution to be considered, and also the one for which model outcomes are the easiest to interpret. A potentially critical aspect of this distribution model is that it should accommodate the property of independence of irrelevant alternatives (IIA). This IIA requires that for any choice alternatives, the relative odds of choosing one alternative rather than another are the same, irrespective of the availability of the other alternatives or consideration of their attributes (Train, 2003). A nested logit model was then also tested. Nested logit models impose a more complex hierarchical structure that could both alleviate the risk of failing the IIA property by limiting its application to alternatives of the same nest, and better mimic, at least conceptually, the fishers' decision-making process (Holland and Sutinen, 1999; Marchal et al., 2009).

Table 4**.** Description of the explanatory variables used in the Random Utility Model.

RUM explanatory variables	Lag	Description
VPUE_MONTH_1 **VPUE_MONTH_12**	1 month 12 months	Profit expected by choosing a given métier, based on value per unit effort experienced in the past with this métier
EFF_MONTH_1 **EFF_MONTH_12**	1 month 12 months	Habit of a vessel, reflected by past effort allocation by métier
EFF_OTH	No lag	Pressure exerted by other French fleets in a given statistical rectangle
EFF_GB	No lag	Pressure exerted by English fleets in a given statistical rectangle
∑POURC_CPUE	1 month	Proportion of each main species in the landing of a vessel one month before the current trip
SURF_AREA_OCCUP	No lag	Spatial constraint exerted by maritime traffic, estimated by the proportion of each statistical rectangle overlapped by the extended vessel separation system
SURF_12NM	No lag	Spatial constraint exerted by the 12-mile coastal zone, estimated by the proportion of each statistical rectangle overlapped by the management area.

For the conditional logit model, within a fleet, we assumed that at the start of a fishing trip, each individual vessel (v) may choose among several alternatives (i). Each alternative was defined by combining a métier and a statistical rectangle (Figure 16; Table 3). This allocation process is divided in two steps in the nested logit model, with at first, métier's choice corresponding to the nest and then within each nest, the area selection. All areas visited by fishing vessels outside Sub-Division VIId were merged in a unique area (named ZZZZ in this study). Each alternative was associated to a utility function.

RUM explanatory variables

The deterministic part of the Utility function (U_i) was composed of 7 explanatory variables. We assumed that fishers choose their métier and fishing ground with the aim to maximize their returns based on their own experience and also on information gleaned from the other vessels in the same fleet operating the same métier, such as the profit realised by the fleet in the past (Holland and Sutinen, 1999; Marchal et al., 2009). We also assumed that fishers interact spatially with other French and English fleets and that they may be constrained by both Channel maritime traffic and the 12-mile zone.

The main economic variable driving effort allocation decisions was assumed to be $VPUE_i$ defined as the expected returns from choosing métier in a given area. To take into account the potential effects of price differences between species, $VPUE_i$ was derived by weighting past $CPUE_{i,s}$ aggregated per species group s, month and métier, with the current monthly average price (€/kg) per species $Price_s$ (Equation 1).

$$VPUE_i = \sum_s (CPUE_{i,s} * Price_s) \quad (1)$$

Most studies of fishing decisions to date have shown that the decisions by fishers are also often based on their own past fishing patterns (i.e., there is a degree of adherence to traditional fishing grounds and/or métiers) (Holland and Sutinen, 1999, 2000; van Putten et al., 2011, 2013; Vermard et al., 2008). For this reason we included a variable $EFF_{i,v}$ which represents the past monthly average effort allocated for each alternative by each vessel. $EFF_{i,v}$ can be considered to represent the habits of fishers but also their knowledge of fishing grounds. Two different time lags (1 month and 12 month) were applied for each of the variables above (the suffixes *_MONTH_1* and *_MONTH_12* were added to distinguish between these two categories of lagged variables). The monthly average proportion of catch of a species s per unit of effort of a vessel *v*, $POURC\_CPUE_{i,v,s}$, was introduced in the model to represent the degree of targeting of specific species or groups of species by fishers. This was calculated for the top six species in terms of commercial value for the fleets under investigation. These included two flatfish species, sole (SOL) and plaice (PLE), seabass, Dicentrarchus labrax (BSS), cephalopods, *Sepia officinalis* and *Loligo forbesi* (CEPH) and cod, Gadus morhua (COD). Scallops (SCE), were also included as the main target species for the dredging fleets. Other species were aggregated in a seventh species group (OTHFF). Only one month lag was applied for those variables. This is because when the $POURC\_CPUE_{i,v,s}$ with 1- and 12-month lags were used in the same model, none of the other explanatory variables were significant, likely due to a problem of multiple correlations between explanatory variables which was not observed when only one of the two lagged variables was used. The two different time lags for the variables $VPUE_i$ and $EFF_{i,v}$ were kept, to explicitly represent the effect of seasonality in fishing some of the target species, and the influence on decisions of the most recent exploitation cues, hereby observed in the previous month.

To capture the impact of other fishing activities on fisher choices, three choice-specific variables were introduced in the model. The first, EFF_oth_i, represents the spatial interaction with the other French fleets, and it is derived from the sum of monthly average current effort allocated by other fleets to a particular area. The second, EFF_GB_i is the mean cumulative effort allocated by English vessels to a particular area, and represents the spatial interaction between the French fleet under consideration and English vessels fishing at the same time. The two remaining explanatory variables that were calculated represent the spatial constraint exerted by maritime traffic and area-based management on the French fleets. $SURF\_AREA\_OCCUP_i$ is the monthly average overlap between the extended VSS and the fishing grounds, and provides an estimate of the pressure exerted by maritime traffic per ICES rectangle. The variable $SURF\_12NM_i$ represents the 12-mile zone, and was calculated as the percentage of each statistical rectangle that overlapped with this restricted fishing zone. Finally, correlations have been tested between each couple of variables.

In summary, the deterministic part of the utility function was written as follows (equation 2):

$$Ui \sim VPUE_i + EFF_{i,v} + EFF\_oth_i + EFF\_GB_i + \sum_s POURC\_CPUE_{i,v,s} + SURF\_AREA\_OCCUP_i + SURF\_12NM_i \quad (2)$$

<u>Model selection and probability</u>

The two different models, nested and conditional logit, were tested on each fleet. Both models were tested against the IIA hypothesis. The test consists of comparing the estimation of the model with the set of all alternatives *C,* with the same model using only a subset of alternatives *A*. Hausman and McFadden (1984) provide a description of this test which leads to the formulation of a test statistic *S* (equation 3):

$$S = (\theta_A - \theta_C)' * [\text{cov}(\theta_A) - \text{cov}(\theta_C)]^t * (\theta_A - \theta_C) \quad (3)$$

where θ_A and θ_C are respectively the maximum likelihood estimators of the conditional logit model with the subset of alternatives *A* and the one with the set of alternatives *C*. This test statistic *S* follows a χ^2 distribution. The test is performed by comparing the full-alternative model with the model with one alternative missing, for each alternative.

Selection of the best model is based on the McFadden's likelihood ratio index (LRI) (McFadden, 1974), which is similar to a R^2. The model was fitted to 2007-2008 data. The model retained can then be used to calculate the probability of each possible choice i by maximizing U_i. The calculus of this probability is detailed in equation 4 for the conditional logit model with N as the total number of alternative choices for a given fleet.

$$P(i) = \exp(U_i) / \sum_{i=1:N} \exp(U_i) \quad (4)$$

Concerning the two-level nested logit model, this probability may be described as (equation 5; Train, 2003):

$$P(i) = P(m) * P(i|m) \quad (5)$$

where P(i|m) (equation 6) is the conditional probability that the skipper will choose the alternative i after having selected the métier m. P(m) (equation 8) is the unconditional probability that the skipper will choose the métier m before each trip. The deterministic component of U_i can be derived on factors applied to the selection of a nest (a métier) hereafter called Z and others use in the second decision step (ICES area) hereafter called Y. P(i|m) can be expressed as

$$P(i|m) = \exp(\beta' Y_{i|m}) / \exp(IV_m) \quad (6)$$

where β is the parameter vector to be estimated, and

$$IV_m = \log \{ \Sigma_{i \in Cm} \exp(\beta' Y_{i|m}) \} \quad (7)$$

is the inclusive value for métier m. The unconditional probability of selecting à métier m is

$$P(m) = \exp(\gamma' Z_m + \sigma_m IV_m) / \Sigma_{m \in C} \exp(\gamma' Z_m \sigma_m IV_m) \quad (8)$$

where σ_m is the inclusive parameter value for métier m and γ is the parameter to be estimated. The consistency of using a nested logit model is assessed by testing the null hypothesis $\sigma_m=1$ with a Wald χ^2 test.

Forecast

We used the models previously calibrated over 2007-2008 to forecast trip choices in 2009. For each fleet, a set of explanatory variables was considered, and only the coefficients associated to the variables that best explained the model's variability ($p < 0.05$) were used to predict choices in 2009. The input data were derived from the same source of information that was used to describe the fleet choices over the 2007-2008 period, and these were processed in the same way. In many fisheries applications of discrete-choice models, the forecasted choice is taken to be that with the highest probability (see equations 4 and 5) (Marchal et al., 2009; Vermard et al., 2008). However, this approach appears to be rather *ad hoc*, and the prediction performances of the maximum probability estimator have, to the best of our knowledge, never been contrasted with those of alternative predictors, such as the median of the distribution.

In the present case, two methods of prediction were used. With the first method, the choice actually made is assumed to be as in previous studies, the alternative with the highest probability. The second method requires performing 200 simulations. Within each simulation, the choice is randomly selected from a multinomial distribution parameterized by the probability distribution derived from the model calibration. The frequency of each of the alternative choices actually made is then calculated for both methods for each month. For the second method, the median of the 200 frequencies obtained with the random iterations is defined as the frequency of forecasted choices.

To assess the capacity of each method to forecast the trip choice made in 2009, the frequencies of forecasted choices per month are compared to the observed frequencies. χ^2 tests are usually performed to compare observed and theoretical proportions. However, in our case, some choices will not be selected given the information provided by the explanatory variables. Because theoretical frequencies are used as denominators in the χ^2 equation, null values will by construction compromise the utilization of that test. For that reason, another indicator has been calculated in order to evaluate the respective performances of the two prediction methods. This is the mean absolute error (*MAE*) weighted by the total number of trips per month obtained with each method, for each fleet (equation 9) (Willmott and Matsuura, 2005).

$$MAE = [1 / (M * N)] * \sum_{i=1:M} \sum_{j=1:N} |F_{i,j} - Fpred_{i,j}| / F_i \quad (9)$$

Where $F_{i,j}$ is the frequency of observed choice j during month i; $Fpred_{i,j}$ is the frequency of the forecasted choices; F_i is the total number of trips performed by a fleet during month *I*; *N* is the number of alternative choices for a given fleet; and *M* is the number of months during which trips are operated. The method with the smallest *MAE* is considered to be the one which best predicted the global behaviour of the fleets. The package mlogit of the R 2.14.1 software was used to estimate the model and perform the forecasts (Croissant, 2011; R Core Team, 2012).

Results

Model goodness of fit

The correlation between explanatory variable is most of time less than 0.2, except for some fleets for which it can be around 0.5 (especially for variable VPUE or EFF with two different time lags), so all the variables previously described have been tested. The goodness of fit tests for the two models for each fleet using 2007-2008 data are presented in Table 5.

Table 5. Comparison, for each fleet, of the model's goodness of fit to the 2007-2008 data, for the conditional logit model (MNL) and the nested logit model (NMNL) and test of the nested structure with a Wald χ^2 test. An alternative correspond to a métier and area choice combined.

		Number of alternatives	McFadden R^2		LRTEST		Wald χ^2 test (p-wald)
			MNL	NMNL	MNL	NMNL	NMNL
Demersal trawlers	<10m	**16**	**0.68**	**0.69**	**4309.5**	**4358.8**	**90.18** (<2.2e-16)
	10-12m	**29**	**0.55**	**0.56**	**5796.2**	**5876**	**134.32** (<2.2e-16)
	12-18m	**38**	**0.41**	**0.42**	**3272.2**	**3364.9**	**81.71** (<2.2e-16)
	18-24m	**31**	**0.26**	**0.26**	**3208.5**	**3221.5**	**7.59** (0.022)
	24-40m	**24**	**0.17**	**0.18**	**816.59**	**819.54**	**4.34** (0.114)
Dredgers	10-12m	**25**	**0.54**	**0.55**	**4874.4**	**4967.3**	**93.43** (<2.2e-16)
	12-18m	**56**	**0.38**	**0.39**	**12222**	**12272**	**60.69** (6.64e-14)
Polyvalent active gear	10-12m	**33**	**0.33**	**0.34**	**3435.1**	**3548.3**	**60.92** (3.74e-13)
	12-18m	**38**	**0.31**	**0.31**	**3789.4**	**3790.1**	**0.59** (0.75)
All passive gear	<10m	**21**	**0.68**	**0.68**	**28941**	**29298**	**197.11** (<2.2e-16)
	10-12m	**28**	**0.58**	**0.59**	**9838.5**	**9870.5**	**17.31** (0.00017)
Fixed nets	12-18m	**24**	**0.64**	**0.64**	**3252**	**3234.4**	**2.29** (0.32)

For all fleets, the McFadden R^2 was slightly higher when the nested logit model was used and the same result was observed with the likelihood ratio test. The IIA was tested for each fleet; however the property was never fully satisfied for the demersal trawlers of length below 10 m (Table 6).

Table 6. Tests for the IIA property, based on the S statistic, performed on demersal trawlers composed of vessels of less than 10 m and passive gear fleet composed of vessels of less than 10 m.

FL07			FL43		
Deleted choice	**S statistic**	**P-value**	**Deleted choice**	**S statistic**	**P-value**
NOS01 27E9	Negative	-	NOS34 27E8	**34.22**	**0.27**
NOS01 out of VIId	16.12	0.93	**NOS34 27E9**	**13.90**	**0.99**
NOS05 27E9	15.01	0.96	**NOS34 27F0**	**1.27**	**1**
NOS05 27F0	9.09	0.99	**NOS34 28E8**	**Negative**	**-**
NOS05 28E9	Negative	-	**NOS34 28E9**	**17.80**	**0.96**
NOS05 28F0	Negative	-	**NOS34 28F0**	**Negative**	**-**
NOS05 28F1	6.53	0.99	**NOS34 28F1**	**Negative**	**-**
NOS05 29F1	31.42	0.21	**NOS34 29F1**	**41.84**	**0.07**
NOS05 out of VIId	Negative	-	**NOS34 30F1**	**Negative**	**-**
NOS22 28F1	1.16	1	**NOS34 out of VIId**	**399.90**	**<0.0001**
NOS22 29F1	241.84	<0.0001	**NOSZZ 27E8**	**Negative**	**-**
NOS34 out of VIId	Negative	-	**NOSZZ 27E9**	**338.32**	**<0.0001**
NOSZZ 27E9	Negative	-	**NOSZZ 27F0**	**Negative**	**-**
NOSZZ 27F0	Negative	-	**NOSZZ 28E8**	**Negative**	**-**
NOSZZ 28F0	Negative	-	**NOSZZ 28E9**	**Negative**	**-**
NOSZZ 29F1	Negative	-	**NOSZZ 28F0**	**Negative**	**-**
			NOSZZ 28F1	**Negative**	**-**
			NOSZZ 29F0	**Negative**	**-**
			NOSZZ 30F0	**4.58**	**1**
			NOZZZ 31F1	**1.70**	**1**
			NOSZZ out of VIId	**Negative**	**-**
Degree of freedom	**26**			**30**	
Critical chi-squared[df]	**38.89**			**43.77**	

The statistic S was often negative, which does not necessarily contradict with the IIA assumption (Hausman and McFadden 1984). Nevertheless, the S statistic is higher than the critical value for some alternatives (e.g., NOS22

29F1 for FL07, NOS34 outside area VIId and NOSZZ 27E9 for FL43 in Table 6), which contradicts the IIA property. Even if the model was further tested using the nested RUM (this approach relaxes IIA and assumes correlation across alternative choices e.g. (see, Ben-Akiva and Lerman, 1985), the IIA property within nests was still not fully satisfied. Moreover, the goodness of fit of both the nested and the conditional logit models, as given by the LRI index, were very similar, and overall there was little difference between model estimates (Figure 19).

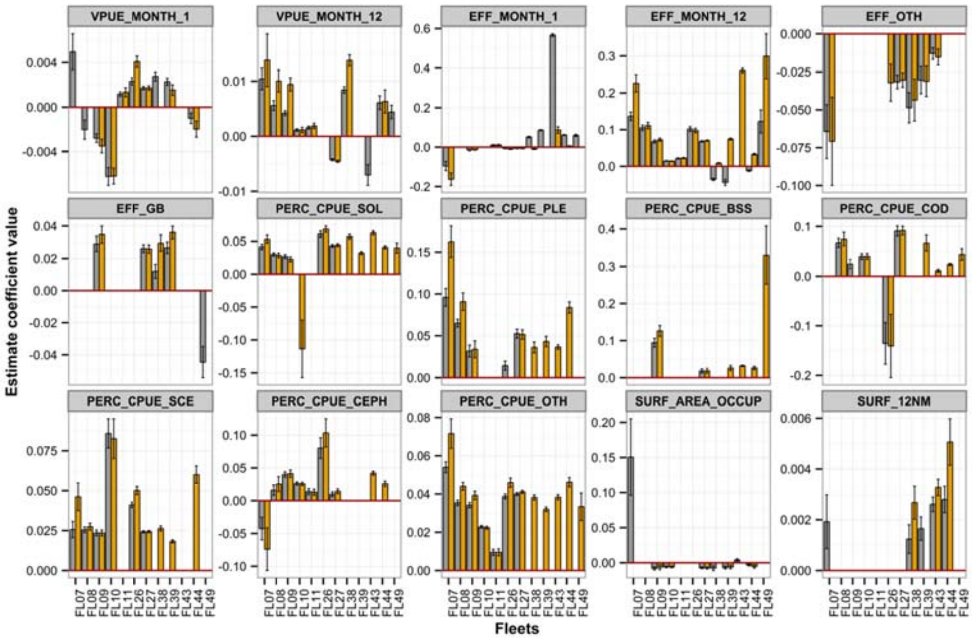


Figure 19. Comparison of each estimate per selected fleet. Grey bars represent the conditional logit model and orange bars the nested logit model with the choice of a métier for the first level and an ICES area for the second level. Only significant estimates are presented.

In addition, considering the result of the Wald χ^2 test, nested models for 24-40m demersal trawlers, 12-18m vessel using polyvalent active gears and 12-18m netters are considered similar to conditional logit models ($p > 0.05$; Table 3). So, further analyses were performed using the most parsimonious model, the conditional logit model. Overall the model provided a good fit for all fleets in 2007-2008 and on average resulted in a McFadden LRI of 50% and a maximum value of 68% for the fleet of polyvalent passive gears of vessel < 10 m. The other fleets resulted in a McFadden LRI of 30% which is still reasonable for a mixed fishery while the poorest fit observed was for the 'large demersal trawler' fleet, with a McFadden LRI of 17% (Table 3).

Parameter estimation

Expected economic opportunities

The effort allocation of all demersal trawlers fleets (from FL07 to FL11) and all of the passive gear fleets >10 m (FL44 and FL49) were always positively influenced by the variable $VPUE\_MONTH\_12_i$, while the effect of variable $VPUE\_MONTH\_1_i$ was dependent on vessel length and gave a negative coefficient for all demersal trawlers of length range 10-24 m (FL08, FL09 and FL10). By contrast, the effort allocation of all dredgers and polyvalent active gear fleets respectively (FL26, FL27, FL38 and FL39) was positively affected by the variable $VPUE\_MONTH\_1_i$, while the impact of variable $VPUE\_MONTH\_12_i$ was dependent on vessel length (Table 5).

Table 7. Parameters estimates from RUM on trip choice behaviour for each fleet. Only the significant parameters are shown and used to forecast the year 2009. The positive coefficients are shown in bold characters (P-value: 0 '***', 0.001 '**', 0.01 '*', 0.05< '-')

Variables	Demersal Trawlers					Dredgers		Polyvalent active gears		All Passive gears		Fixed nets
	<10m	10-12m	12-18m	18-24m	24-40m	10-12m	12-18m	10-12m	12-18m	<10m	10-12m	12-18m
VPUE_MONTH_1	0.0050**	-0.002*	-0.003***	-0.006***	0.0012***	0.0023***	0.0017***	0.0009*	0.0015**	-	-0.0015**	-
VPUE_MONTH_12	0.0104***	0.0056***	0.0042***	0.0012***	0.0016***	-	-0.0043***	0.0104***	-	-	0.0059***	0.0028*
EFF_OTH	-0.064***	-	-	-	-	-	-0.0316***	-0.0434***	-0.0298**	-0.0166***	-	-
EFF_GB	-	-	0.0290***	-	-	-	0.0262***	0.0291***	0.0371***	-	-	-
EFF_MONTH_1	-0.096***	-	-0.015***	-	0.0106***	-0.0056*	-0.0051***	-0.0102***	-	0.0875***	0.0046***	-
EFF_MONTH_12	0.1364***	0.1052***	0.0678***	0.0147***	0.0214***	0.1018***	0.0681***	0.0105***	0.0741***	0.2370***	0.0290***	0.2591***
POURC_CPUE_SOL	0.0414***	0.0300***	0.0268***	-	-	0.0607***	0.0430***	0.0462***	0.0320***	0.0509***	0.0321***	0.0340***
POURC_CPUE_PLE	0.0959***	0.0651***	0.0318***	-	-	0.0144*	0.0526***	0.0313***	0.0427***	0.0309***	0.0707***	-
POURC_CPUE_BSS	-	-	0.0943***	-	-	-	0.0180***	-	0.0263**	0.0286***	0.0207***	0.2920***
POURC_CPUE_COD	-	0.0677***	0.0248*	0.0400***	-	-0.1356**	0.0909***	0.0237*	0.0664***	0.0102***	0.0216***	0.0382***
POURC_CPUE_SCE	0.0257***	0.0255***	0.0235***	0.0859***	-	0.0411***	0.0242***	0.0237***	0.0183***	-	0.0569***	0.0165***
POURC_CPUE_CEPH	-0.0426*	0.0158*	0.0400***	0.0262***	0.0140**	0.0803***	0.0098***	-	-	0.0359***	0.0241***	-
POURC_CPUE_OTH	0.0540***	0.0354***	0.0341***	0.0228***	0.0095***	0.0386***	0.0400***	0.0320***	0.0325***	0.0340***	0.0427***	0.0302***
SURF_AREA_OCCUP	0.1506**	-	-0.008***	-0.006***	-	-	-0.0071***	-	-0.0060**	-	-0.0037*	0.0060*
SURF_12NM	0.0019*	-	-	-	-	-	-	0.023***	-	0.0028***	0.0043***	-

Traditional fishing

The current effort allocation of all fleets rigged with active gears (demersal trawlers, dredgers and polyvalent active gears) was negatively (or not) affected by their past short-term effort allocation, except for the fleet of demersal trawlers 24-40 m (FL11) and all of the passive gears, which were positively influenced by past effort in the same month in the previous year.

Influence of other uses of maritime space

Three different variables represent the potential spatial interactions, which may potentially interact with the French fishing fleet. These include (i) other fleets from France or England, (ii) maritime traffic, and (iii) the 12-mile zone where trawling is prohibited to large trawlers. The presence of English vessels reflected by the variable EFF_GB_i was positively correlated with several of the French fleets: 12-18 m demersal trawlers (FL09), 12-18 m dredgers (FL27), and all polyvalent vessels using active gears (FL38 and FL39). That presence has no effect on the other fleets.

However, most of the French fleets tend to avoid areas with an overlap with other French fishing fleets, as represented by EFF_oth_i which always has a negative influence on the choice of a statistical rectangle.

The proxy representing maritime traffic, $SURF\_AREA\_OCCUP_i$, had a negative influence on the choice of activities by fleets of larger active gear vessels (FL09, FL10, FL27 and FL39), and also the 10-12 m passive gear fleet (FL44). However, the smallest demersal active gear fleets (<12 m, FL07, FL08, FL26 and FL38) display a positive or null coefficient. Choices by the fixed nets fleet (FL49) are also positively impacted by the maritime traffic overlap variable.
The proxy representing the overlap with the 12-mile coastal management area, $SURF\_12NM_i$, has a positive coefficient for fleets consisting of small vessels: demersal trawlers under 10 m (FL07), 10-12 m polyvalent active gears fleet (FL38), under 10 m and 10-20 m passive gears fleet (FL43 and FL44).

Forecasted fishing effort allocation (2009)

The test of the two ways to forecast area and métier choice (based on either the maximum probability or the simulated median method) for 2009, indicated that the median value derived from a random sampling of 200 alternative within the multinomial probability distributions estimated by the RUM best matched the observations. As shown in Table 8, the *MAE* was always lower with the random sampling method than with the method using the maximum of probability as a choice.

Table 8. Comparison of two methods to forecast the trip choice in 2009 based on the parameter estimates from discrete choices models previously analysed. The MAE (Mean absolute error) of each method is shown for each fleet.

Forecast method	FL07	FL08	FL09	FL10	FL11	FL26	FL27	FL38	FL39	FL43	FL44	FL49
Maximum of probability	8.32	2.06	1.89	1.62	3.02	2.65	1.24	3.49	2.48	5.5	1.40	2.31
200 random iterations	6.64	2.01	1.83	1.60	2.50	2.71	1.12	2.65	2.324	3.51	1.07	2.14

Only the small dredger fleet had a better forecast with the maximum of probability method. On average, the percentage of error in the prediction (*MAE*) is low, in most cases less than 5%, and always less than 10%, which is confirmed by visual inspection (see examples in Figure 20).

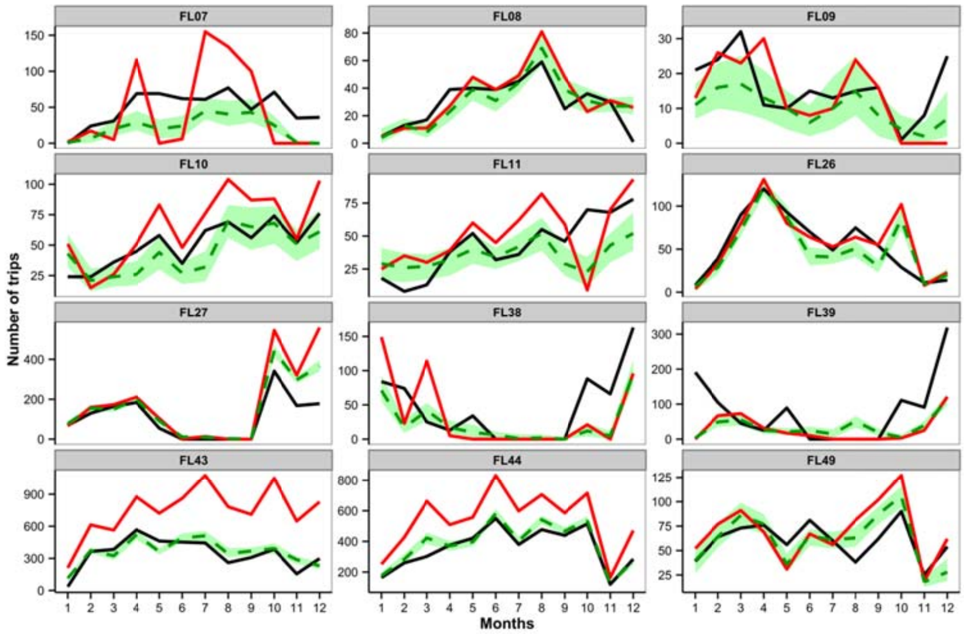


Figure 20. Example of forecast of data in 2009 in number of trips per month for most frequent alternative choice of each fleet: the fleet FL07 when other métiers are chosen in the area 27F0; the fleet FL08 when bottom otter trawling for demersal fish in area 27E9; the fleets FL09, FL10, FL11 when bottom otter trawling for demersal fish in the outside of area VIId; the fleet FL26 when other métiers are chosen in the area 29F1; the fleet FL27 when dredging for molluscs in the area 29F0; the fleets FL38 and FL39 when dredging for molluscs in the area 27E9; the fleet FL43 when other métiers are chosen outside of area VIId; the fleets FL44 and FL49 when trammel netting for demersal fish in the area 30F1. The dark line represents the observed choice in 2009, the red line represents the forecast based on the maximum of probability predictor, the green dotted line represents the median predictor derived from the 200 random iterations and the green area represents the range of predictors obtained with the 200 random iterations.

Discussion

In this study different drivers of fishers' behaviour were quantified using a random utility modelling approach. A novel dimension of our investigation is that, in addition to the explanatory variables usually considered in this type of exercise (e.g., expected profit, tradition), we also considered the impact on the effort dynamics of selected French fleets, in terms of spatial interactions between fleets, the overlap with a spatially competing sector of activity (maritime traffic), and the area based management constraint (12-mile zone). Our results showed the existence of different behavioural dynamics, depending on the main gear used by the fleets and the size of the vessels in these fleets.

Models' selection

All of the models provided a reasonable fit to the 2007-2008 data, even though the IIA property was not satisfied. For spatial analysis, Wilen et al. (2002) have shown that the use of a conditional logit model often causes the IIA property to be at fault. An alternative used in many studies is the nested logit model (Holland and Sutinen, 1999; Marchal et al., 2009; Wilen et al., 2002). However, by considering nested model, the IIA property is still not satisfied within each nest and the information provided is similar to that obtained with the conditional logit model. Train (2003) suggested using the mixed logit model, for which the IIA property is relaxed. Although the mixed logit model can also include choices and individual characteristics, it is also more difficult to interpret, and so was not tested in this study. While the IIA property was not respected, the conditional logit RUM fitted the 2007-2008 fishing effort data well, providing satisfactory predictions compared to the actual 2009 data (average prediction error always lower than 10%).

Another important finding of this study were the limitations associated with the maximum of probability method (e.g. amplification of model outliers) often used to simulate fisher's decision based on random utility models (e.g., Holland and Sutinen, 1999; Vermard et al., 2008; Marchal et al. 2009). We proposed here a method where an alternative is randomly sampled within the probability distribution derived from the RUM. This technique improves the predictions, and it also takes account of the variability of the fitted model. However, this method is more computer-intensive due to the important number of simulations that are needed to reduce prediction error.

Fishers' behaviour driven by past activities

The decisions made by the different fleets in our models are strongly determined by the past activity of each fleet and more precisely by their activity in the previous year. However, the analysis of active demersal fleets also highlights the importance of scallop dredging in the Eastern Channel, which to a large extent determines the short term behaviour of these fleets. Scallop dredging is prohibited to French vessels between the 15th of May and the 1st of October, by ministerial order. Given the economic importance of this activity in the overall pattern of fishing of the fleets, any change in the regulation of this métier can be expected to induce important modifications in fisher behaviour. This regulation implies a seasonal switch in the métier choice of demersal active fleets (Figure 18), which is reflected in the estimated coefficients. Hence, fishers' métier choices are negatively impacted by their past short-term effort allocation, which confirms the strong seasonal variations in fishing effort observed for these fleets. The fleets maintain a similar pattern of choice from one year to another that is shown by the positive value of the variable associated to long-term habits.

The influence of expected returns differs between the demersal trawlers and the other active gear fleets. The positive impact of the *VPUE_MONTH_1* on the small demersal trawlers, dredgers and polyvalent active gears (respectively FL07, FL26, FL27, FL38 and FL39) may be due to their ability to change métier relatively more easily compared to the larger demersal trawlers. Indeed, operators of these small trawlers are used to working across a greater diversity of fishing activities than those of larger trawlers. The large demersal trawlers (from FL08 to FL11) appear to be less reactive to changes in the relative profitability of alternative activities. Based on the model results, it appears that operators of these vessels tend to plan their fishing strategy based on the returns per métier in the previous year, when scheduling a change in the gear used and (or) in the area fished. The largest class of demersal trawlers (FL11) targeting fish (NOS05) as its main activity responds positively to variation in expected returns in the previous month, which could be explained by the fact that most of the activity of this fleet occurs outside of the Channel. The same hypothesis could be invoked to explain the behaviour of the passive gear fleet of vessels 10-12m in length (FL44), the activity of which is mainly focused on the use of trammel net (more than half of the fleet's effort is allocated to this métier)(NOS34). The only fleet with a negative response to relative expected revenue in the previous year is the dredger fleets of 12-18m vessels (FL27). This could be explained by two different hypotheses. Firstly, the effort allocation of this fleet could be explained by an increase of scallop biomass in 2008 compare to 2007. The impact of Scallop availability is shown in Figure 18 where the proportion of effort allocated to the dredge métier (NOS01) in May 2008 (more than 60%) is much higher than it was in May 2007 (20%). Secondly, fishers could have reached their scallop catch quota earlier than expected in the 2007 season, which could also explain the previous observation. However, the results obtained with respect to this 12-month lagged variable must be interpreted with great caution, since only two years of data have been used in this study.

Is there an impact of spatial management and other maritime activities on fisher's behaviour?

Large vessels fishing with active gears are spatially constrained by the fishing activity regulation within the 12-miles zone, inducing an allocation of their effort in the middle of the Channel. Their activity then competes with maritime traffic which is highly concentrated in this part of the Channel. Fishers seem to change their effort allocation during the period of the year with the most important shipping intensity, as shown by the negative coefficient for the variable $SURF\_AREA\_OCCUP_i$ for demersal trawlers (FL09 and FL10), dredgers and polyvalent vessels using active gears (respectively FL27 and FL39). By contrast, the small demersal trawlers fleet (FL07) and the fixed nets fleet (FL49) choose fishing areas where traffic is intense. Fleets of small vessels using active gears (FL07 and FL39) focus their activity in the inshore area, as shown by the positive correlation with the variable $SURF\_12NM_i$ where (except in the Dover Strait) they are not impacted by shipping. This fleet spends most of its fishing activity near the Dover Strait where the maritime traffic is the most intense due to the narrowing of the strait in that part of the Channel but this fact is not captured by the model. Unlike larger boats, smaller vessels using active gears are also limited in terms of the distance to fishing grounds (these vessels operate daily trips, have limited fish storage capacity and limited engine power). For the fleet fishing with fixed nets (FL49), the

Strait of Dover corresponds to the presence of their target species and more particularly sole, which could explain the positive correlation of their area choices with the variable $SURF\_AREA\_OCCUP_i$ (Carpentier et al., 2009). This fleet thus allocates its effort in the statistical rectangle close to the Strait where shipping is the most intense. Moreover this fleet sets its nets on each side of the maritime traffic lines (Carpentier et al., 2009), while the demersal trawlers, dredgers and polyvalent vessels using active gears need to be able to travel across the VSS whilst fishing, which could explain the behaviour difference.

When the interaction between fishing fleets is significant, vessels seem to avoid areas occupied by other French fleets. Small vessels generally fish inshore, while larger vessels using active gears are not meant to be fishing within the 12 miles area, which could partially explain the spatial separation between these fleets. Another hypothesis could be that smaller vessels are able to profitably fish in areas with lower fish density than larger vessels. If this is the case, if localised depletion of fish or congestion of fishing capacity is observed in an area, smaller boats might be able to reallocate their effort to an area with lower fish density but with less competition. Moreover each target species gets its own spatial repartition that could explain the difference of effort allocation observed between each French fleet. The model also, rather counter-intuitively, predicts that French 12-18 m demersal trawlers and dredgers, as well as both polyvalent active gear fleets (respectively FL09, FL27, FL38 and FL39) seem to prefer fishing in areas where UK vessels also allocate their effort. The English fleet is mainly composed of beam trawlers and dredgers both targeting the same species as the fleet segments in France. In particular, both the French and English vessels operate the métier targeting scallops (NOS01), a poorly mobile species, which probably explains why English and French fleets targeting scallops coexist on the same fishing grounds.

Forecast 2009 data

The forecasting model fitted the 2009 data reasonably well. This indicates that our model may be used to predict effort allocation one year ahead with a small level of error. By using the methods of forecast with several iterations, we take into account model variability and increase the accuracy of the prediction, even for the fleets with the weakest model fit. However RUMs are strongly data-driven and they need to be re-evaluated in case of a stepwise regime shift such as the introduction of a brand new spatial constraint (e.g., a marine protected area, or a wind farm). The model could be improved using finer scale data for fishing effort allocation (e.g. satellite based information). Such high resolution data could also be used to assess the impacts of aggregate extraction on fishing effort allocation. The use of detailed indicators of shipping intensity could also add information to our study.

Perspectives

To simulate the ecosystem conservation performances of different management regimes, this model needs to be integrated in a holistic modelling framework which can also predict the responses of the key target species to alternative harvesting patterns. Changes in spatial effort distribution and/or species targeting will change the dynamics of the underlying populations of these species, which might in turn lead to new changes in fishing effort allocation. Such a holistic model should in principle also take into account the process of entering and exiting the fishery. Some studies have already investigated this complex process (Le Floc'h et al., 2011; Pradhan and Leung, 2004b; Thébaud et al., 2006; Tidd et al., 2011), exploring the processes driving structural changes in fishing fleets. In the present paper the RUM can be used as the basis for a fleet dynamics sub-model in an existing holistic model such as ISIS-Fish (Pelletier and Mahévas, 2005), that simulates all the dynamics of the fishery from the biology of the target species to the response to management strategies, or Atlantis (Fulton et al., 2007) that takes into account all parts of the marine ecosystem in interaction with human activities and their management. Such coupled models can be used to test different management strategies and the effect of spatial interactions between different uses of the marine ecosystem.

Conclusion

In this study, RUMs have been used to understand fishers' behaviour interacting with other maritime activities in one of the busiest seas of the world, the Eastern English Channel. Several explanatory variables have been used in accordance with literature. To assess the impact of others maritime activities, the overlap between fishing activities, maritime traffic area and the 12 miles restricted management area has been built in our model. Finally, the between-fleets interactions are also represented in those models. Two different models have been tested, the conditional logit and the nested logit models. None of them fully satisfied the IIA property, and both fitted the 2007-2008 data similarly, so we selected the more parsimonious logit model in subsequent analyses. We showed that all of the fleets considered in this study were strongly influenced by their past activities with specific responses depending on the fleet considered. However, we also showed the importance of the maritime traffic which negatively impacted large vessels using active gears. To simulate the ecosystem conservation performances of different management, considering all of the interactions that occurred between the different maritime activities, this model needs to be integrated in a holistic modelling framework.

1.2.2 Eastern Channel: Spatial effort allocation of English vessels interacting with other fleets, aggregate extractions, maritime traffic and coastal management

The following study is due to be published as a paper with the following reference:
Tidd, A.N., Vermard, Y., Marchal, P., and Pinnegar, J. Fishing for space. Manuscript in preparation.

Section Abstract
Since 2008, the European Union has had objectives for spatial planning and regulation to deal with increasing human activities and pressures at sea. Integrating spatial planning with existing fisheries regulations has been difficult because of the spatial scale at which landings are reported and the fear among practitioners of conceding space to competing activities. To determine the extent that spatial competition influences the choice of fishing grounds, a discrete choice model was applied to fine spatial resolution data obtained from the Vessel Monitoring System (VMS). We analysed the determinants of English and Welsh scallop-dredging fleet behaviour, including competing sectors operating in the eastern English Channel. Results show that aggregate activity, maritime traffic, expected costs, English inshore 6 and French sovereign 12 mile nautical limit negatively impact the choice of fishers, and conversely that past success, expected revenues and fishing within the 12 nautical mile limit have a positive effect on their utility. The model has potential application for Marine Spatial Planning (MSP).

Introduction

As human pressures increase there is a need to balance competing demands for natural resources that society is challenged to manage and conserve for future generations. Experience has shown that once humans have fully exploited a resource on land they look for alternatives at sea. The sea, traditionally seen as a common property resource, is confronted increasingly with competition for space by competing sectors, e.g. fisheries, oil and gas exploitation, aggregate extraction, wind energy, shipping and transport, recreation, dumping and the military. The spatial planning and regulation of the increasing human activities and pressures at sea are therefore becoming a concern, especially given that some resources are limited in space and quantity. If the limited resources are poorly regulated, there may be a race to exploit them, a situation commonly known as the “Tragedy of the Commons” (Hardin, 1968).

Since 2008, the European Union has had objectives that place a responsibility on member states to achieve common principles. It is called the “Roadmap for spatial planning” (EC, 2008c) and falls under the Integrated Maritime Policy (IMP; EC, 2007), and is now generally referred to as Maritime Spatial Planning (MSP). The objectives of MSP are to manage anthropogenic activities in space and time, precluding or minimising conflicts between competing sectors without negatively impacting the ecosystem, operating within the Marine Strategy Framework Directive (MFSD; EC, 2008d) and covering human activities. MSP is therefore an integrated marine management plan to alleviate conflict and balance ecological, social and economic demands to achieve Good Environmental Status (GES) in EU waters. However, because sectors at sea can change rapidly and the complexities of natural systems are linked and inter-reliant, a management decision for one may affect others, and MSP needs to be treated as a process of continuous, adaptive management. Uncertainty associated with compliance to management measures and thus its effectiveness has been linked to a lack of knowledge on the motivations associated with people. Traditional fisheries management treats fishers as fixed components with no consideration of their behaviour in terms of attitudes to fishing (i.e. spatial, temporal, social, ecological and economic) and individual aims (Salas and Gaertner, 2004; McKelvey 1983; Smith and McKelvey, 1986).

The EU's Common Fisheries Policy (CFP) recognised the importance of these factors (EC, 2009a) and is now committed to both an ecosystem approach and more regional approach, whereby fleets and fisheries and their interactions are to be managed within smaller regional areas rather than the broad ecoregions used in the past. Given the importance of MSP, several writers have stressed the relevance of designing fleet-based spatial management in the commercial fisheries sector (Botsford *et al.*, 2007; Kraus *et al.*, 2009; Bastardie *et al.*, 2010a), accounting for different fleet activities at a scale fine enough to feed into the MFSD. To date, integration has been difficult owing to the broad scale (ICES statistical rectangle ~900 nautical miles^2) at which some data (e.g. landings) are reported. With the emergence of Vessel Monitoring Systems (VMS) over the past decade, however, MSP is now potentially possible at a finer scale. Issues of data confidentiality between member states have hampered the process, though, and there is also a historic reluctance of fishers to provide accurate landings information for fear of conceding knowledge of profitable fishing grounds (NSRAC, 2005). Degnbol and Wilson (2008) suggested that fishers are concerned about data confidentiality, especially how the data they provide would be used and by which authority. For example, they especially raise concerns regarding how the data would be used against them by conservationists, as the data could potentially be used to identify productive fishing grounds as suitable for Marine Protected Areas (MPAs) or by fisheries managers to implement tighter enforcement constraints. In the light of the limited data availability and confidentiality, fisheries managers are looking now for alternative approaches to assist spatial planning, which will reduce implementation error i.e. where the effects of management differ from that intended (Peterman, 2004). One such approach involves anticipating fisher behaviour in response to regulation. Recent studies have applied random utility model (RUM) methodology (Vermard *et al.*, 2008; Andersen *et al.*, 2010; Tidd *et al.,* 2012) to this issue, because such models offer an opportunity to study individual behaviour at a finer scale of space and time than previous approaches (Coglan *et al.*, 2004). Fisher behaviour cannot be predicted with certainty because of the many factors (see above) which influence where and when a fisher will operate. If managers can better anticipate fisher behaviour, then they may be able to reduce the unanticipated side-effects of management actions aimed both at the fishery sector and at other sectors.

The objective of the present study was to analyse and model the key determinants of where fishers choose to fish, building on retrospective time-series and including competition between a selection of key sectors of activity and understanding their interaction to these activities. The focus was the English and Welsh scallop-dredging fleet operating in the eastern English Channel (ICES Division VIId). That area also contains one of the busiest shipping lanes in the world, the route between the Atlantic Ocean and the North Sea, and there is a traffic separation scheme (TSS) in operation with 100 vessels in and 100 vessels out per day. It is perceived that such a concentration of vessels would have a negative impact on commercial fishers.

There are also several active marine aggregate extraction sites and fishers have expressed concerns about the accumulation of marine aggregate sites where licences are permitted and the effect of fishing pressure concentrating itself elsewhere for fear of gear damage and the sustainability of fish stocks (Cooper, 2005). In terms of fishing restrictions in the eastern Channel there is a 12 nautical mile belt of territorial water surrounding the base coastline that is sovereign waters (English and French), also English local bylaws restrict beam trawlers of 300 hp or 70 grt from this area and as such restrict competition with the inshore fleet fishing for sole (Figure 21). This ruling also prevents fishing by any international fishing vessel, though the area can be used for safe passage. The 6 mile limit is also a restricted zone to assist inshore vessels by restricting vessels of size >14m. Most of the vessels operating in the region are small (<10 m) inshore boats that deploy gillnets, trawls, longlines, traps and pots, and target sole (*Solea solea*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*), bass (*Dicentrarchus labrax*) and some skates (Rajidae; Pawson, 1995).

A mixed RUM was developed to analyse the determinants of fisher behaviour at a fine scale (a trade-off between ICES rectangle and individual position) using English and Welsh VMS data, highlighting the effect of the key potential competing sectors on fishing behaviour. Suggestions are then made as to how the method can be used in integrated MSP in anticipation of the potential establishment of Special Areas of Conservation (SACs) in the area as part of UK commitments to the EU's Habitats Directive (EC, 1992).

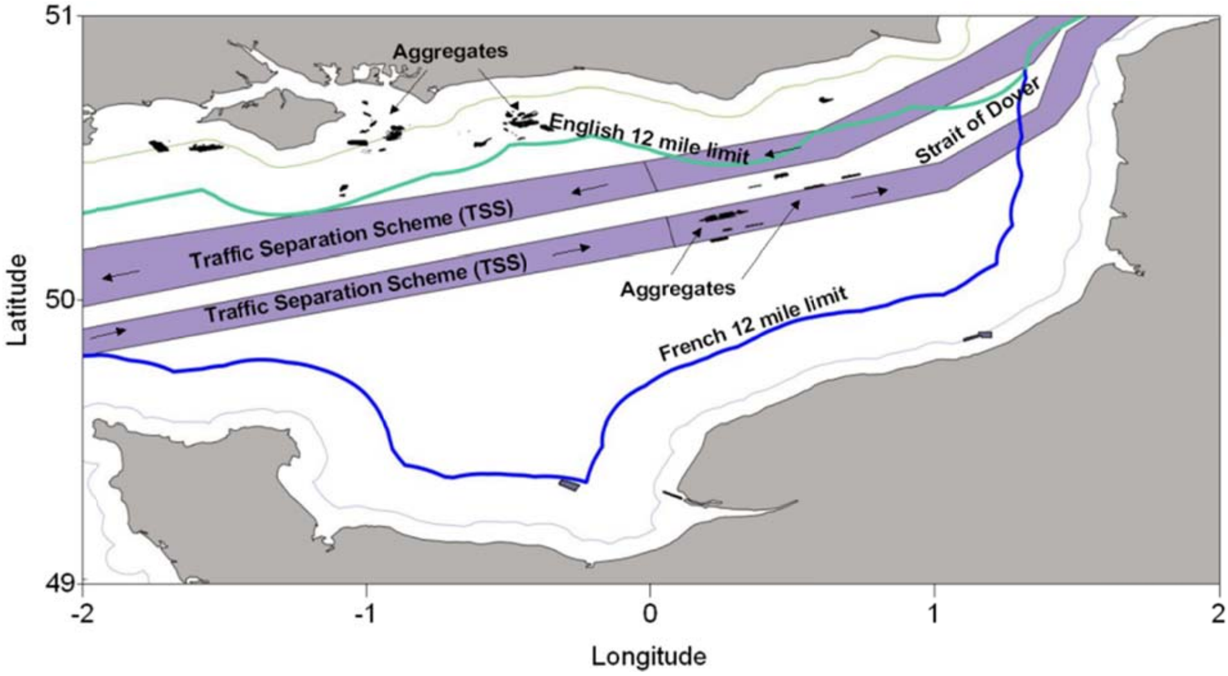


Figure 21. Competition among sectors within the English Channel.

Materials and methods

The UK scallop fleet

The UK scallop (*Pecten maximus*) industry is one of the UKs most valuable fisheries and was valued at >£47 million (£13 million in the eastern English Channel) in 2009, employing >13,000 people in the catching sector and 17,000 in the processing sector (Defra, 2011). Scallops are fished in one of three ways, dredging, trawling and hand-diving. Dredging is the most common method and consists of deploying a heavy metal frame with a chain mesh and a set of spring-loaded teeth pointed downwards to assist in raking out the scallops into the dredge's chain mesh. These dredges are connected to a beam, which in turn is connected to heavy warps that are towed over the seabed by a fishing vessel.

The UK scallop-dredging fleet is said to be nomadic in nature, moving around the UK coast to fish where scallop abundance is best and operating there until those grounds become economically non-viable. They then apparently move to other areas and only return to fished-out areas a few years later when stocks there have recovered (Defra, 2011). The eastern English Channel was traditionally a winter fishery because, following spawning in early summer, the scallops were in poor condition so unmarketable. In recent years, however, there has been an increasing trend in the number of vessels operating in this fishery as fishers in other fisheries have had to confront changes in regional management (e.g. more restricted fishing opportunities elsewhere, such as Cardigan Bay), and market conditions so have subsequently changed their own tactics and strategies in order simply to survive (Mangi *et al.,* 2011). This statement also applies particularly to UK whitefish vessels, for which economic performance has been hit by rising fuel costs and hence high running costs (Curtis *et al.*, 2006).
Scallop fishing is less fuel-intensive (in terms of search behaviour of the fleet) because fishers are chasing a high-value, stationary stock rather than one that is moving continually. There is also the additional pressure for summer fishing grounds for vessels to use, because the Irish Sea fishery is closed from June to October. This notwithstanding, there is discussion of a summer closed season in the Channel being imposed, as is the case in France. A further pressure over the past six or so years has been changes in Scottish fisheries which led to their largest scallopers (14 per side) being banned from Scottish waters, meaning that they can now work only south of the Scottish border (Howell *et al.* 2006).

Defra (2011) suggest that there has been a noticeable increase in fishing effort in the eastern English Channel from 2008 to 2010 and this is predominantly from the larger ≥15 m long more powerful vessels due to the increase in scallop abundance resulting from heavy recruitment. The variability in landings resulting from fluctuations in recruitment, market demand, regulations and more recently fuel price are common features of scallop fisheries. Historically the consequences of which include variability in the number of vessels participating in the fishery due to there being no restrictions on licences or total scallop catches. In 1999 the number of vessels was particularly high so regulatory authorities attempted to cap licences on vessels (≥10 m) (Brand, 2006). However it has been suggested that it had little impact on the fishing effort as there were more licences granted than there were boats fishing in the fishery (Brand, 2006). Nevertheless there are periods of temporal inactivity when stock abundance is low and the fleet move to other fishing grounds (Beukers-Stewart and Beukers-Stewart, 2009). Generally current management of scallop fisheries are controlled through minimum landing sizes and the numbers of dredges regulated by local sea fisheries committees as there are no catch limitations.

Data

The UK's Department for the Environment, Food and Rural Affairs (Defra) database for fishing activity and the fleet register were used to select commercial landing and vessel data from the English and Welsh fleet (excluding Scottish and Northern Irish due to confidentiality issues). Individual trip data for commercial scallopers were collated for the years 2005–2010. The data collected for each vessel included species landed, hours fished, landed weight per ICES statistical rectangle (kg), month of fishing, year of fishing and total value of the catch by species, vessel and trip. Within the EU, it is currently only a requirement for vessels >10 m long to submit logbooks, but the database also contains a subset of catch from <10 m vessels that historically reported their catches by means of logbooks.

Methodology for the definition of fleets was based on the European Commission's Data Collection Regulation (DCR; EC, 2000). A method was developed independently (see EC, 2006), preceding the present Data Collection Framework (DCF; EC, 2008e), which defines the scallop-dredging fleet on the basis of its use of a scallop dredge for >50% of a fishing trip. It is assumed that dredge catches consist mainly of molluscs and that their tactics/métiers can be defined based on the proportional composition of mollusc value to the total value of landings, so removing the differences in catch rates attributable to vessel capacity.

VMS monitoring in the European Union (EC, 2003, 2009b) has been in place since 2000, initially for fishing vessels of ≥24 m long, post-2005 for vessels ≥15 m long, and in 2012 ≥12 m long. The data are designed to help regulatory authorities determine whether a vessel is rule-breaking by receiving a ping every 2 h giving position, course and speed. However it is not totally clear from VMS data whether the vessel is in port, steaming to and from fishing grounds, hauling, shooting or fishing. Over the past few years, authors such as Mills *et al.* (2007), Lee *et al.* (2010) and Hintzen *et al.* (2012) have described methods to determine fishing or steaming activities from unprocessed VMS data, methods that include removal of erroneous data, e.g. positions on land, unusually high speeds, positions close to port and duplicate records. No individual method in the scientific literature has been adopted as the definitive process or preferable to another, however, but for ease and accessibility, the data for the years 2005–2010 were processed in the manner described by Lee *et al.* (2010). Logbook data and VMS fishing records were selected, combined by vessel and ICES rectangle between departure and arrival dates, forming a detailed dataset of fishing activity. The ICES rectangle was further formatted into 200 (3' × 3')-pixel squares coded from 000 to 199, starting from top left and moving to bottom right, placing all the coordinates from the VMS data into the pixels.

Marine diesel prices, excluding value-added tax (VAT) and duty, were obtained from the Department of Energy and Climate Change (DECC). Aggregate-extraction intensity data by month for the years 2005–2010 were obtained from the UK's Royal Haskoning and Ifremer. In terms of shipping/transport traffic information from Automatic Identification System (AIS) was obtained from the Maritime Coastguard Agency (MCA) which is used by port authorities to help prevent shipping collisions and control sea traffic for all vessels over 299 grt. Finally, UK 6-mile and French 12-mile limits were added to the maritime activities dataset because it was considered that competition for space with the local inshore fleet would be an influencing factor. Having populated the dataset with all covariates, the dataset could be used in a mixed RUM to determine the key determinants of fisher behaviour in relation to the key competing sectors of activity as well as fishing specific covariates. It is likely that key competing sectors of activity as well as costs (i.e. fuel price) will negatively impact fishing specific operations (Figure 22), in contrast to expected revenues and past effort (knowledge or habit) largely influencing fishing operations. The scale of the analysis and variables selected are descried below.

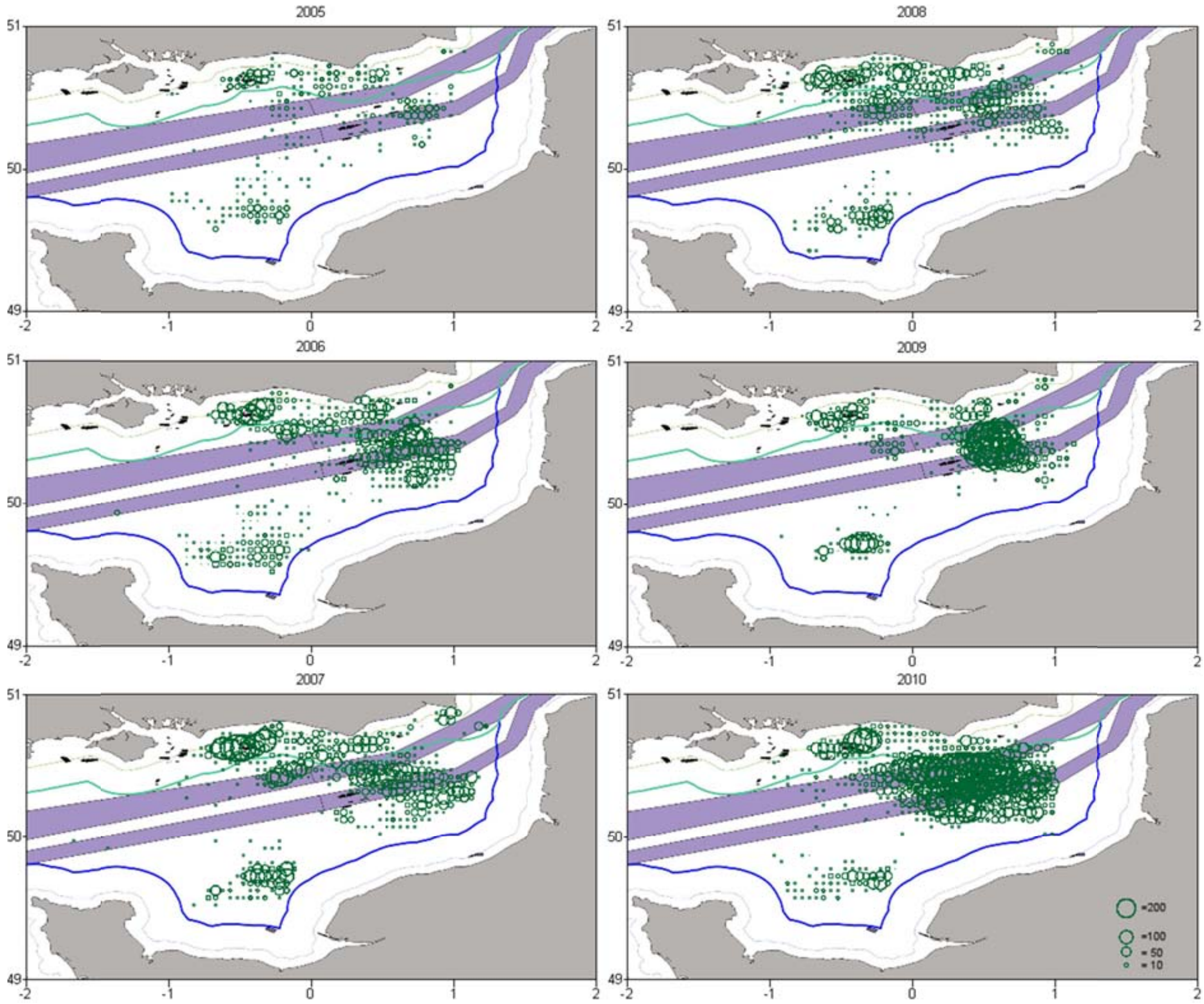


Figure 22. The eastern English Channel displaying scallop dredging effort in hours fished represented by green circles. (See Figure 1 for other activities).

The model

In keeping with the work of Chapter 4 describing the dynamics and drivers of fisher location choice, a mixed logit choice RUM was implemented because it relaxes the non-IIA (Independence of Irrelevant Alternatives) assumptions associated with preference heterogeneity among fishers. This approach is efficient in dealing with panel data for repeated individual choices, as is the case within this study. For a detailed explanation of mixed logit, see Hensher and Greene (2003) and Train (2003). Succinctly, the total utility μ_{njt} of fisher n for site j in trip t is

$$\mu_{njt} = \bar{\beta}x_{njt} + \sigma_n x_{njt} + \epsilon_{njt} \ . \tag{6.1}$$

where $\bar{\beta}x_{njt}$ represents the observed utility and $\sigma_n x_{njt}$ the unobserved utility due to heterogeneity, and ϵ_{njt} is the error distribution that is part-correlated and part independently and identically distributed (iid) over alternatives and individuals (McFadden, 1981; Maddala, 1983). The mean $\bar{\beta}$ plus its standard deviation σ_n are used to represent the preference distribution in the population of fishers (Train, 1998). All covariates met the normality assumption following log-transformation. Within the mixed logit framework, β_n was assumed to follow a normal distribution, and for a given value of n (for simplicity disregarding *t*), the conditional probability of choice *j* across all other choices *k* = 1 to *J* is estimated by drawing random values β by simulation using

$$P_n(j) = \frac{\exp(\beta x_{nj})}{\sum_{\mathrm{k=1}}^{\mathrm{J}} \exp(\beta x_{nk})} \quad , \tag{6.2}$$

where β is a vector of coefficients that varies across individuals, and x_{nj} is a vector of the attributes of each of the choices made. Cost data enter the model with a negative sign and revenues with a positive sign, as suggested in the economic literature (Train, 1998; Ran *et al.*, 2011). The analysis was carried out in the SAS package PROC MDC (SAS, 1999) using quasi-Newton optimisation and 100 Halton draws.

The definition of choice set

When designing RUMs, fisheries scientists are confronted with the problem of creating a choice set, which covers the individual sites to which a fisher travels to fish. If sites are too small (individual latitude/longitude positions), there may not be sufficient site-specific information, but if they are too large, important site-specific information can be lost when aggregating, losing information valuable to policy-makers. Handling many variables with zero data in the choice set may cause problems of maximum likelihood estimation and result in model non-convergence.

Fishers have prior knowledge of resource distribution and habitat (Hilborn and Ledbetter, 1979; Gillis *et al.*, 1993; Pet-Soede *et al.*, 2001), and scallops are relatively static molluscs, suggesting that in future years, any choice set will be subject to relatively little or no change. On the basis of this assumption, the predetermined area making up the choice set for this study was based on the 2005–2010 effort distribution of scallop dredgers plotted from the VMS records (Figure 22). The investigative plots displayed effort coverage over a large area within the small number of ICES statistical rectangles (as previously ICES rectangles were considered too large for spatial planning purposes with pixels too finite). Therefore a trade-off was necessary and the pixels were grouped (25 pixels) into 8 subrectangles based on area (the 15' × 15' rectangles also used by Ifremer's Channel Groundfish Survey, CGFS). These areas were georeferenced into 45 subrectangles, so determining the choice set (Figure 23).

Variable selection

As with other economic/fisher behaviour studies, data on the costs of fishing trips are not always available because of the time and cost taken to collect such information, and the information is also likely to be confidential. Researchers therefore use a proxy of value per unit effort (vpue) rather than cost, which relates to the utility/net benefit of variations in stock density (Marchal *et al.*, 2007; Vermard *et al.*, 2008). Value per choice was calculated as a proportion of the total value (revenues from landings) per ICES rectangle based on effort derived from the VMS, and vpue was then computable. The average vpue by year and month and location choice was calculated for the fleet and lagged in two ways: lagged vpue for a particular month in year t = $-m$; lagged annual vpue in year t–1 = m_{t-1}, i.e. taking account of strong or weak temporal and spatial fluctuations. Habit, knowledge and experience of fishing locations influence fisher behaviour (Begossi, 2001). The past percentage of a particular vessel's scallop trips to a fishing location as a percentage of the fleet total elsewhere was used as the habit/experience variable and to track the seasonal nature of the fishery, as in Holland and Sutinen (1999). These variables were lagged in the same method as explained above.

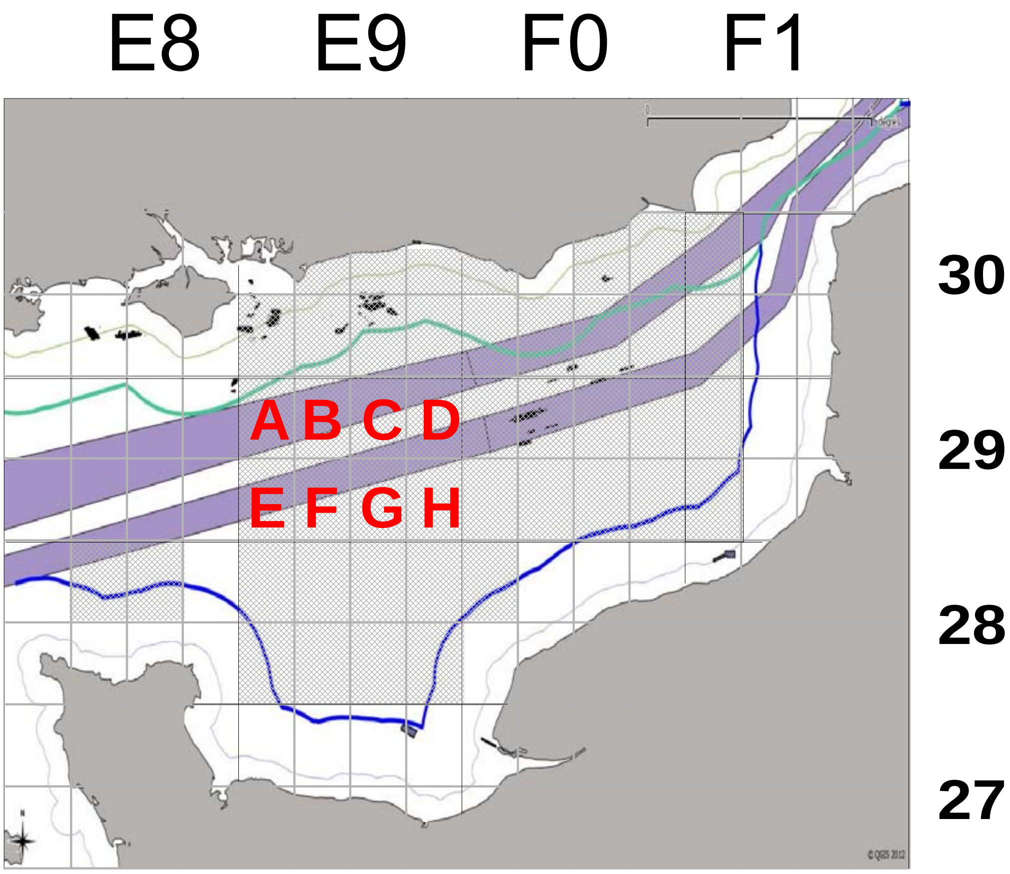


Figure 23. The eastern English Channel with ICES rectangles overlaid and the choice set represented by the hatching geo-referenced by ICES rectangle and the eight sub-rectangles within.

Fishers are assumed to maximise their returns (Robinson and Pascoe, 1997), so depending on weather and other factors, they trade off travel costs against the quality of the fishing grounds. An increase in distance linearly relates to an increase in fuel costs and hence time and energy, so removes the potential for participating in other activities, e.g. fishing closer to shore or non-fishing activities (Daw, 2008). Therefore, in terms of accounting for the expected travel costs and the landing behaviour of the fleet, a proxy for cost was calculated based on the average fleet distance to landing port from VMS fishing locations, calculated using the Haversine formula (Sinnott, 1984), weighted by mean average fuel price, from fishing in the same location in the same month of the previous year fishing (i.e. lagged average costs) as a measure of perceived costs. Aberthany et al (2009) conducted a social survey of fishers in the south west of England and provided year to year evidence that fishers routinely keep track of fuel prices in order to forecast their potential earnings after deductions for other costs are subtracted e.g. crew share. Landing port was used because of the nomadic behaviour of this fleet; it was assumed that the fishers would have prior knowledge of seasonal market prices in the proximity of fishing locations.

Aggregate activity enters the model as the average percentage coverage per choice by fishing year the previous month (to capture potential past activity as a nuisance to fishing operations), but because of inconsistencies between French commercial aggregate data expressed at a daily scale and English intensities at a monthly scale, daily scale records could not be used. The 6 mile limit (as a proxy for the English restricted zone for vessels over 14m) and the 12-mile limit (as a proxy for the French internationally restricted zone) were treated as a spatial constraint (as above). One might assume that the greater the percentage coverage of a restriction, the greater the negative impact on site choice and that site preference would then be elsewhere due to activities that would be a nuisance to fishing. Maritime traffic information in the form of shipping densities from the AIS database was included as average hours occupied by marine traffic as a measure of 'intensity' the previous month in the year of fishing). It could be expected that in some instances high concentrations of shipping could hinder fishing activity and as such have a negative influence in determining site choice. Finally, as a proxy for congestion and social influencing effects by the inclusion of the average hours fished the previous month in the year of fishing by

English, French and other (unidentified fishers grouped) fishing vessels. These data were extracted from the AIS database and treated as separate entities from the maritime traffic. The variable selection set described above was merged with individual scallop trip data by year, month and choice, such that for every trip, the decision-maker had a choice of the specified 45-subrectangles. If the choice was made, the score took a value of 1 if selected or 0 otherwise. The definitions of the variables are listed in Table 9.

Table 9. Definition of variables used in the RUM to model fisher location choice for the 45 ICES sub-rectangles in the eastern English Channel as defined in Figure 23.

Variable	Definition
effyr	Percentage of trips to the location in the same month the previous year (taking account of trips by the scallop fleet fishing in other areas outside of the eastern English channel
vpueyr	Average vpue of scallop from fishing in the same location in the same month in the previous year.
vpuem	Average vpue of scallop from fishing in the same location the previous month in the actual year of fishing.
effm	Percentage of trips to the location in the previous month in actual year of fishing. (taking account of trips by the scallop fleet fishing in other areas outside of the eastern English channel).
traffic	Average hours occupied by marine traffic as a measure of 'intensity' the previous month in the year of fishing.
aggregate	Average % coverage of area occupied by aggregate activity 'intensity' the previous month in actual year of fishing.
eng/fra/oth fleet	Average hours occupied by fishing activity by English, French and other fleets identified in the AIS database the previous month in the year of fishing.
cost	Average distance to port of landing from the same location the previous year of fishing multiplied by the fuel price.
mpa12fra	Average % coverage of area occupied by French 12 mile limit.
mpa6eng	Average %coverage of area occupied by English 6mile limit.

Results

The results from the mixed model showed a McFadden's pseudo-R^2 of 0.19, suggesting a very good fit (McFadden, 1979). Theoretically, the range for McFadden's pseudo-R^2 is between 0 and 1, but the general rule of thumb is that any value from 0.2 to 0.4 suggests an excellent fit as shown in an earlier study by Domenech and Mcfadden (1975) in which they compared ordinary least squares (OLS) R^2 of 0.7–0.9 with the above pseudo-R^2 range. Pseudo-R^2 method differs from a traditional R^2 where the parameter estimates were not calculated to minimise variance via (OLS) goodness of fit process, instead they are calculated via maximum likelihood iterative process and the low values between 0.2–0.4 are considered to be acceptable (McFadden, 1979). Observations from the parameter estimates showed some key features, in terms of significance and direction of the signs. Holland and Sutinen (1999) suggested that the direction of the sign of the coefficient in terms of profit or revenue is an indicator of average risk preference in terms of variability, suggesting as an example that if fish aggregations are not present at certain times of the year, fishers would not go to an area; as such there would be an increase in variability in profit or revenue and the coefficient would be negative. Conversely one may view a positive sign and a small coefficient of variation as showing that fishers are risk-averse and fish in locations of past success or experience.

The estimated coefficients from the mixed model on the 3019 observations available are presented in Table 2. All coefficients were statistically significant ($p < 0.01$) except the coefficient for the average vpue of scallop from fishing in the same location in the same month in the previous year (vpueyr_M, $p > 0.1$) and the proxy for congestion/social influence during the previous month in the actual year of fishing for the French fleet (frafleet_M, $p < 0.1$). The estimated standard deviations of the estimates were not significantly different from the mean indicating that the parameters do not vary in the population of fishers for past expected revenues (vpuem_S), average distance to port of landing from the same location the previous year of fishing weighted by the fuel price (cost_S), average percentage coverage of area occupied by marine traffic (traffic_S) and average hours occupied by fishing activity by English/other fishing vessels (engfleet_S/othfleet_S). Conversely, the percentage of trips to the location in the previous month in the actual year of fishing (effm_S), the average percentage coverage of area occupied by aggregate activity (aggregate_S) and the average percentage trips to the location in the same month the previous year (effyr_S) did vary, perhaps relating to variations in characteristics of the fishers not captured in the model. The signs of the standard deviations in some instances are negative, but for estimation purposes they are free to take any sign, because the normal distribution is symmetrical around its mean, and the absolute value can be taken to estimate the variance.

The effort distribution maps in Figure 22 show the interactions of the scallop dredges with the traffic separation scheme (here represented by the TSS) and the aggregates and fisheries outside the English 6 and French 12-mile limit. Coupled with the model outputs, these results display some notable features. In general the mean coefficients show the signs one would expect (Table 10). The negative sign on the coefficient for the English 6 and 12 mile limit (mpa12fra_M/mpa6eng_M) show that English scallop fishers are negatively affected by the restrictions within these choices (Figure 22). The negative signs on the mean coefficients for aggregates (aggregate_M) and the traffic variables (traffic_M) imply that these sectors impede fishing operations. However, in every year of the study there was a large amount of fishing effort in these areas, even more so in 2010 within the TSS. Perhaps that result is a trade-off in terms of larger expected revenues in these areas. Expected revenues (vpuem_M) show positive signs, which clearly demonstrates that revenue has a significant influence on the tactics of fishers. Nevertheless vpueyr_M was insignificant, which strongly reinforces the in year behaviour as the key driver. In contrast, the cost proxy (cost_M) was found to be negative as expected. Past effort variables (effm_M and effyr_M), which were included to depict habit or knowledge of past success of fishing grounds, have positive coefficients, suggesting they are important drivers in determining fisher location choice.

Table 10. Estimated parameter estimates, the dependent variable took a value of 1 if a choice was made or 0 otherwise ("_M" and "_S" refer to the mean and standard deviation of the variable it relates to, respectively.

Parameter	**d.f**	**Estimate**	**Standard Error**	
traffic_m	1	-0.1589	0.0299	***
traffic_s	1	0.0257	0.3244	
vpueyr_m	1	0.0109	0.0231	
vpueyr_s	1	0.1677	0.0715	**
vpuem_m	1	0.1317	0.0218	***
vpuem_s	1	0.0708	0.1289	
effyr_m	1	0.1479	0.0429	***
effyr_s	1	0.8723	0.0985	***
cost_m	1	-0.2184	0.0421	***
cost_s	1	-0.0105	0.4042	
effm_m	1	0.9894	0.0432	***
effm_s	1	0.8238	0.0786	***
aggregate_m	1	-0.0955	0.0156	***
aggregate_s	1	-0.3503	0.0513	***
mpa6eng #	1	-0.3133	0.0863	***

mpa12fra #	1	-0.2206	0.1097	**
engfleet_m	1	0.0364	0.006452	***
engfleet_s	1	-0.005047	0.0443	
frafleet_m	1	-0.004345	0.009317	
frafleet_s	1	-0.0412	0.0406	
othfleet_m	1	0.0214	0.006978	***
othfleet_s	1	-0.009928	0.0562	

* Statistical significance at *, 10% level, **, 5% level, and ***, 1% level.

Parameters marked _M are the lognormal mean coefficients and _S are their between-population standard deviations. Note: The coefficients for these variables (marked #) are assumed to be fixed as this variable allows for the fact that the probability of visiting a larger less restricted choice is higher than that for a smaller more restricted choice, or else equal (having this variable vary over fishers would not be meaningful) (Train, 1997).
To test the sensitivity to different variables, the mean choice probabilities were calculated from the model output and then compared with mean choice probabilities after re-running the model under alternative scenarios where each variable was doubled/halved one at a time. The differences in probability of location choice, under each of these scenarios, show that the magnitude of the effect on location choice (Figure 24) and how sensitive the variables are to changes i.e. how the variables that penalise fishing operations (e.g. aggregate extraction, marine traffic, and fuel costs) affect fishers, in contrast to expected revenue which should encourage fishing operations.

In terms of aggregate extraction, fishers responded to a decrease in % area covered which most noticeably resulted in a difference in probability of +0.012, in a close to shore associated with aggregate extraction, 30E9G, there were small noticeable increases in 30E9F and 29F0C. Doubling the effect, increasing the size of the site resulted in fishers moving out of the areas of aggregate extraction, notably to 30E9G, 30E9F and 29F0C with a change of probability of –0.018, –0.012 and –respectively. Nevertheless there was an increase in probability into 29F0B, a sub-rectangle which contains aggregate activity which. These observations would suggest that sites that contain aggregate activity heavily influence fisher decision making possibly due to having knowledge of the habitat that scallops live in, coupled with past experience at the more off shore site 29F0B which in recent years are shown to contain the most fishing effort (Figure 22). It would also appear that most of the main scallop grounds are in marine traffic areas (TSS/Traffic densities; Figure 22) and therefore one would expect that with a decrease in traffic intensity there would be less competition for space and fishers would move into these areas.

Maritime traffic, however, surprisingly showed relatively little small effects, doubling the coefficient of maritime traffic intensity resulted in fishing effort being displaced out of the area of the traffic lanes, essentially spreading out, whereas halving the coefficient led to an increase in predicted effort into the areas of the traffic lanes, most notably 29F0A, 29F0B and 29F0C. However, expected fuel cost did not show large significant differences in probabilities of site choice when increased or decreased. Figure 24 suggests that with a halving or doubling of the fuel price fishers change their behaviour, i.e. when fuel prices are halved fishers move closer in shore to the English ports to maximise their utility, in contrast when they are doubled fishers move to areas offshore where the concentration of fishers and expected revenue is at its highest (e.g. areas, 29F0B, 29F0C and 29F0D) or nearer to French landing ports, resulting in a trade-off with expected costs and expected revenue (net benefits).

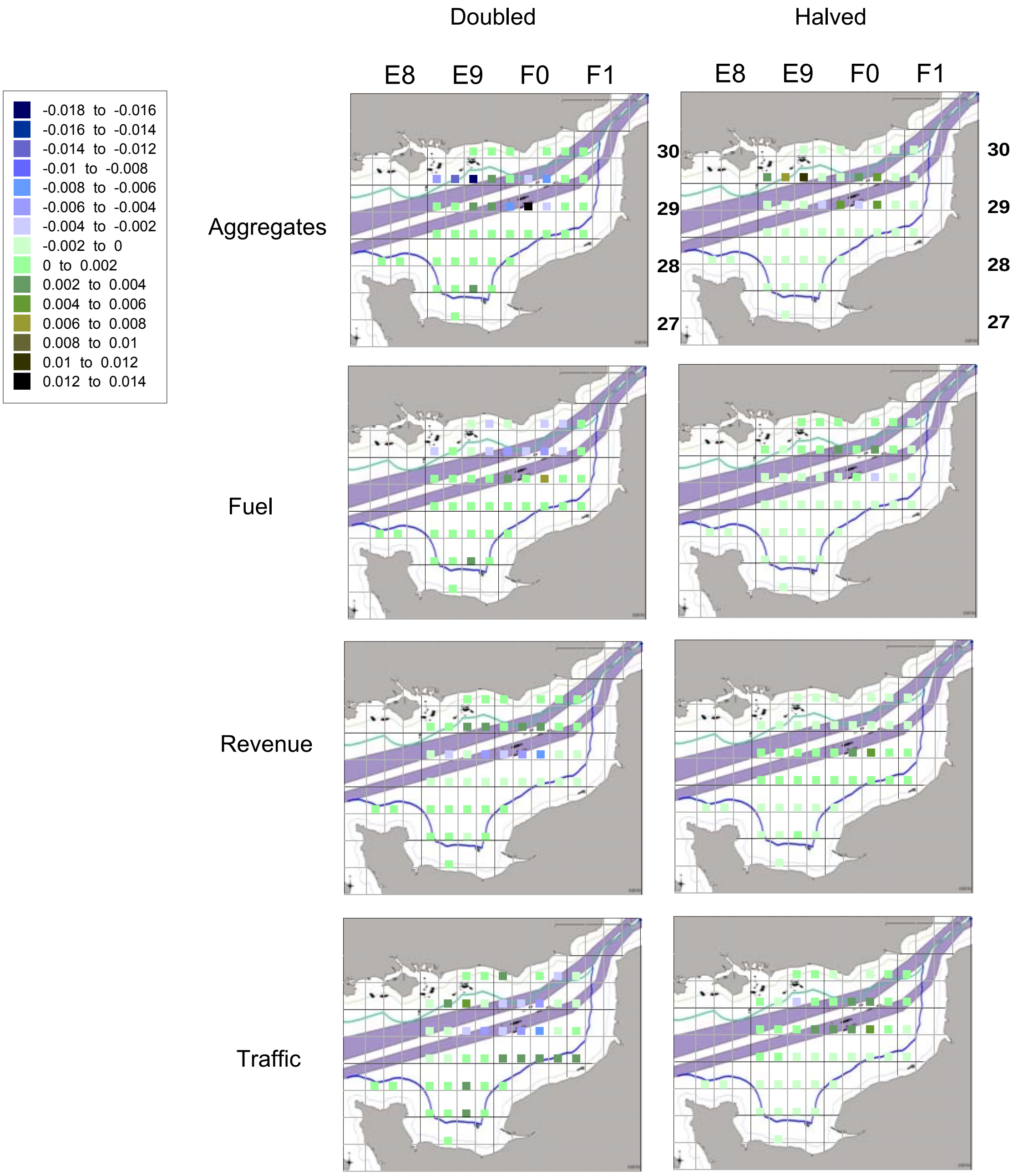


Figure 24. Changes in probabilities when halving or doubling the effects of each variable in contrast to the benchmark model.

Discussion

It is widely recognised that decision-makers and managers now require an ecosystem-based approach to address current interlinked problems social well-being (FAO, 2003). Since the Earth Summit in Rio de Janeiro in 1992 there have been pressures from environmental organisations, increased public and political interest and a concurrent implementation of directives and policies to improve management of human activities on a regional basis by different stakeholders. Marine Spatial Planning (MSP) requires the balancing of multiple objectives, e.g. fisheries managers need to understand the implications of effort displacement from closing an area and the unforeseen consequences of their management actions (e.g. effects on other marine life, economic implications and effects on other maritime sectors).

Several authors have stressed the importance of anticipating fisher behaviour in response to management regulation, in order to reduce implementation error (Dugan and Davis, 1993; Allison *et al.*, 1998; Fulton *et al.*, 2011). Here, a mixed RUM was applied at fine-scale resolution to assess the key determinants of scallop fisher behaviour in the eastern English Channel, so that if there is a new regulation or activity, emerging pressures as well as potential hazards were present, fishing effort re-allocation could potentially be predicted.

A key finding was that past success in a location within the previous month was a predictor of continued fishing in that location. I interpret this as a proxy for habit, knowledge or experience as in other studies (Holland and Sutinen, 1999; Salas and Gaertner, 2004; Andersen and Christensen, 2006). Similarly, the expected utility of visiting one fishing site rather than another in terms of marginal revenue, expressed as vpue, was as significant as expected (Ran *et al.*, 2011). This is more apparent for the vpue in the previous month, rather than in the same month the year before, potentially capturing either seasonality or relatively short term temporal correlations in stock abundance (see Table 10). Surprisingly, perceived fuel costs were not a major driver in choice of fishing grounds, possibly because of the proximity of grounds to landing ports in the eastern English Channel. The French12-mile limit (international restriction/MPA) and English 6 mile limit (inshore vessels <14m/ MPA) unsurprisingly had negative influences on fisher site choice, possibly because of productive fishing grounds adjacent to these limits which are restricted for this size of fishing vessel and/or due to international restrictions. Nevertheless competition from the national fleet could become an issue if the fleet was squeezed into a small enough space, for example by spatial closures. Of policy importance are the effects of the commercial marine environment and associated maritime activities on the behaviour of the scallop fleet; if these are better understood then the additions of other sectors or the addition of other potential aggregate site plans and their implications to this fleet can be assessed in terms of potential effort re-allocation.

In terms of average risk preferences in determining site choice, this fleet is generally risk adverse as the mean of the coefficients does not generally differ from 0, meaning that the choices fishers make generally balance out in the population of fishers. However, by assessing the coefficients that do vary e.g. effm, effyr and aggregates, we are able to assess what proportion of the population of fishers see these factors as positive or negative when making decisions about site choice. Taking together the result of the significant ($p < 0.05$) standard deviation (e.g. effm_S) and mean of the coefficients (e.g. effm_M) for past success in a location within the previous month we can deduce that 88% of the population of fishers see this as a positive inducement and a negative inducement for the other 12%. Similarly past effort in the same month the year previous (effyr) imply that 58% of fishers see this as a positive factor determining their decision making.

The areas occupied by aggregate extraction sites are chosen more than expected with about 40% preferring fishing in these areas, in contrast to the other 60% seeing it as a negative influence, confirming the assumption that the aggregate industry does impact scallop fishing, which takes place in large areas where aggregate licences have been granted since 2005 (Vanstaen *et al.,* 2007). This is contrary to Desprez and Lafite's (2012) findings for sole, which suggests that aggregate extraction can have a positive effect on the catchability of sole by beam trawlers and hence on profitability. Perhaps, increased turbidity increases sole catchability (by reducing visual cues for escape and/or fish being disturbed from the seabed) or the dispersal of food into the water column encourages sole to move away from the bottom to feed.

The existence of the TSS in one of the busiest shipping lanes in the world is a management attempt to alleviate maritime accidents which can also impede fishing. The output from the model suggests that the presence of a TSS significantly reduces the probability of a fisher choosing a location, suggesting that the policy is having the desired effect of separating fishing from other activities, though at the cost of reduced ability to choose areas of potential high profitability. Nowadays, policy makers require information on predictions of potential shares of each alternative chosen by the fishers, and the analysis shows that changing a particular preference parameter it is possible to calculate choice probabilities under alternative policies. For example, an increase in aggregate activity and the likely choices of fishers in response to this, or an increase in traffic densities and the likely effects of effort displacement would have a high chance of displacing effort to local inshore waters (Figure 24). The results from the sensitivity analysis (Figure 24) show that the fleet trades off higher fuel cost by going further off shore with the expectation of the reward of higher returns, and when costs are lower they fish more inshore.

As mentioned above, the fleet is affected by maritime traffic densities; fishing further inshore under increased traffic and surprisingly 'spreading out' of the way of any potential dangers. This may be because the majority of the traffic lanes are home to the main scallop fishing grounds and the specific location they relocate to inshore/offshore have the next best expected catch rates and lower costs in terms of distances to landing ports. This is also apparent for the competition with the aggregate sites, which are located in the heart of scallop fishing grounds. Any reduction of the space taken up by aggregate extraction, especially inshore, shows an increase in effort allocation to those locations. An important point from Figure 24 is that if one of the parameters that disadvantages fishers (e.g. increasing the traffic densities – doubling the effect) is altered, then effectively the competition for space increases and the fishery spreads out, and as such fishers 'fish for space'. This could mean that a reduction in the total space occupied by the vessels could be interpreted as a direct measure of competition within the fleet as well as a response to other sectors. Further investigation would be necessary to prove or disprove this theory, along with the inclusion of other international fishing fleets. Overall, the model describes the nomadic behaviour of the fleet, i.e. in-year behaviour with respect to habit, expected revenue, proximity to landing ports and competition from other maritime sectors.

Conclusions and future work

The Eastern English Channel is a shared resource and there is increasing competition for space and new challenges for novel management approaches by understanding all or some of the interactions between sectors. In parallel to this work, progress is being made on several dynamic processes (e.g. larvae distribution, consequences of aggregate extraction on benthic communities and fishing interactions) that will be implemented into a bio–economic mixed fishery model and a complex ecosystem holistic model using the ATLANTIS (http://www.csiro.au/en/Organisation-Structure/Divisions/Marine--Atmospheric-Research/Atlantis-ecosystem-model.aspx) framework Different management strategies can be performed and their outcomes assessed.

To my knowledge, no other study has used a mixed RUM at fine resolution to assess key determinants of human behaviour in relation to different maritime sectors and as a possible tool for MSP. The results are promising and lay the foundations for future work which could include Marine Conservation Zones (MCZs). Final decisions on where MCZs will be enforced in the English Channel are still a work in progress, so it was not appropriate here to incorporate simulated closure and effort displacement evaluated using Equation (2). Nevertheless, the principle outlined and the approach taken could already be applied to other fleets, as RUMs offer the capacity to model individual behaviour at fine spatial and temporal scales, which is needed for policy decisions (Smith, 2002). Further work could include evaluating trade-offs with both socio-economic and conservation objectives using efficient and effective spatial planning tools such as Marxan and MinPatch, as performed in a study by Wallace (2012) whereby cost layers were introduced in order to evaluate trade-offs. However, Wallace (2012) did not incorporate fisher behaviour and the author stresses the importance to include this in any future analysis. Nevertheless, before such use for policy, the predictive ability of these models does need to be evaluated using a form of cross-validation (see Tidd *et al.,* 2012).

1.2.3 Eastern Channel: Spatial effort allocation of Dutch vessels interacting with other fleets, aggregate extractions, maritime traffic and coastal management

Section Authors
Poos, J.-J. (IMARES), Tidd, A.N. (CEFAS), and Hamon, K.G. (LEI-DLO)

Section Abstract
The RUM structure developed in Section 1.2.2. was also used to evaluate the interactions of fishing effort allocation and shipping for the Dutch demersal fleet fishing in the English Channel, the analyses done for the French and UK fleets was also done for Dutch seiners operating in the Eastern Channel. The parameters associated with the gross revenue all had positive parameter estimates for the means, as is expected from fishers seeking to maximise net revenues. The parameters associated with costs are also positive, which is striking, given that one would expect a cost minimization. The positive estimates could be caused by the trips to Dutch harbours that are in the data set. The closed area parameters are both negative, reflecting the fact that fishing is not allowed in these areas. The parameters associated with the shipping lanes had negative estimates, as in the French and English case, but these estimates did not differ significantly from zero.

Introduction

In Section 1.2.2, an extensive study was done on the spatial effort allocation on French and UK fleets in the English Channel, using Random Utility Models (RUMs). The focus of that analysis was to evaluate the interactions of fishing effort allocation and shipping. Given that there is a Dutch demersal fleet fishing in the English Channel, the analyses done for the French and UK fleets was also done for the Dutch fleets.

Methods

We used information on the Dutch fleet fishing in the Channel from the period 2002-2010 for these analyses. The size of the Dutch "fishing fleet" in the Eastern Channel can be defined by counting all vessels with at least one registered fishing operation in the given year. In 2010 the Dutch fleet consisted of 31 vessels. All Dutch vessels are at least 24 meters long. Total effort of the Dutch fleet in 2010, is smaller than the French effort in the Eastern Channel. However, although the effort is smaller compared to the French effort, it has increased over the last 10 years.
In the analyses we focused on the demersal fleet. This fleet mainly uses Scottish seines. This fleet targets mainly species for which there are no European quota, such as red mullet, gurnard spp., squid and bib. In addition, whiting is caught, which is managed by means of quota set at a European level.

We used three different mixed multinomial logit models, similar to the English and French case study. These models describe the choice of fishing ground as a response to a number of variables, equal to the English and French case study. The difference between the three models is the set of explanatory variables. In model A, we used a set of explanatory models that include the revenue from gurnards (one of the main target species), and the costs (related to the distance from port). Model B is equal to model A, but the costs are removed from the explanatory. Model C is equal to model A, but instead of the revenue from gurnards, we use the revenue from gurnards, red mullet, bib, and whiting.

Results and Discussion

All models significantly explained the observed variance in choices. Table 11 gives the goodness of fit values for model A. The parameter estimates for the three models were fairly similar, especially for the means. The parameters associated with the gross revenue all had positive parameter estimates for the means, as is expected from fishers seeking to maximise net revenues. The parameters associated with costs are also positive, which is striking, given that one would expect a cost minimization. The positive estimates could be caused by the trips to Dutch harbours that are in the data set. The closed area parameters are both negative, reflecting the fact that fishing is not allowed in these areas. The parameters associated with the shipping lanes had negative estimates, as in the French and English case, but these estimates did not differ significantly from zero. This could be caused by the limited set of observations for the Dutch fleet (2008-2010 for a small fleet of vessels).

Table 11. Goodness of Fit values for model A.

Measure	Value	Formula
Likelihood Ratio (R)	3547.5	2 * (LogL - LogL0)
Upper Bound of R (U)	28614	- 2 * LogL0
Aldrich-Nelson	0.5122	R / (R+N)
Cragg-Uhler 1	0.65	1 - exp(-R/N)
Cragg-Uhler 2	0.6502	(1-exp(-R/N)) / (1-exp(-U/N))
Estrella	0.674	1 - (1-R/U)^(U/N)
Adjusted Estrella	0.6718	1 - ((LogL-K)/LogL0)^(-2/N*LogL0)
McFadden's LRI	0.124	R / U
Veall-Zimmermann	0.5726	(R * (U+N)) / (U * (R+N))
N = # of observations, K = # of regressors		

Table 12. Parameter estimates from the three models

		Model A			Model B			Model C		
Parameter	DF	Estimate	SE	Approx	Estimate	SE	Approx	Estimate	SE	Approx
lnlavg_vpue_M	1							0.073	0.023	0.002
lnlavg_vpue_S	1							0.001	0.671	0.999
lnlavg_vpueguu_M	1	0.071	0.024	0.003	0.087	0.023	<.001			
lnlavg_vpueguu_S	1	-0.353	0.044	<.001	-0.377	0.042	<.001			
lnlag_effyr_M	1	0.392	0.037	<.001	0.382	0.034	<.001	0.399	0.037	<.001
lnlag_effyr_S	1	-0.460	0.104	<.001	0.001	0.805	0.999	-0.487	0.094	<.001
lncost_M	1	0.198	0.040	<.001				0.199	0.038	<.001
lncost_S	1	0.016	0.692	0.981				0.005	0.815	0.995
lnlag_effmth_M	1	0.600	0.033	<.001	0.598	0.034	<.001	0.594	0.033	<.001
lnlag_effmth_S	1	0.757	0.056	<.001	0.7966	0.055	<.001	0.748	0.056	<.001
MPA_IV_UK6	1	-0.638	0.089	<.001	-0.797	0.088	<.001	-0.659	0.089	<.001
MPA_IV_FR12	1	-0.753	0.075	<.001	-0.875	0.072	<.001	-0.702	0.075	<.001
lnoth_M	1	0.098	0.013	<.001	0.098	0.012	<.001	0.096	0.012	<.001
lnoth_S	1	-0.059	0.036	0.095	0.058	0.036	0.100	-0.052	0.039	0.186
lnfra_M	1	0.046	0.007	<.001	0.041	0.007	<.001	0.047	0.007	<.001
lnfra_S	1	-0.003	0.085	0.976	-0.002	0.114	0.988	-0.001	0.089	0.996
lneng_M	1	0.028	0.006	<.001	0.029	0.006	<.001	0.029	0.006	<.001
lneng_S	1	0.062	0.022	0.004	-0.071	0.020	<.001	0.059	0.022	0.007
lnsoa_tra_M	1	-0.027	0.020	0.176	-0.030	0.018	0.098	-0.020	0.019	0.290
lnsoa_tra_S	1	0.052	0.133	0.694	0.0285	0.162	0.860	-0.047	0.139	0.734

1.2.4 Dogger Bank & German Bight: Spatial effort allocation of Dutch fleets interacting with other fleets

The following study is due to be published as a paper with the following reference:
Hamon, K.G., Girardin, R., and Poos, J.-J. Spatial effort allocation of Dutch fleets interacting with other fleets.

Section Abstract
The RUM developed in Section 1.2.1 was also applied to the Dutch beam trawl fleet (2008-2010). The Dutch fleets' activity was well captured by the model including only biological and economic drivers. Predictions were accurate and followed the seasonal patterns well. To predict the long term changes in fishing activity additional factors, such as the competition for space with other marine users, should be included and changes in fish distribution should be linked to the current model.

Introduction
The method developed by Girardin et al (1.2.1) was applied to the Dutch beam trawl fleet (2008-2010).

Material and methods
The beam trawlers were separated in four fleets according to the vessel size. The four fleets are described in Table 13.

Table 13. Dutch beam trawler fleet included in the study with number of vessels.

Fleet	Fleet code	Number of vessels
12-18m beam trawlers	FL03	5
18-24m beam trawlers	FL04	248
24-40m beam trawlers	FL05	57
>40m beam trawlers	FL06	107

The activity of those four fleets was characterized by i) the fishing activity codes[4] defined at the EU level as the combination of the gear and the targeted species and ii) the fishing area (taken here as the ICES rectangles). Only 2 main fishing activities were identified based on gear and targeted species: beam trawl targeting crustaceans (NOS21) and beam trawls targeting demersal fish (NOS22), other activity is characterized as NOSZZ. The fleets operate the 3 activities in different areas, the number of areas where activity has been observed is shown on

Table 14. The total number of métiers (activity x area) is shown for each fleet.

Table 14. Number of areas in which each activity is operated (based on 2008-2009 data)

Targeted species		FL03 12-18m	FL04 18-24m	FL05 24-40m	FL06 >40m
Crustaceans	NOS21	14	21	15	
Demersal fish	NOS22	3	31	35	51
Other	NOSZZ	3	22	23	15
all		20	74	73	66

The method applied consists of understanding the choice of metier for each fleet/vessel per month. A number of drivers have been selected a priori to explain individual choices (see table 3). They include

- attractiveness of the metier for the fleet (captured by a constant);
- value per unit of effort (VPUE) of the metier the previous month and the same month the previous year;
- effort of other fleets in the area for the month (other Dutch fleet, German fleets, Danish fleets and English fleets);
- the effort of the vessel in the metier the previous month and the same month the previous year;
- and the importance of key species in the catch composition (key species include shrimps, sole, plaice, cod, brill, flounder, dab and turbot).

Other activities such as transport and wind farms were tentatively included but the low extent of these activities compared to the size of the area (North Sea) created singularity issues.

[4] DCF - Annex III of Council Regulation (EC) No 199/2000

Table 15 Factors included in the model for each fleet

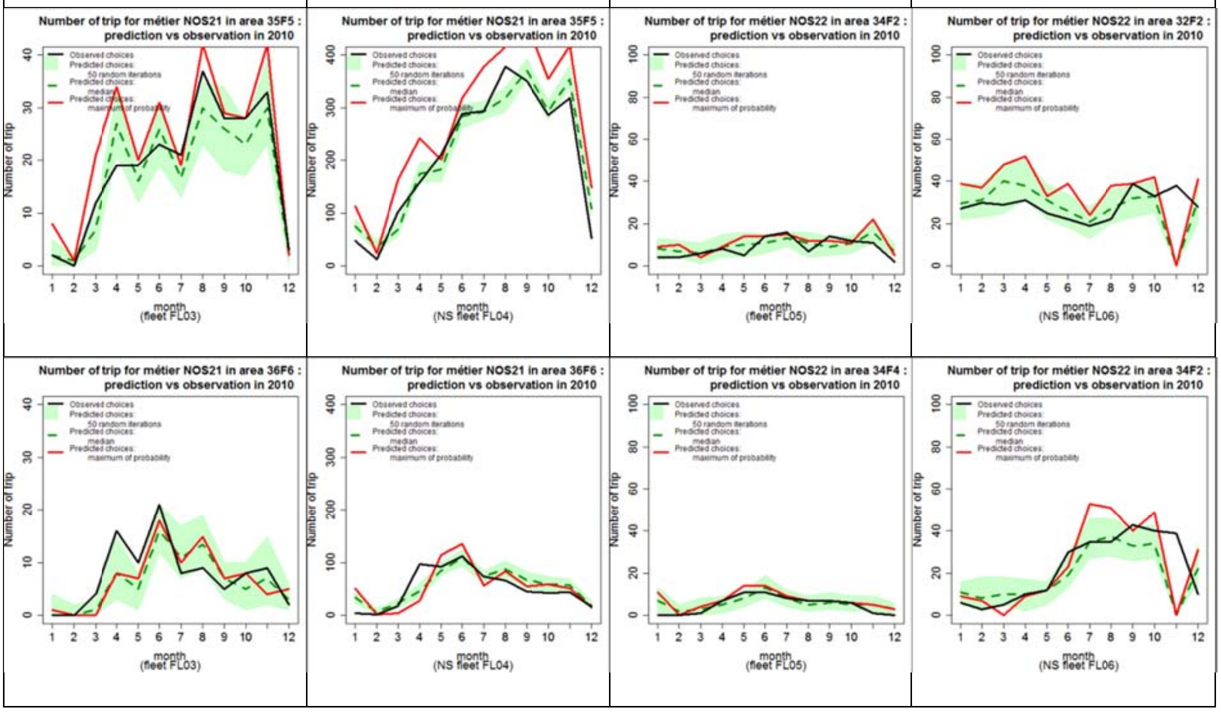
	12-18	18-24	24-40	>40
Constant per choice	X	X	X	X
VPUE m-1	X	X	X	X
VPUE m-12	X	X	X	X
Effort other NL	X	X	X	X
Effort DE	X	X	X	X
Effort DK	X	X	X	X
Effort EN	X	X	X	X
Effort m-1	X	X	X	X
Effort m-12	X	X	X	X
% CPUE CSH	X	X	X	
% CPUE SOL	X	X	X	X
% CPUE PLE		X	X	X
% CPUE COD	X	X	X	X
% CPUE BLL		X	X	X
% CPUE FLE	X	X	X	X
% CPUE DAB	X	X	X	X
% CPUE TUR		X	X	X
% CPUE other	X	X	X	X

The parameters calculated on the 2009 data (and 2008 for the effort and VPUE of the same month, previous year) were used with the 2010 data to predict the choice of the fleets in 2010.

Results and Discussion

The monthly predictions fitted the observations well despite the large number of choices (as shown on a subset of options Figure 25, the predictions for the four most frequent observed metier for each fleet). The intensity of the choices as well as the seasonality are well captured with the model except for the choices made in November by the larger beam trawlers (FL06).

FL03	FL04	FL05	FL06



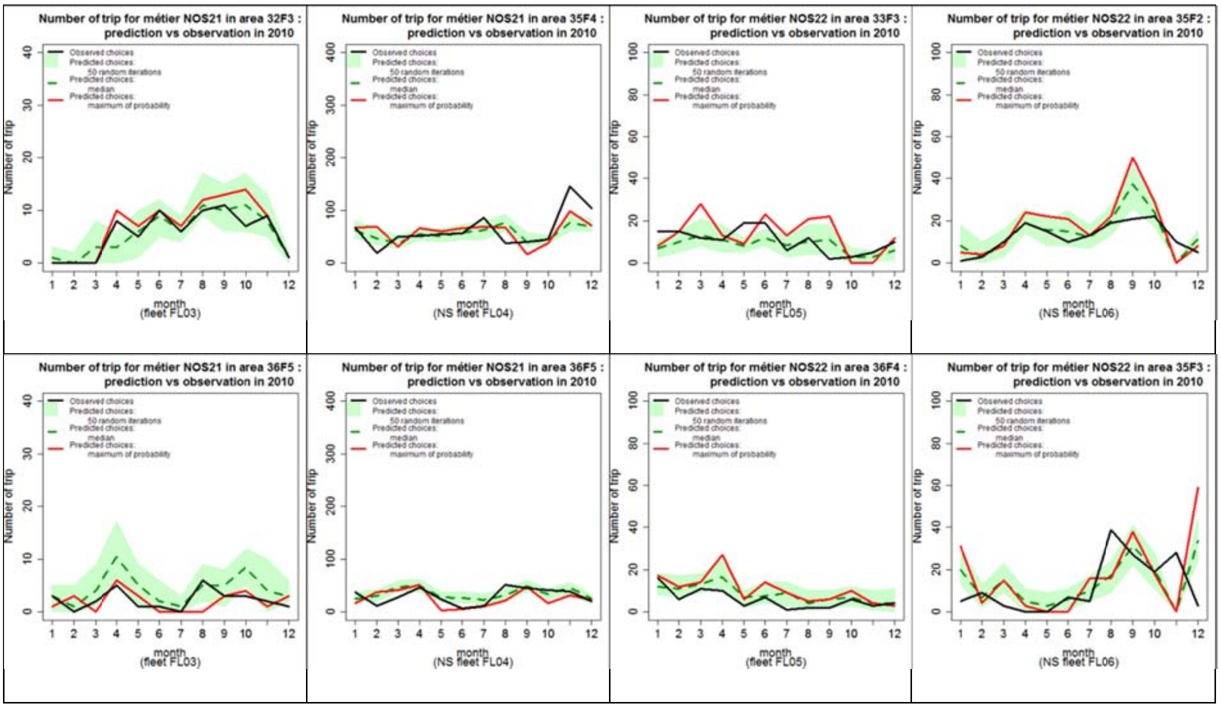


Figure 25. Monthly predictions of fishing activity for the four most frequent trips observed for each fleet. Black lines correspond to the observed values in 2010, the red lines correspond to the prediction choosing the metier highest probability, the green areas correspond to 50 random iterations (drawing the predictions from the probabilities of the metiers to be chosen) and the green dashed lines correspond to the median of those predictions.

The significant factors for the prediction of the choice of the fishing metiers are shown in Figure 26. For all fleets the effort the same month the previous year (EFF_MONTH_12) is the factor with the highest coefficient, this means that all the fleets have a seasonal pattern that is repeated from year to year (at least in 2008 and 2009), this seasonal pattern is also marked with the negative coefficients of the effort the previous month (EFF_MONTH_1) for the three fleets 12-18m, 18-24m and 24-40m, meaning that those fleets change activity from one month to the next. While effort in the previous month is not a positive factor of choice, a high value per unit of effort (VPUE) in the metier (VPUE_MONTH_1) increases the chance of the metier being chosen the next month for fleets FL04 and FL05. The VPUE in the metier the year before (VPUE_MONTH_12) also lead to an increased liklehood of the choice being chosen for FL04 and FL06.

The presence of other fleets impacted the four fleets differently. The presence of other Dutch fleets (EFF_OTH_MONTH) showed a significant positive coefficient for all fleets with vessels larger than 18m meaning that those vessels share fishing grounds at the ICES rectangle level. The presence of German vessels (EFF_DE) is also positively correlated to effort for the four fleets and more so when only the German Bight is detailed (which is where most common grounds for Dutch and German fleets are). The presence of English and Danish fleets (resp. EFF_UK and EFF_DK) is negatively correlated to the presence of the larger beam trawlers (FL06) if only German Bight is detailed but the English fleet is positively correlated with the fleets 18-24m (FL04) and 24-40m (FL05) at the North Sea level.

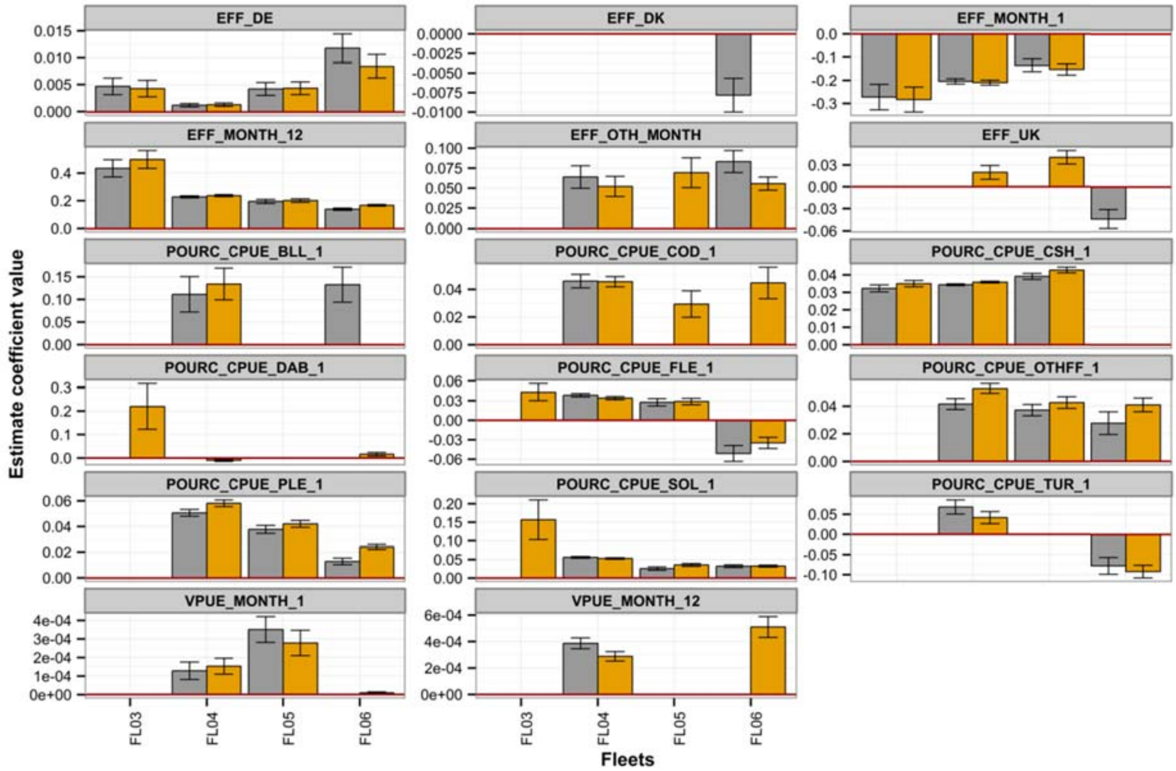


Figure 26. Significant factors and their coefficient values predicting the fishing choices of the four fleets. The grey bars are the coefficient using the choices only in the German Bight (rest of the North sea is aggregated as one area) and the orange bars are for the model with the all North Sea (as the results shown above).

The species composition of the catch is also an important factor for the choice of metier and fishing ground. As expected, the fleets FL03, FL04 and FL05 have significant positive coefficients for shrimp (POURC_CPUE_CSH_1) and for some flatfish (sole – POURC_CPUE_SOL_1 and flounder – POURC_CPUE_FLE_1). The small vessels (FL03) have also a strong positive coefficient for DAB (POURC_CPUE_DAB_1) while the fleets FL04 and FL05 fish more in areas with a lot of plaice, other flatfish and cod. The largest trawlers (FL06) are driven mainly by flatfish (sole, plaice, other flatfish) and by cod while the tend to avoid areas with large amount of flounder and turbot.

Discussion

Random utility models (RUM) can be used to identify important factors guiding the choice of fishing activity and fishing grounds. Unfortunately, area closures due to other activities such as maritime traffic, nature conservation areas or wind farms could not be included in this exercise because it led to singularity in the system. The species composition of the catch, previous experience of the activity and presence of other fleets could be included and tested for four Dutch beam trawler fleets with vessel sizes between 12-18m (FL03), 18-24m (FL04), 24-40m (FL05) and over 40m (FL06).

Different factors proved important for the four fleets, the fleets FL03, FL04 and FL05 presented stronger seasonality patterns (change of activity from one month to the next) that are consistent with the knowledge of the double activity of some vessels in those fleets who fish crustaceans (here shrimps) and demersal fish. The larger trawlers (FL06) do not catch shrimps and do not display such a pattern of change of activity from month to month. The importance of the different target species in the landings shows expected results, flatfish are important to the fleets FL04, FL05 and FL06 and in a lesser extend also to FL03. The negative relationships between the larger trawlers (FL06) and the proportion of flounder and turbot in the landings could come from the spatial distribution of the species, which represent only a small share of the fleet's landings (because it is not targeted for the case of flounder and because the quota is low for turbot).

The fleets' activity is well captured by the model including only biological and economic drivers. Predictions are accurate and follow the seasonal patterns well (Figure 25). The poor estimation of the November choices for the large beam trawlers could be due to a change in weather conditions in autumn for the year used to estimate the parameters (2009) and the predicted year (2010). The large trawlers can fish further offshore than other fleets but this is dependent on weather conditions, particularly in autumn when storms occur regularly in the North Sea. It would be possible to include a time series of weather conditions to test if weather influences the decision of fishers.

To predict the long term changes in fishing activity additional factors such as the competition for space with other marine users should be included and changes in fish distribution should be linked to the current model.

1.3 Other spatial and statistical approaches

1.3.1 Do aggregate extractions adversely affect fishing activities in the Eastern Channel?

The following study is due to be published as a paper with the following reference:
Marchal, P., Desprez, M., Vermard, Y., and Tidd, A. How do fishing fleets interact with aggregate extractions in a congested sea? Manuscript in preparation.

Abstract
The effects of aggregate extraction intensity and the proximity to dredging 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 the majority of fleets fishing in the proximity of aggregate extraction sites were not deterred by dredging activities. In contrast, the fishing effort of dredgers and potters could be greater in the vicinity of marine aggregates sites than elsewhere, and also positively correlated to extraction intensity with a lag of 0 to 6 months. The distribution of fishing effort of French netters remained consistent over the study period. However, it is important to note that the fishing effort of netters has increased substantially in the impacted area of the Dieppe site (where it is correlated to dredging intensity with a lag of 6 months), while remaining almost constant in the intermediate and reference areas. The attraction of fishing fleets is likely due to a local and temporary concentration of their main target species. However, knowledge of the vulnerability and life-history characteristics of these species to aggregate extractions suggests that over-extending the licensed areas would be detrimental to them and to their related fisheries in the longer term.

Introduction

Human use of maritime domains is increasing and diversifying. The present and historical 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 aimed at managing human activities by adopting new philosophies such as marine spatial planning (MSP) 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, 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 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 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 given various scenarios of spatial management, including any 'knock on' affects 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 Eastern Channel) which has, for a long time, supported the activities of a wide range of sectors. It is considered one of the most intensively used sea areas in the world, including for fishing, maritime transport, aggregate extraction, discharges, offshore windfarms, aquaculture and tourism (Carpentier et al. 2009). It is also a productive ecosystem that forms important fishing grounds for a range of commercial species, including cod (*Gadus morhua*), sole (*Solea solea*) and plaice (*Pleuronectes platessa*), and also encompasses some of their spawning and nursery areas and migratory routes, as well as unique transitional benthic communities. It represents a major biogeographic boundary between the Lusitanian province in the south and the boreal province in the north. At the same time, the Eastern Channel is a relatively well-circumscribed geographical area, "a world within Europe" (Buléon and Shurmer-Smith 2007; Carpentier et al. 2009), which makes it an appropriate site for investigating the complex interactions between intense and diverse human activities

Of these human activities; fishing, maritime transport and aggregate extractions are probably the most notable for that area. In 2011 there were approximately 4,200 fishing vessels registered in Channel harbours employing 9,800 fishers generating gross revenue of €500 million (Turbout 2013). Maritime transport is also a major economic activity in the Channel whereby approximately 500 ships of over 300 tons enter and leave the Channel every day, making it 1 craft every 3 minutes. Perpendicular to this cargo traffic, there are 90-120 daily journeys operated by ferries between the continent and the British Isles transporting 17 million passengers per annum (Buléon and Shurmer-Smith 2007). Marine aggregates have been exploited along the UK coasts of the Channel for several decades, and more recently along the French coasts (Desprez 2000; Boyd and Rees 2003; ICES, 2009). In 2007, 5.5 million tonnes of marine aggregates were extracted from several tens of km² in UK southern coastal waters and 1 million tonnes from less than 10 km² along French coasts. Recently, this activity moved further offshore to areas also trawled by French fishermen. Several hundred km² are presently prospected by French companies both in the eastern and central Channel. All these activities have in isolation or in combination, long been recognised to be major vectors of change for the ecosystem structure and functioning, and also having an economic effect on the maritime sectors of activity.

Here the purpose of the study was to get a better insight as to how fishers and aggregate activity in the Eastern Channel interact spatially with one another by analysing a time series of different spatially-explicit metrics of fishing activities and aggregate extractions using English and French data.

Material and methods

Material

<u>Fisheries information</u>

Fisheries information was provided under the same format by IFREMER (French fishing fleets) and CEFAS (English fishing fleets). Fishing effort was made available from satellite-based data as hours fished, with a 3' × 3' spatial resolution. Only those vessels above 15 m were considered, because vessels below that size 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° × 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, netters and scallop dredgers, while the most important English fleets were scallop dredgers, beam-trawlers and potters. Figure 27a and b show the spatial fishing distribution of all French and UK vessels >15m in the Eastern Channel.

Aggregate extractions information

Dredging intensity for all French and English aggregation extraction sites was collated from the different Eastern Channel aggregate extraction companies. The format under which these data were collected differed between French and English aggregate extraction companies. For the French aggregate extraction sites, the dredging intensity was made available as number of days dredged per month, and the volume of sands and gravels extracted was also made available. For the English aggregate extraction sites, the dredging intensity was provided as number of hours dredged per month. Dredging intensities were binned into 3’ × 3’ squares (Figure 27c). Five aggregate extraction sites were defined in the English EEZ: UK01 (West of Isle of Wight), UK02 (South-East of Isle of Wight), UK03 (East of Isle of Wight), UK04 (Central Eastern Channel) and UK05 (South-East England), and these were treated as independent units for subsequent analyses. Three French aggregate extraction sites were identified and treated independently in this study: FR01 (Baie de Seine), FR02 (Le Havre) and FR03 (Dieppe).

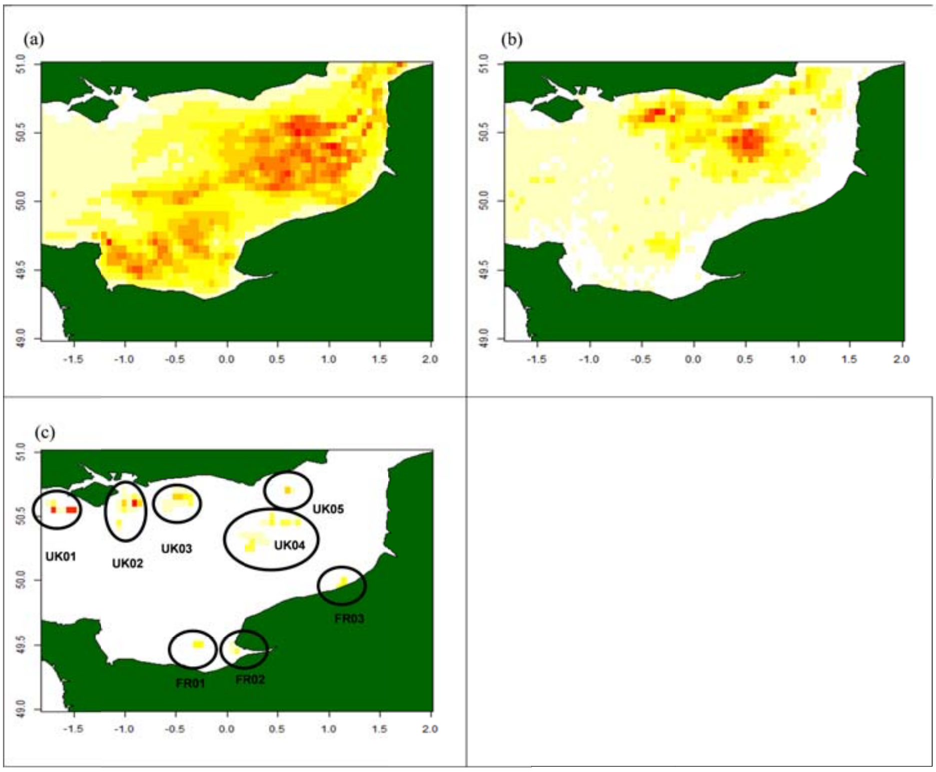


Figure 27. Eastern Channel maps showing the spatial distribution (3’ x 3’) of, (a) the hours fished by French vessels exceeding 15 m cumulated over 2007-2012, (b) the hours fished by UK vessels exceeding 15 m over 2007-2011 and, (c) dredging intensity in the vicinity of all French and UK aggregate extraction sites identified by their respective codes: FR01 (Baie de Seine), FR02 (Le Havre), FR03 (Dieppe), UK01-UK05.

Data exploration

The intensity of aggregate extraction varied without trend in five sites (UK01, UK03, UK05, FR02 and FR03), increased in two sites (UK04 and FR01) and decreased at site UK02 (Figures 2–4).

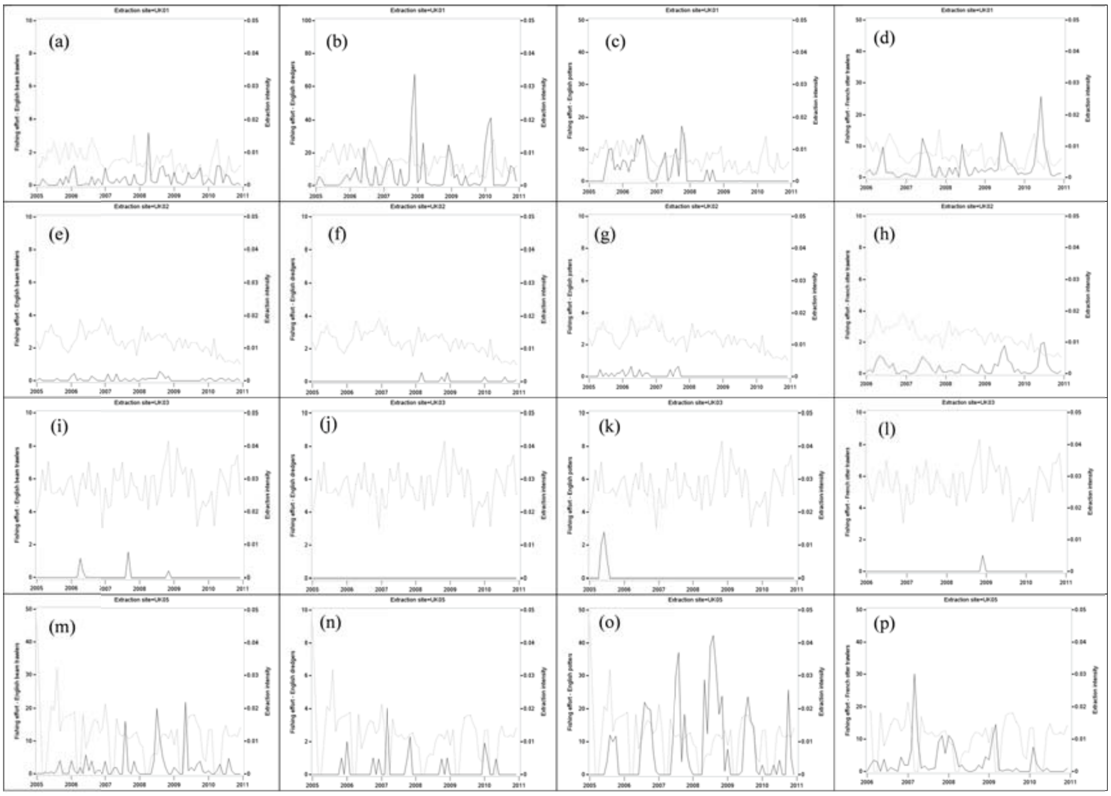


Figure 28. Fishing effort (average hours fished per month and per 3’ x 3’ square – plain line) of (a, e, i, m) English beam-trawlers, (b, f, j, n) English dredgers, (c, g, k, o) English potters, (d, h, l, p) French otter-trawlers, and aggregate extraction intensity (average surface exploited per month and per 3’ x 3’ square) in English aggregation sites (a, b, c, d) UK01, (e, f, g, h) UK02, (i, j, k, l) UK03, (m, n, o, p) UK05.

There was substantial fishing activity by English beam-trawlers, scallop dredgers, potters and French otter-trawlers at sites UK01 and UK05, but activity was more limited at sites UK02 and UK03 (Figure 28). English scallop dredgers, French otter-trawlers and French scallop dredgers were the main fleets operating around UK04 (Figure 29). French otter-trawlers and French scallop dredgers were the main fleets operating around FR01, whilst only French otter-trawlers had a substantial amount of fishing activity around FR03. All French fleets (otter-trawlers, scallop dredgers, potters, netters) had substantial fishing activity around FR03.

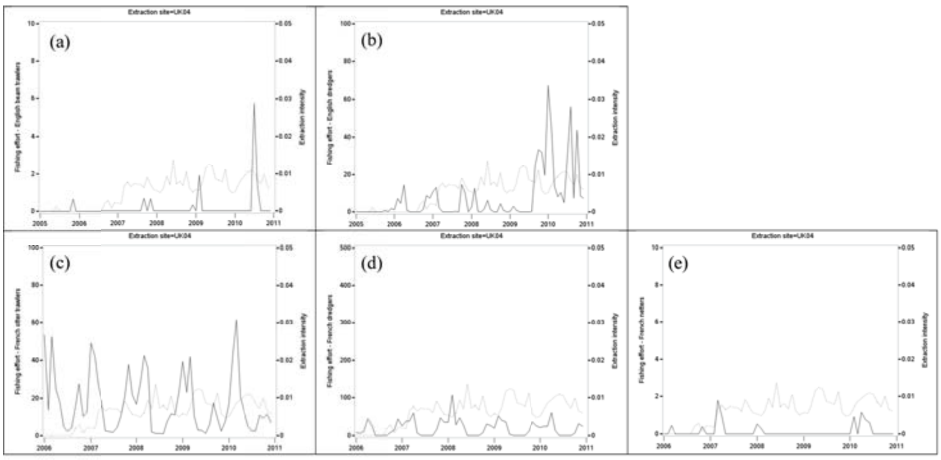


Figure 29. Fishing effort (average hours fished per month and per 3’ x 3’ square – plain line) of (a) English beam-trawlers, (b) English dredgers, (c) French otter-trawlers, (d) French dredgers, (e) French netters, and (a, b, c, d, e) aggregate extraction intensity (average surface exploited per month and per 3’ x 3’ square) in English aggregation site UK04.

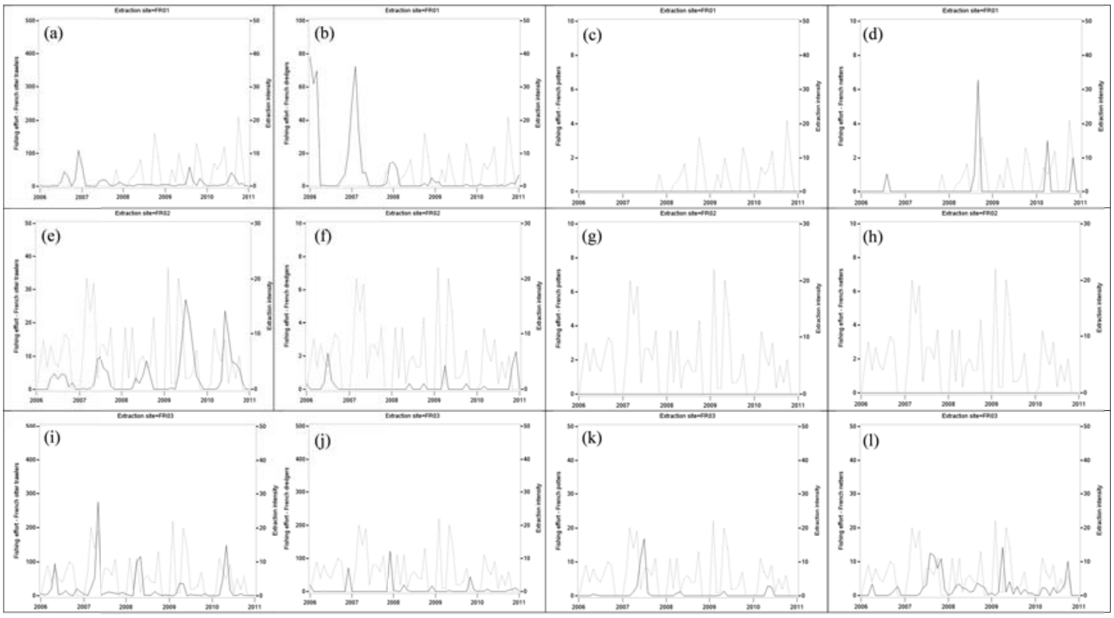


Figure 30. Fishing effort (average hours fished per month and per 3’ x 3’ square – plain line) of (a, e, i) French otter-trawlers, (b, f, j) French dredgers, (c, g, k) French potters, (d, h, l) French netters, and aggregate extraction intensity (average surface exploited per month and per 3’ x 3’ square) in French aggregation sites (a, b, c, d) FR01, (e, f, g, h) FR02, (i, j, k, l) FR03.

French and English landings data were only available at the scale of an ICES rectangle, which is a much coarser resolution than that used to group fishing effort (3’ x 3’). Figure 31 to Figure 33 show landings from ICES rectangles including the different aggregate extraction sites. As a result of the coarse resolution scale it was not possible to distinguish between the landings from extraction sites UK01-UK03, and UK04-UK05, and subsequently these were grouped into larger areas (hereby referred to as UK123 and UK45 respectively). English beam-trawlers primarily landed sole and plaice, and also a quantity of scallops (*Pecten maximus*) and cephalopods (*Loligo* spp. and *Sepia officinalis*) (Figure 31a & Figure 32a). English and French scallop dredgers landed almost exclusively scallops, although sole were occasionally taken in reasonable quantities by French scallop dredgers, possibly due to gear mis-specification (Figure 31c, Figure 32b,e, Figure 33b,f,j). French otter-trawlers operate in a true mixed fishery, mainly landing in different quantities of bass (*Dicentrarchus labrax*), cephalopods, red mullet (*Mullus surmuletus*) and whiting (*Merlangius merlangus*) (Figure 31b, Figure 32d, Figure 33a,e,i). Landing information from English and French potters, although more limited than for other fleets, indicated a clear targeting of edible crab (*Cancer pagurus*), European lobster (*Homarus gammarus*) and whelk (*Buccinum undatum*) (Figure 31d, Figure 32c, Figure 33c,g,k). Finally, French netters primarily landed sole, with a bycatch of cod (*Gadus morhua*).

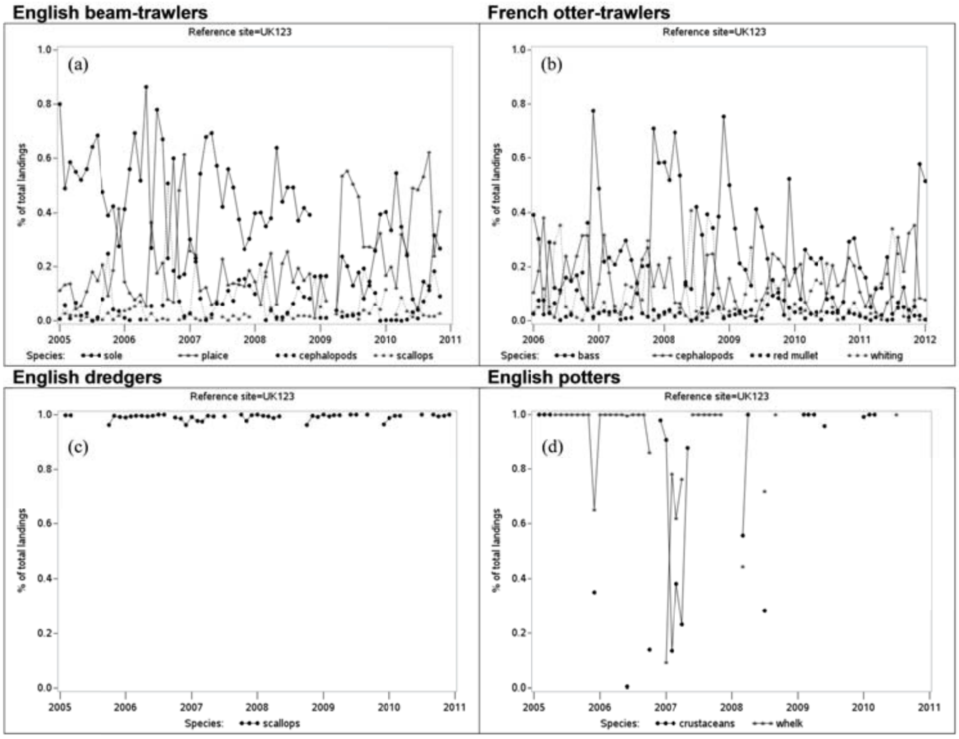


Figure 31**.** Proportion of; (a) sole (*Solea solea*), plaice (*Pleuronectes platessa*), cephalopods (*Sepia officinalis* and *Loligo* sp.) and scallops (*Pecten maximus*) in English beam-trawlers landed value; (b) bass (*Dicentrarchus labrax*), cephalopods (*Sepia officinalis* and *Loligo* sp.), red mullet (*Mullus surmuletus*) and whiting (*Merlangius merlangus*) in French otter-trawlers landing value; (c) scallops (*Pecten maximus*) in English dredgers landing value, (d) large crustaceans (edible crab, *Cancer pagurus*, European lobster, *Homarus gammarus*) and whelk (*Buccinum undatum*) in English potters landing value, in the ICES rectangles including English aggregate extraction sites UK01, UK02, UK03.

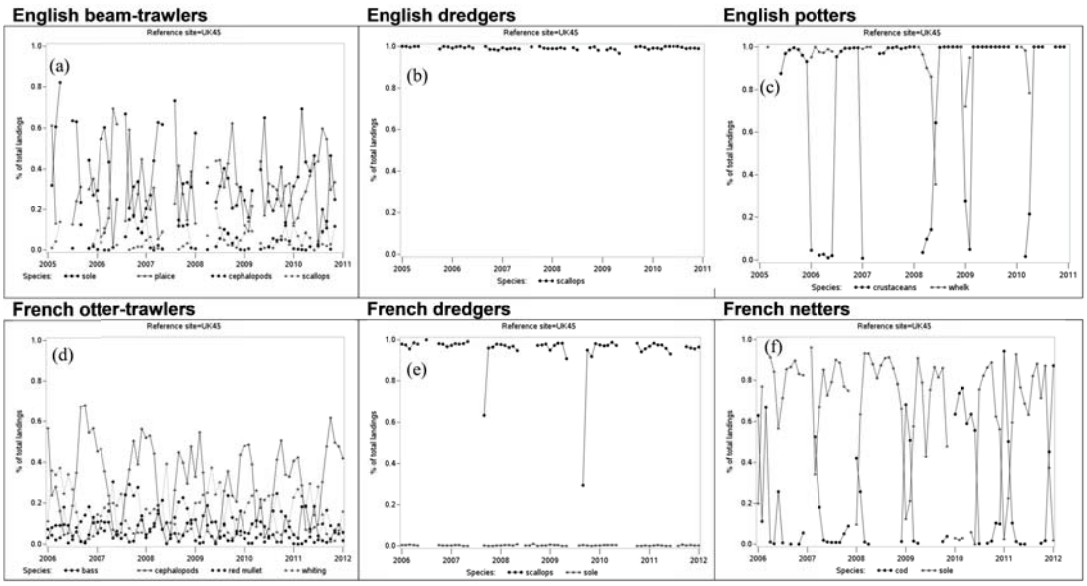


Figure 32**.** Proportion of (a) sole (*Solea solea*), plaice (*Pleuronectes platessa*), cephalopods (*Sepia officinalis* and *Loligo* sp.) and scallops (*Pecten maximus*) in English beam-trawlers landed value; (b) scallops (*Pecten maximus*) in English dredgers landing value, (c) large crustaceans (edible crab, *Cancer pagurus*, European lobster, *Homarus gammarus*) and whelk (*Buccinum undatum*) in English potters landing value; (d) bass (*Dicentrarchus labrax*), cephalopods (*Sepia officinalis* and *Loligo* sp.), red mullet (*Mullus surmuletus*) and whiting (*Merlangius merlangus*) in French otter-trawlers landing value, (e) scallops and sole in French dredgers landing value, (f) sole

and cod (*Gadus morhua*) in French netters landing value, in the ICES rectangles including English aggregate extraction sites UK04, UK05.

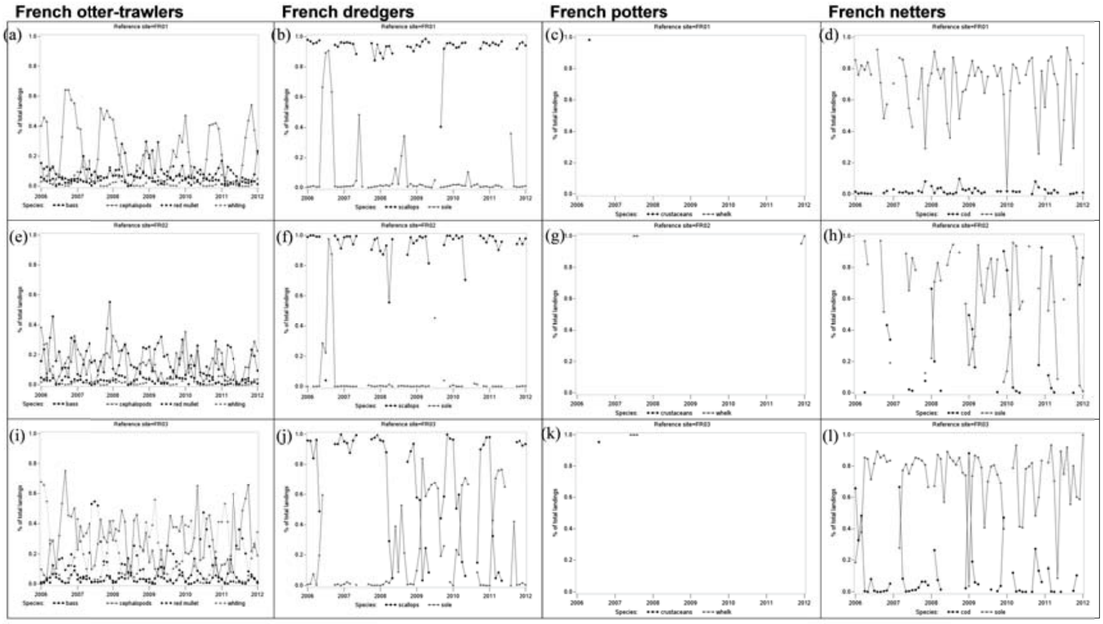


Figure 33**.** Proportion of (a, e, i) bass (*Dicentrarchus labrax*), cephalopods (*Sepia officinalis* and *Loligo* sp.), red mullet (*Mullus surmuletus*) and whiting (*Merlangius merlangus*) in French otter-trawlers landing value; (b, f, j) scallops (*Pecten maximus*) and sole (*Solea solea*) in French dredgers landing value; (c, g, k) large crustaceans (edible crab, *Cancer pagurus*, European lobster, *Homarus gammarus*) and whelk (*Buccinum undatum*) in French potters landing value; (d, h, l) cod (*Gadus morhua*) and sole in French netters landing value, in the ICES rectangles including French aggregate extraction sites (a, b, c, d) FR01, (e, f, g, h) FR02, (i, j, k, l) FR03.

Data analysis

An investigation was conducted to observe whether and to what extent fishing effort was modified in the areas impacted by aggregate extraction. Aggregate extraction could affect fishing activities as a result of extraction intensity, but also through the proximity of the extraction site to the actual fishing grounds.
To test the first hypothesis, cross-correlation was calculated between the time series of fishing effort and aggregate extraction intensity. The time series of fishing effort and aggregate extraction intensity was derived for each aggregate extraction site and for each fishing fleet by averaging values across all spatial units directly impacted by an aggregate extraction. The cross-correlation was derived at different time lags to differentiate between instantaneous and delayed effects. Both input and output time series were pre-whitened using an ARIMA model filter (Box and Jenkins 1976) to facilitate results interpretation. Both pre-whitening and cross-correlation calculations were operated using the PROC ARIMA procedure from the SAS/ETS package (SAS 2010).

To examine whether and how the proximity to aggregate extraction sites had any effect on the spatial allocation of fishing effort, a comparison of fishing effort of the different fleets between three sets of spatial units was conducted. The first set, hereby referred to as the impacted area, included all spatial units where sands and aggregates were extracted, and was allotted a proximity index with a value of 2. The second set, hereby referred to as the intermediate area, included all spatial units bordering the impacted area (proximity index value = 1). The final set, hereby referred to as the reference (or unimpacted) area, included all spatial units bordering the intermediate area (proximity index value = 0). Large proximity indices are associated to a small distance to the aggregate extraction site, and vice versa. The effect of the proximity from extraction sites on fishing effort was tested using a time series cross-section regression analysis, where each section consisted of the spatial units included in the impacted, intermediate and reference areas, and where the explanatory variable was the proximity index with its three possible values (0: reference area; 1: intermediate area, 2: impacted area). The analysis was carried out using the SAS procedure PROC TSCREG (SAS 2010).

Results

The results of the cross-correlation analyses are shown in Table 16. Pre-whitening was necessary to de-trend and/or de-seasonalise most of the English aggregate extraction intensity time series. The French otter-trawlers fishing effort was positively cross-correlated to aggregate extraction intensity with a time lag ranging from 0–3 months, and then negatively correlated with a time lag of 4–8 months, on sites UK01 (Figure 28d), FR02 (Figure 30e) and FR03 (Figure 30i). A reverse pattern was found between the fishing effort of French otter-trawlers and aggregate extraction intensity on site UK04, with a negative cross-correlation at lag 2 and a positive cross-correlation at lag 5 (Figure 29c). The fishing effort of English and French potters was instantaneously cross-correlated with aggregate extraction intensity at lags 0 (instantaneously) in site UK01 (Figure 28c) and 2–3 months in site FR03 (Figure 30k). Finally, a positive cross-correlation between the fishing effort of French dredgers and aggregate extraction intensity was found at lag 6 in site UK04 (Figure 29d). The cross-correlation between the other fishing effort and aggregate extraction intensity time series was not significant ($p < 0.05$), or could not be calculated when the time series was too short (FR01).

Table 16. Tests of, (1) cross-correlation between pre-whitened fishing effort and aggregation extraction intensity time series and, (2) effect of the proximity from extraction sites on fishing effort (as output from time series cross-section regression analysis), for different French/English fleets and extraction sites ("-" means not statistically significant with $p < 0.05$).

Extraction site	Pre-whitening			Fleet	Cross-correlation	Proximity to extraction	
	p	d	q		Lags (correlation)	Coefficient	p
UK01	1	0	0	English beam-trawlers	ns	-0.11	0.69
				English dredgers	ns	3.11	<0.01
				English potters	0 (+)	1.23	<0.01
				French otter-trawlers	6 (-)	-0.95	0.24
UK02	0	1	1	French otter-trawlers	ns	-0.36	0.18
UK04	1	0	1,12	English dredgers	ns	2.25	<0.01
				French otter-trawlers	2 (-); 5 (+)	-3.64	0.11
				French dredgers	6 (+)	2.38	0.07
UK05	12	0	1	English beam-trawlers	ns	0.65	0.13
				English dredgers	ns	-0.43	0.25
				English potters	ns	2.05	0.04
				French otter-trawlers	ns	-11.12	0.01
FR01	-	-	-	French otter-trawlers	-	-1.32	0.43
	-	-	-	French dredgers	-	-3.35	0.14
FR02	0	0	0	French otter-trawlers	(2,3) (+); (7,8) (-)	1.73	0.36
FR03	0	0	0	French otter-trawlers	(0,2) (+); (4,5) (-)	2.62	0.47
				French potters	(2,3) (+)	0.20	<0.01
				French netters	6 (+)	0.12	0.78

The results of the Time Series Cross Section Regression (TSCREG) analysis indicated that the fishing effort of all English and French potters targeting large crustaceans and whelk was larger in the vicinity of aggregate extraction sites (Figure 34c, Figure 38o, Figure 36k). The fishing effort of English scallop dredgers targeting scallops also increased with the proximity to aggregate extraction sites UK01 (Figure 34b) and UK04 (Figure 35b). Only the fishing effort of French otter-trawlers decreased in the vicinity of aggregate extraction site UK05 (Figure 34p). The distribution of fishing effort was not related to the distance to aggregate extraction sites for the other fleets.

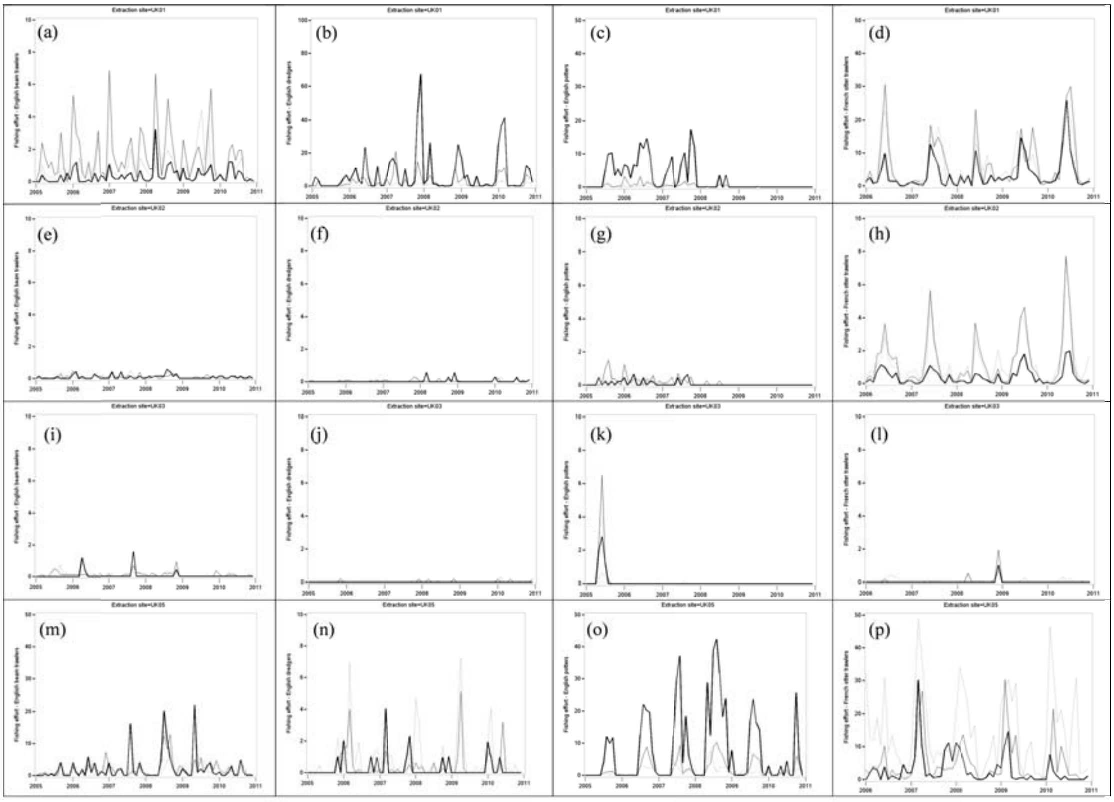


Figure 34. Fishing effort (average hours fished per month and per 3’ x 3’ square) of (a, e, i, m) English beam-trawlers, (b, f, j, n) English dredgers, (c, g, k, o) English potters, (d, h, l, p) French otter-trawlers, inside (thick plain line), around (thin plain line) and outside (thin dotted line) English aggregation sites (a, b, c, d) UK01, (e, f, g, h) UK02, (i, j, k, l) UK03, (m, n, o, p) UK05.

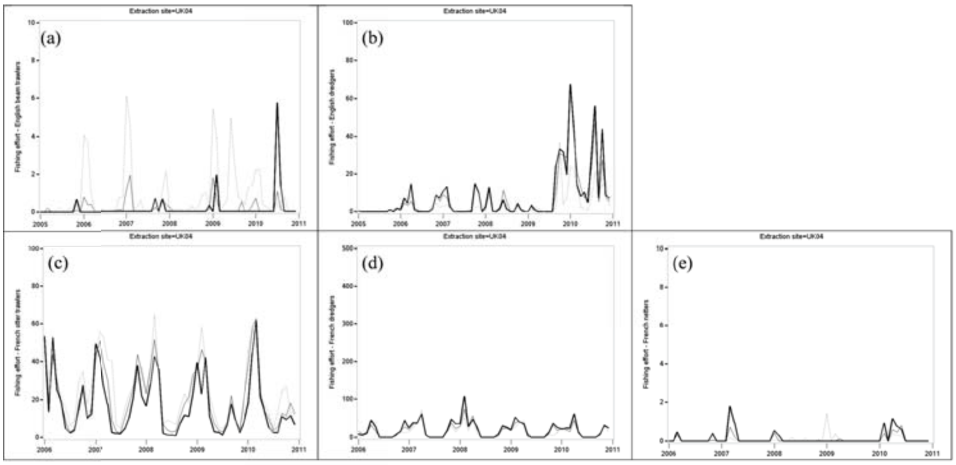


Figure 35. Fishing effort (average hours fished per month and per 3’ x 3’ square) of (a) English beam-trawlers, (b) English dredgers, (c) French otter-trawlers, (d) French dredgers, (e) French netters, inside (thick plain line), around (thin plain line) and outside (thin dotted line) English aggregation site UK04.

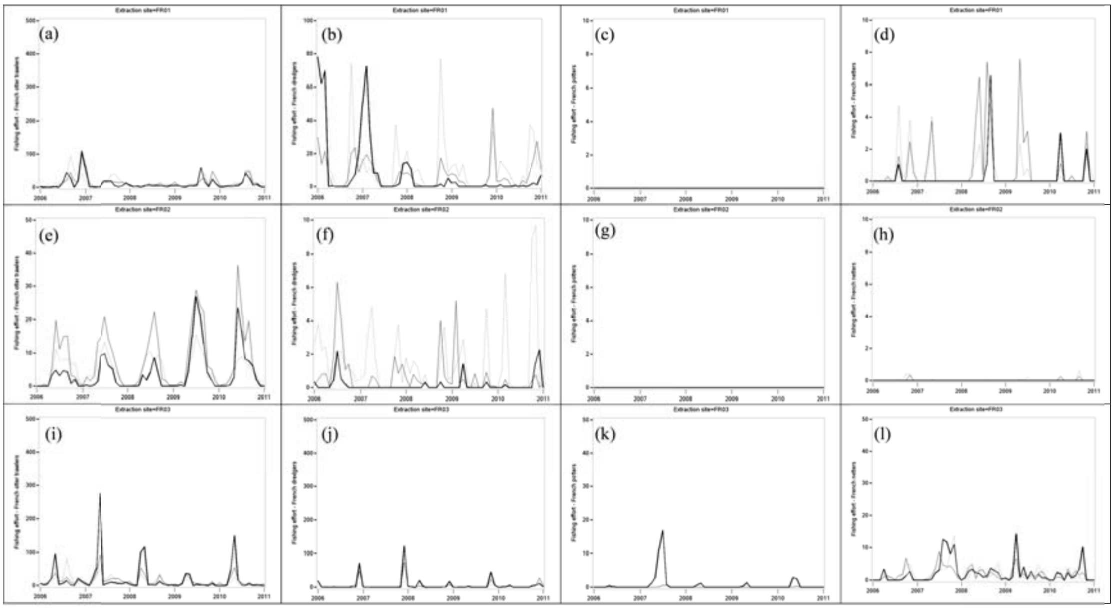


Figure 36**.** Fishing effort (average hours fished per month and per 3’ x 3’ square) of (a, e, i) French otter-trawlers, (b, f, j) French dredgers, (c, g, k) French potters, (d, h, l) French netters, inside (thick plain line), around (thin plain line) and outside (thin dotted line) French aggregation sites (a, b, c, d) FR01, (e, f, g, h) FR02, (i, j, k, l) FR03.

Finally the relative annual shifts in fishing effort (i.e. ratio between current effort and the effort at the start of the time series) across the impacted, intermediate and reference areas were compared. The difference across the three areas was generally minimal for most fleets operating around English aggregation extraction sites (Figure 37 and Figure 38). On the French aggregate extraction sites, a steep increase in fishing effort was evident in the impacted area for the French otter-trawlers (Figure 39e), French potters (Figure 39k) and French netters (Figure 39l), while the fishing effort in the intermediate and reference years remained constant or even decreased.

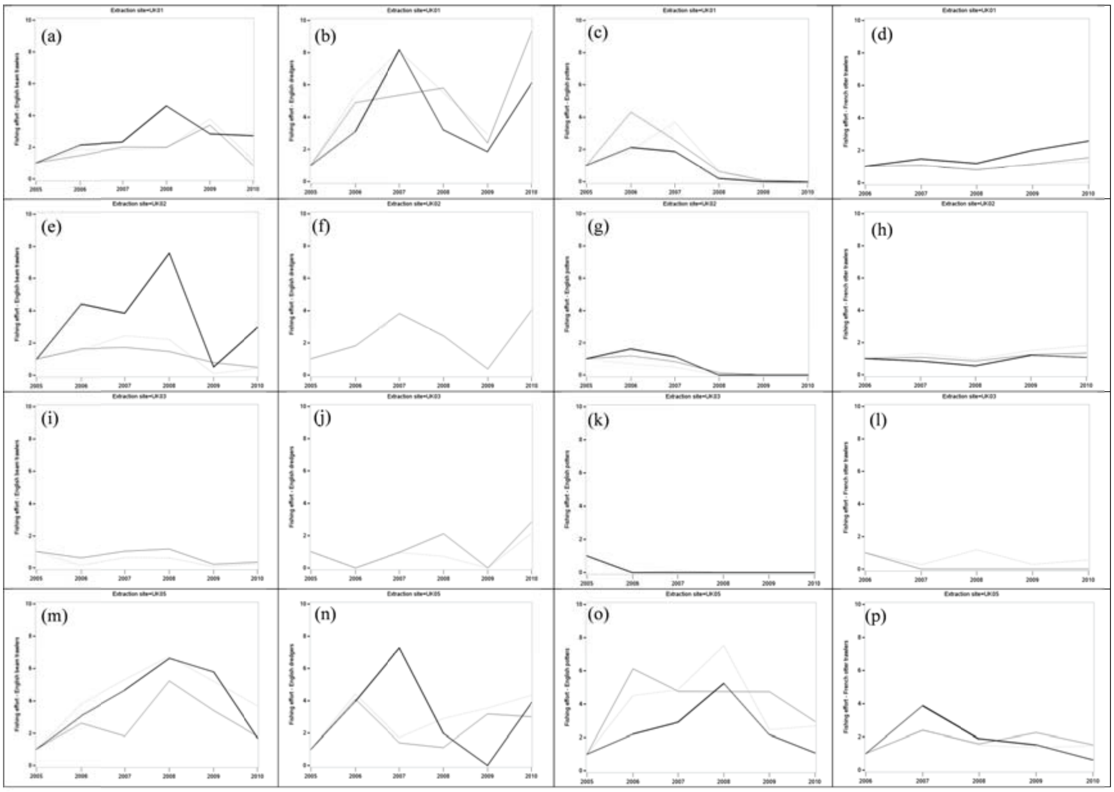


Figure 37. Annual trends in fishing effort (average hours fished per month and per 3' x 3' square relative to starting year) of (a, e, i, m) English beam-trawlers, (b, f, j, n) English dredgers, (c, g, k, o) English potters, (d, h, l, p) French otter-trawlers, inside (thick plain line), around (thin plain line) and outside (thin dotted line) English aggregation sites (a, b, c, d) UK01, (e, f, g, h) UK02, (i, j, k, l) UK03, (m, n, o, p) UK05.

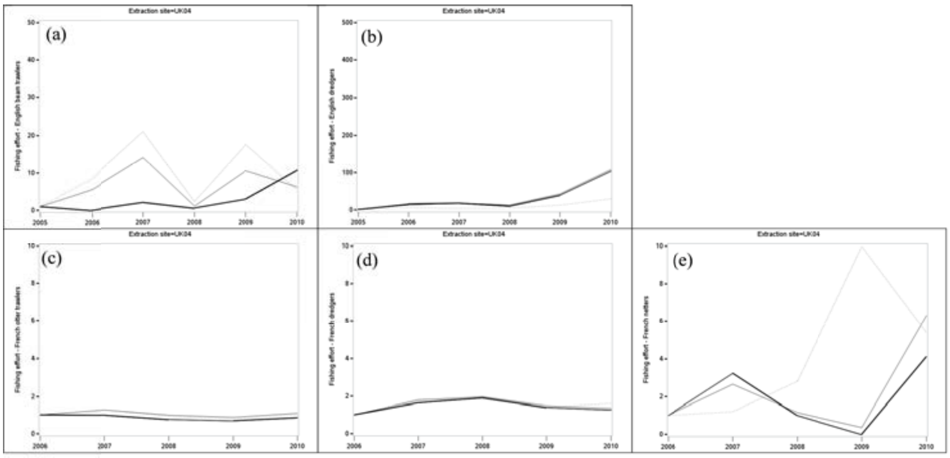


Figure 38. Annual trends in fishing effort (average hours fished per month and per 3' x 3' square relative to starting year) of (a) English beam-trawlers, (b) English dredgers, (c) French otter-trawlers, (d) French dredgers, (e) French netters, inside (thick plain line), around (thin plain line) and outside (thin dotted line) English aggregation site UK04.

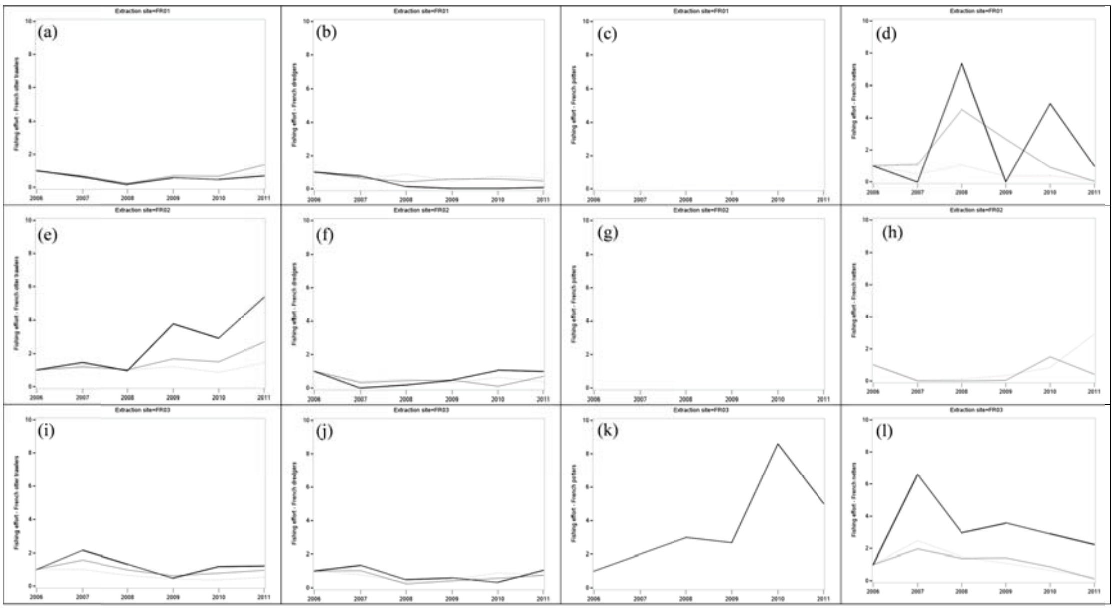


Figure 39. Annual trends in fishing effort (average hours fished per month and per 3' x 3' square relative to starting year) of (a, e, i) French otter-trawlers, (b, f, j) French dredgers, (c, g, k) French potters, (d, h, l) French netters, inside (thick plain line), around (thin plain line) and outside (thin dotted line) French aggregation sites (a, b, c, d) FR01, (e, f, g, h) FR02, (i, j, k, l) FR03.

Discussion

In this study, the effects of both dredging intensity and the proximity to aggregate extraction sites on the distribution of fishing effort was investigated for a broad selection of French and English demersal fleets. The most striking result was that, for most of the fishing fleets and aggregate extraction sites, neither dredging intensity nor the proximity to the extraction site had a deterring effect on fishing activities. To the contrary, we noted that the fishing effort of dredgers and potters could be greater in the vicinity of marine aggregates sites than elsewhere and also positively correlated to dredging intensity with a lag of 0 to 6 months. The fishing effort distribution of French netters was consistent over the whole time period under investigation. However, it is important to note that the fishing effort of netters has increased substantially in the impacted area FR03 (where it is correlated to dredging intensity with a lag of 6 months), whilst remaining almost constant in the intermediate and reference areas. The results obtained for French otter-trawlers were clearly mixed and site-dependent.

The general lack of a negative impact of aggregate extractions on fishing activities bear out the outcomes of preliminary impact studies conducted by Vanstaen et al. (2010) on English aggregate sites in the Eastern Channel, over various time periods. Vanstaen et al. (2010) concluded there was no evidence that marine aggregates exploitation had significantly altered the spatial fishing distribution of fleets operating various mobile gears. Vanstaen et al. (2010) even indicated some increase of fishing activity for scallop dredgers targeting scallops in the vicinity of marine aggregates sites exploited in the central Eastern Channel (referred to as UK04 in this investigation).

To understand why marine aggregates extractions did not have the negative impact one would have anticipated on fishing activities, it is necessary to consider the biological and ecological effects of aggregate extractions on marine organisms, and the habitat utilization of target species. It has been shown that aggregate extractions can result in an immediate reduction in the total biomass and species number of benthic invertebrates due to sediment disturbance (Desprez et al. 2000; Barry et al. 2010; Desprez et al. 2010). The recolonization may last several years, possibly with a durable change in the composition of the benthic community when the nature of the sediment composition has been thoroughly modified. However, concomitantly to the immediate removal of benthos, the water column is enriched by the organic matter derived from the dredger outwash (Newell 1999). In the vicinity of some Eastern Channel aggregate extraction sites, the increased deposition of organic detritus during dredging is known to attract suspension-feeders, omnivorous, and/or scavenging species (e.g., porcelain crab, *Pisidia longicornis*, and squat lobster, *Galathea intermedia*) and also fish such as common sole, black seabream, and cod (Desprez et al. 2013).

These ecological considerations could in particular explain why French and English potters, targeting scavenging species such as European lobster, edible crab and whelk (Carpentier et al. 2009) have concentrated in the vicinity of all aggregate extraction sites around which these fleets normally operate. Scallop is a suspension feeder (Carpentier et al. 2009), and so might feed on any increased organic matter in the water column, although the preference of this species for coarse sand and gravel habitats may also be an important factor (Dare et al. 1993), in terms of the aggregate industry exploiting the same habitats as used by scallops. Such factors could explain why English scallop dredgers (which target this species almost exclusively) were relatively more densely distributed over some aggregate extraction sites (e.g., UK01 and UK04). A temporary increased abundance of sole in the vicinity of some French extraction sites, likely due to its ability to switch diet and feed on small crabs and dead bivalves (Desprez et al. 2013) could explain why the increase in fishing effort of the French netters targeting predominantly this species has been substantially larger on the impacted site than in the neighbouring areas. A dynamic change in dredging intensity is in some cases associated with a change in the same direction of fishing effort for these fleets up to 6 months later, which may indicate a persistent modification of the benthic community structure following extraction (Desprez 2000; Boyd et al. 2003; Cooper et al. 2007; Foden 2009). The linkage between aggregate extraction and fishing effort of otter trawlers is more complex to interpret, possibly because this fleet targets a range of species which may respond differently to changes in prey distributions following aggregate extraction.

These results were considered in the light of those obtained from other studies investigating the impact of aggregate extractions on commercial fish and shellfish species. These authors developed a sensitivity index based on seven ecological and life-history characteristics: type of spatial distribution, threat status, importance for fisheries, habitat vulnerability, ability to switch diet and affinity to seabed. Of the 11 case study species considered, scallop and lobster reached the highest scoring, indicating a great vulnerability to aggregate extractions. The scoring for edible crabs and sole was lower, and whelk was not considered. Drabble (2012) suggested that aggregate extractions may have a deterring effect on the recruitment and hence on the longer term adult abundance of sole, which may largely offset the short-term benefits of releasing organic detritus in the water column for this species.

Therefore, while our results suggest that a concentration of species such as sole, lobster, edible crab, whelk, scallop and the fleets which target them is locally and temporarily possible in the vicinity of relatively small-size aggregate extraction sites, there is substantial evidence that extending the licensed areas beyond reason would be detrimental to these species and related fisheries in the longer term.

1.3.2 Do French fleets avoid maritime traffic lanes when targeting demersal fish?

Section Authors

Vermard, Y. (IFREMER), Marchal, P. (IFREMER), Tidd, A. (CEFAS), Lehuta, S. (IFREMER)

Section Abstract

The approach we propose here aims at getting better insights into whether fishermen catch information could be used to inform species distributions and if the observed effort (and catches) could be constrained by other activities such as the maritime traffic. This first attempt to correlate fish distribution observed during a scientific survey and fishing catches via linkage of VMS and logbooks data first emphases a good correlation between the observed biomass in October by a scientific survey and fishing location targeting the different demersal species in the Eastern Channel. Fleets seem attracted by areas identified as of high abundance densities. For most of the species, the maritime traffic seems to be a perturbation for the fishing activities. However, in the case of the red mullet fishery, vessels seem to avoid traffic lanes except when they expect high fish densities. They then may take the risk of fishing inside the traffic lanes or in areas of high marine traffic densities.

Introduction

The maritime domain has been used by distinct activities (marine traffic (goods and passengers), fishing activities, gravel extractions …) for long time. By its localisation between the Atlantic Ocean and the North Sea, the Channel is a strategic area in the north-west Europe. The maritime area handles around 20% global marine traffic, making it one of the intensively used sea in the world. Coming from around the planet, nearly 500 ships of over 300 tons enter and leave the Channel every day, making it 1 craft every 3 minutes. On top of this goods shipping 90-120 daily rotations are operated by ferries between the continent and the British Isles, transporting 17 million passengers per annum (Buléon and Shurmer-Smith 2007). With the development of the AIS (*Automatic Identification System*), and the legal obligation for boats bigger than 300 gross tonnage to have their AIS turned on when shipping now allows for estimating spatial shipping intensity.

The eastern Channel is also rich in term of biodiversity and commercial fishery resources. This area encompass a number of commercial species as well as many location essential to their life circle (feeding grounds, nursery areas as well as migration routes for pelagic fishes, sea birds and marine mammals).

This biodiversity and high commercial interest of the species in this area has contributed to the early development of the fishing activity. Some species have been managed by TAC but most of the commercial species are still not under the TAC system. Other management measures have been in place for a long period such as minimum landing sizes, or spatial fishing restriction (3/12 miles zones).

Fishermen have developed technics and strategies to target the different species of interest. Many studies have put forward the importance of the empirical knowledge and habits (Vermard et al. 2008, Tidd et al. 2012) on the choice of the metier and the fishing area practised during in a given trip. But the improvement of the technology (sonars, echo sounders, fishing power…) also called fishing creep (Mahévas et al., 2011) has also modified fishermen behaviours and their capacity to exploit certain areas. It is usually considered that, given their experience and technology used; fishermen are able to find the targeted fish when they are in the area. However, before the generalization of the VMS (Vessel Monitoring System) their knowledge and the spatial understanding of the realized catches were difficult to address without making intensive interviews as the legal fishing declaration are at the scale of the ICES square (60'*30') which is generally too scarce to get a precise understanding of the spatial allocation of the catches with respect to the species spatial distribution. The generalization of the VMS and the associated procedures developed to link VMS and logBooks (Hintzen, 2012) make it possible to consider studying fine scale spatial distribution of the catches and then understand the drivers of the spatial effort allocation.

The approach we propose here aims at getting better insights into whether fishermen catch information could be used to inform species distributions and if the observed effort (and catches) could be biased by other activities such as the marine traffic. To that purpose we will conjointly analyse fine scale catches extrapolated using logBooks and VMS data, AIS data and survey data.

Material and methods

Material

Fisheries information

Vessel Monitoring System (VMS) was introduced as part of the European Common Fishery Policy. It is applied to boats over 24m since 01/01/2000 (CE No 686/97), to boats over 18m since 01/01/2004 and to boats over 15m since 01/01/2005 (CE No 2244/2003). VMS position and logbooks information were provided by the French administration. VMS provide information on the fishing boat location (longitude and latitude) every hour. However no information on the state of the boat (fishing, travelling or on harbour) is available from the row data. Logbook data inform on the location of the fishing operation at the scale of the ICES square and the fishing day. Coupling both information is essential to get a precise view of the spatial catch distribution. Coupling logbook and VMS data has already proven powerful for describing the spatial distribution of impact on the marine habitat (Bastardie 2010b, Eastwood, 2007). And several methods have been applied. The method always consists in two steps: i) identifying the fishing operation among all position, ii) matching the declared landings (logbook) to the inferred fishing position from VMS. These steps were performed using vmstools (Hintzen et al, 2012). The criterion to define fishing position was based on a simple rule based on a speed threshold upgraded with some rules on distance to harbour. Logbooks were merged day by day and landings reallocated to the inferred fishing position based on the inferred fishing effort.

Marine Traffic information

AIS (*Automatic Identification System*) were implemented initially to avoid collision and control. The International Maritime Organization's International Convention for the Safety of Life at Sea requires AIS to be fitted aboard international voyaging ships with Gross Tonnage of 300 or more, and all passenger ships regardless of size. These data are emitted irregularly at a very fine step (from 2 to 10 seconds) via VHF. The frequency at which data are emitted is speed dependant. The faster the boat goes, the highest the frequency is. AIS transponder has a limited emission distance depending on location and quality of coast based receivers/base stations). It is admitted that vessels are reliably monitored along their coast line and out to a range of 60 nautical miles.
All data were stored in a postgres table, allowing for spatial analysis using postGis.
Vessels were filtered on their activity to remove fishing boats. Time interval between two consecutive locations, representing the time spent in the area located in the area between these two points, was allocated to the last position. Due to the high frequency of the emissions the straight line trajectory is not a strong hypothesis and these times can then be summed over 3'*3' squares to get an occupation index (Figure 40). This occupation index represents the traffic intensity and its unit is computed as:

$$TrafficDensity_{\text{sq}} = \sum_{vessels} \sum_{locations} \Delta t_{\text{locations sq}}$$

with sq a given 3'*3' square.

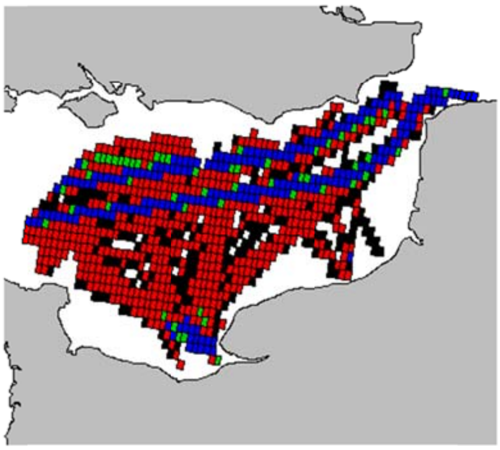


Figure 40. Marine traffic intensity (13th October 2008, right panel and 11th of October 2008, left panel). Black, red green and blue squares represent 3'*3' square where Marine traffic intensity is less than respectively the first, second, third and last quartile of the observed marine traffic intensity during October 2008.

Survey data

Based on survey data (Channel Ground Fish Survey), abundance maps were produced for several species using kriging interpolation (Carpentier et al, 2009). These maps allowed for estimated a relative spatial abundance of species over the Eastern Channel during October (month of the survey) (Figure 69).

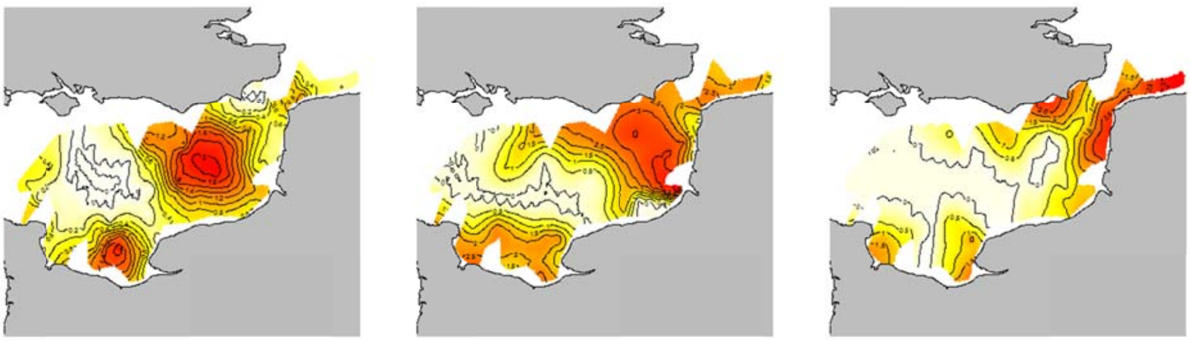


Figure 41. Abundance (number of fish by square km) of cuttlefish (left panel), red mullet (middle panel) and plaice (right panel) observed during CGFS in October 2008.

Methods

We investigated whether and to which extend the fishing effort was distributed in the areas of observed high abundance and how the fishing effort allocation was impacted by the marine traffic.
Abundance classes were computed using the quartile of the observed abundance. Four classes were defined, the first one of low abundance represented by the first quartile, the "medium abundance" corresponding to the second quartile, the "high abundance" as the third quartile and the "very high abundance" as the last quartile.

Marine Traffic was defined in the same way, based on the quartiles of the observed effort over the period. One more category was added for the areas without any traffic. 3'*3' squares where then allocated with the category of the corresponding marine traffic density.

GIS routines were used to extract every day the fishing locations defined as targeting a given species and occurring in the different intersection of traffic and biomass categories.
A fishing density (number of fishing location per square kilometres) per category was then computed to be able to compare the attractiveness of each category (abundance * marine traffic) removing the impact of the surface of each category.

Numbers of fishing positions per categories were analysed using boxplot and linear model to explain the impact of both marine traffic and abundance in the effort allocation.

Results

The results of the fishing density in the different area by species are presented in Figure 42 to Figure 69 and Table 17. The fishing density seems influenced by the fish abundance and the marine traffic. Coefficients for abundance (Table 17) are all significant and positive, showing a positive attraction for areas of high abundance. The coefficient for marine traffic intensity are all significant and negatives (Table 17), showing the negative impact of the marine traffic on the fishing density. Boats seem to be attracted by areas of high abundance and low traffic intensities.

Table 17**.** Outcomes of the model fitting (significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1).

	Intercept	Traffic Intensity	Abundance
Red Mullet	-0.0018887	-0.0016547 (*)	0.0121695 (***)
Plaice	0.0081152 (*)	-0.0017746 (*)	0.0085963 (***)
Cuttlefish	0.0189604 (***)	-0.0028157 (**)	0.0082444 (***)

Figure 42 also shows that even if the linear model tends to explain fishing densities by low marine traffic and high abundances areas, the fishing densities are the highest in the area of high marine traffic densities (5^{th} category). Fishing densities decrease with the increase of marine traffic intensities until abundance category 4, for which marine traffic intensity hardly has any influence on fishing densities.

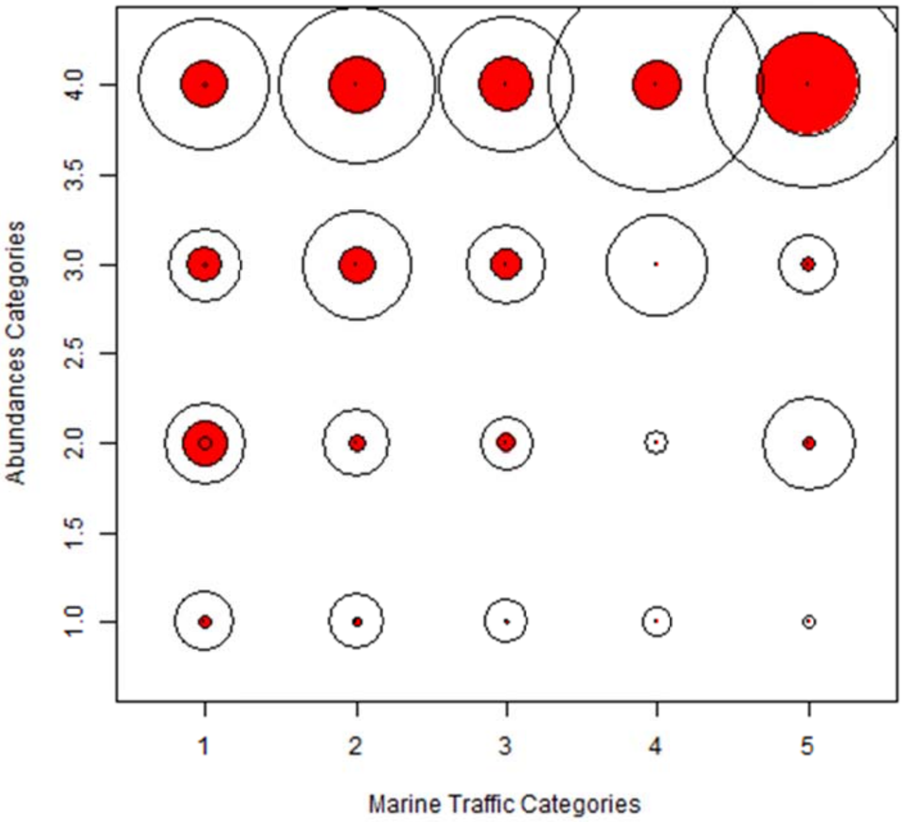


Figure 42. Fishing density targeting red mullet per abundance category (y axis) and Marine Traffic category (x axis). Red dot are the median values and black circles the 5 and 95 centiles values. The biggest red dot represents a fishing density of 0.069 fishing operations per km².

Figure 43 and Table 17 show similar results for the fleets targeting cuttlefish. Fishing effort increases with stock density except for the highest maritime traffic category (5), where stock density is little impacting. Fishing effort decreases as traffic intensity increases from category 1 to category 3, and varies little when traffic intensity increases from category 3 to category 5.

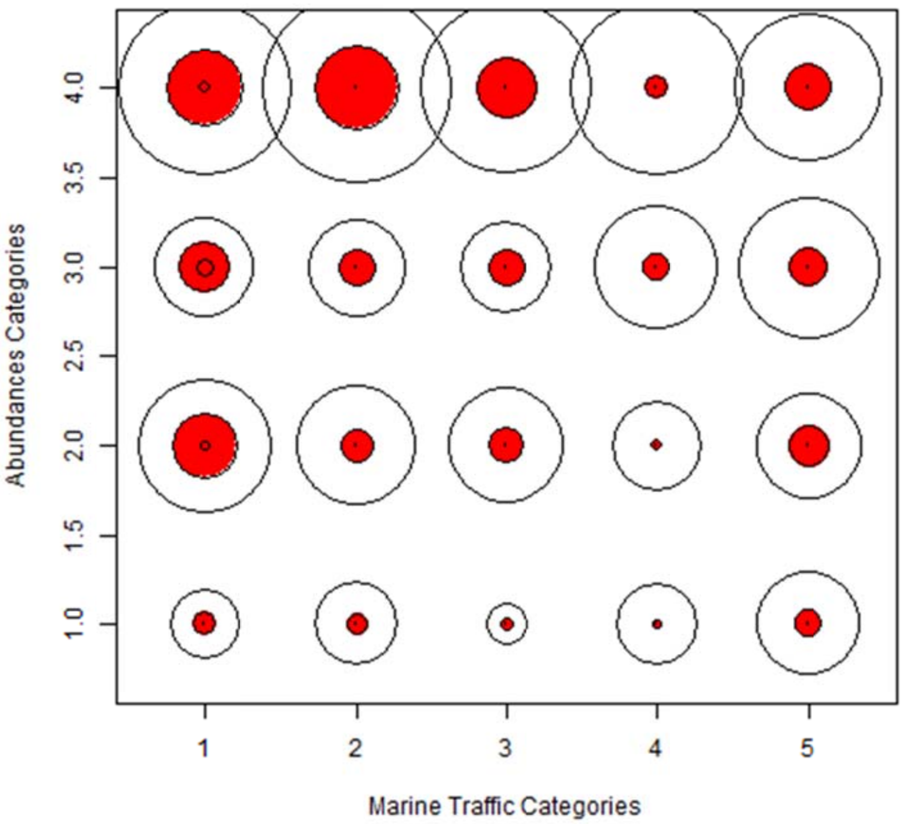


Figure 43. Fishing density targeting cuttlefish per abundance category (y axis) and Marine Traffic category (x axis). Red dot are the median values and black circles the 5 and 95 centiles values. The biggest red dot represents a fishing density of 0.056 fishing operations per km².

For plaice which is not a target species but mainly caught as a by-catch, even if the linear model still return a positive effect of the abundance index and a negative effect of the marine traffic intensity, Figure 43 shows less contrasted patterns.

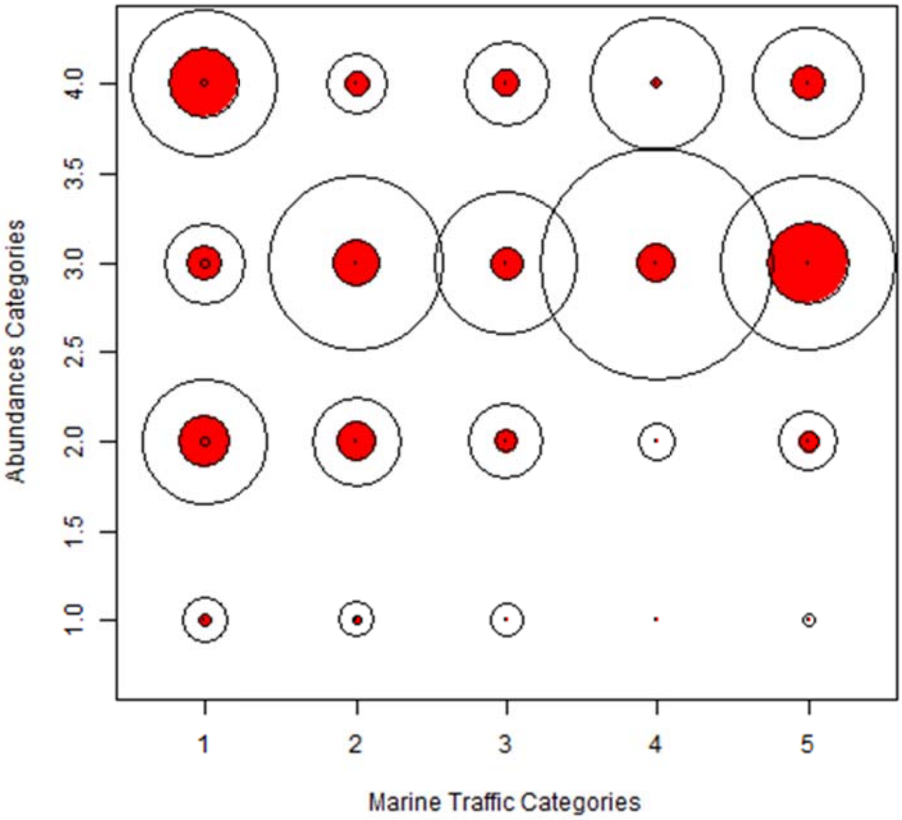


Figure 44. Fishing density targeting plaice per abundance category (y axis) and Marine Traffic category (x axis). Red dot are the median values and black circles the 5 and 95 centiles values. The biggest red dot represents a fishing density of 0.056 fishing operations per km².

Discussion

This first attempt to correlate fish distribution observed during a scientific survey and fishing catches via linkage of VMS and logbooks data first emphasis a good correlation between the observed biomass in October by a scientific survey and fishing location targeting the different demersal species in the Eastern Channel. Fleets seem attracted by areas identified as of high abundance densities. For most of the species, the marine traffic seems to be a perturbation for the fishing activities. However, in the case of the red mullet fishery, vessels seem to avoid traffic lanes except when they expect high fish densities. They then take the risk of fishing inside the traffic lanes or in areas of high marine traffic densities.

Many other factors might influence the spatial effort distribution such as the home range of fishing vessels and their dependencies to home harbour. In order to mitigate this dependency to home harbour, this study focuses on trawlers of length 18 to 24 meters that are able to explore the whole Eastern Channel in a given trip and are not as limited in term of travelled distance as smaller boat can be.

2 Validating fleet dynamics models: an interview-based approach

Section Authors
Delaney, A. (IFM-AAU), Hoefnagel, E. (LEI), Jouanneau, C. (IFM-AAU)

In an effort to understand their fishing behaviour in greater detail, a quantitative survey was designed and administered to fishers operating in the German Bight and the English Channel. In the German Bight, the survey was conducted with Dutch fishermen while French fishers were targeted in the eastern English Channel. The survey was not administered to UK boats in the English Channel.

The survey was designed specifically to gain insight into why fishers choose to fish in certain areas, understand how other stakeholders and events may impact their own actions in the case study areas, as well as to understand how they choose to respond to these pressures.

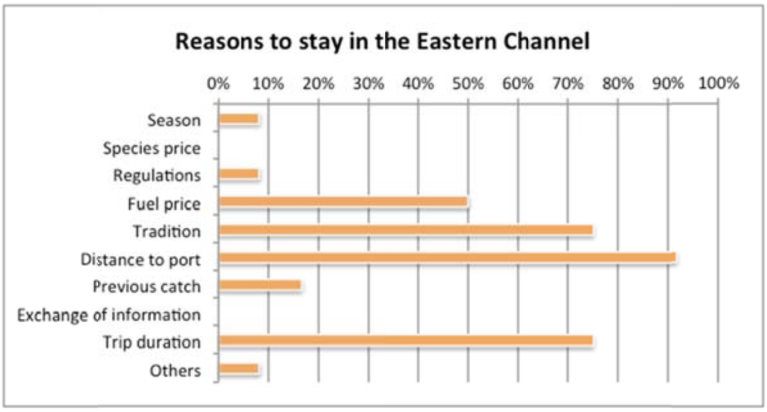
2.1 Eastern English Channel – the French case

Twelve boat owners were surveyed in the spring and summer of 2013. The gear types were split between trawls and dredging with only one using gill nets. Table 18 presents the port of exploitation and the vessel type of the fishers who answered the survey. Most fished for sole, with cod, sea bass, shrimp, scallops, cockles, cuttlefish, turbot, brill, and eel filling in the rest of the species harvested.

Table 18**.** Port of exploitation and vessel type of the fishers who answered the survey.

	Vessel type	
Port of exploitation	Trawler	Gillnetter
Boulogne-sur-Mer	2	3
Dieppe	2	1
Le Hourdel	3	0
Le Havre	1	0

When asked why they fished in a certain areas, almost all fishers (11) cited “distance to port” as a primary reason for fishing where they fished. Almost as many cited a related response, “tradition” as a main reason (9). Other important considerations included fuel price (6) and trip duration (9). The only fisher to practice a more generalized catching pattern (demersal) also cited “season,” “regulations,” “previous catch” and “quotas” as additionally important. The other reasons mentioned were the weather and the will to keep fresh catch (<48h). French fishers seldom went out of their main fishing area, and if they did it was in close-by areas (23F1, 29F1).



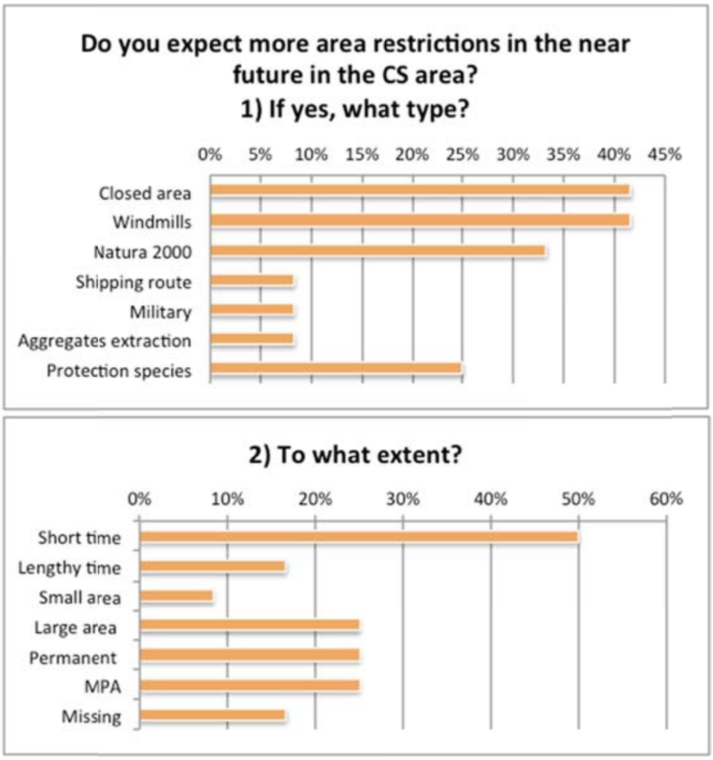
In general, fishers did not feel constraints in the amount of space they had available for fishing. The one who did, cited Natura 2000 and shipping lanes as constraining factors, and said this directly influenced his fishing patterns as he would need to go further.

Four of the interviewed fishers mentioned that they were regularly confronted by competition for space, particularly with the Dutch purse seiners entering the waters and catching large amounts of fish. One fisher mentioned tensions with the maritime surveillance rescue centers (CROSS) who would often tell them off about their trajectories. One also cited aggregate extraction (when completed) as meaning no fishing anymore in that area

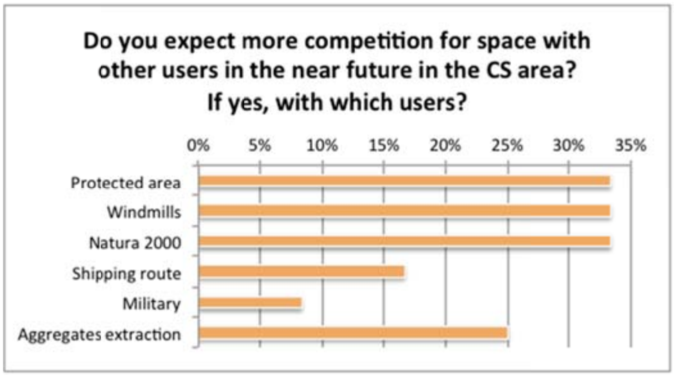
Three fishers felt that there was more competition for space than compared to 10 years previously, all stating that there are more gillnetters now. Only two felt there was more competition for fish species compared to 10 years earlier, and cited quotas and the sale price as the issue.

Restrictions/temporary closures:
Of the 9 respondents who were asked, none had experienced an area restriction or a temporary closure within an area they would normally fish.

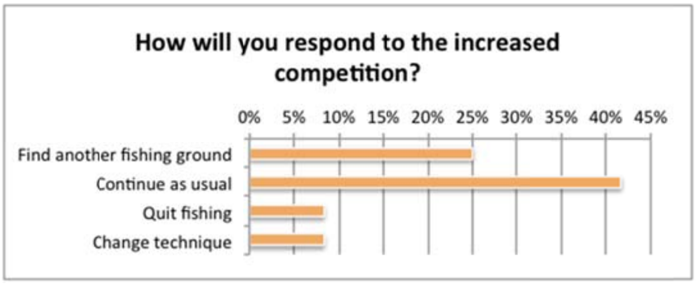
Expectations of future competition
Though conflicts and competition has been minor, half of the respondents expect more competition in the future, particularly in regards to closed areas (5), wind farms (5), Natura 2000 sites (4), and seals (3). Interactions with the "military" concerned demining operations 5-6 times a year, generally well perceived. The extent of these conflicts was felt to be short (6), lengthy, large and small, depending on the type of competition.



67% of the fishers interrogated were not expecting more competition for space in the near future in the Eastern Channel. The 4 respondents who did, cited in bulk protected areas, offshore renewables, and all users to a smaller extent.

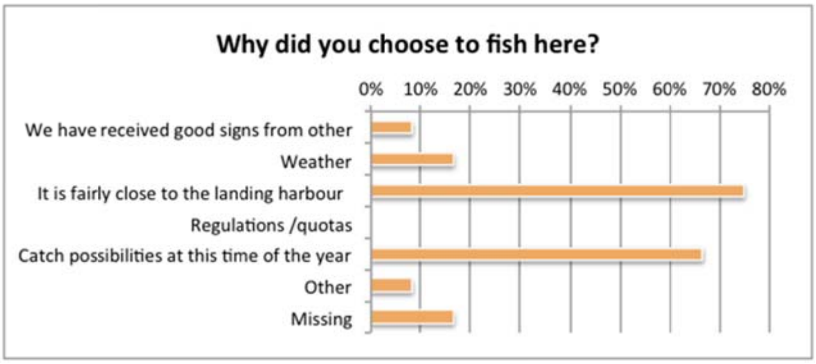


In response to the increased competition, none said they would work to influence decision-making and said in response, they may quit (2), go to another fishing ground (3), change their technique and adapt as possible (1), or they would continue as usual (5). Most (7) felt they had no influence on those developments, only one fisherman mentioned the Regional Fisheries Committees (CRPM) as a way to express themselves. This same person said he would try to influence those developments by different ways of action (communication through CRPM, snail operation, blocking harbour).



Decision-making process:

In choosing to fish in a certain area, the location and fish species availability were the primary rationales, with all deciding upon where to fish before leaving the harbor. One also chose to fish in a locale as his father also fished there.

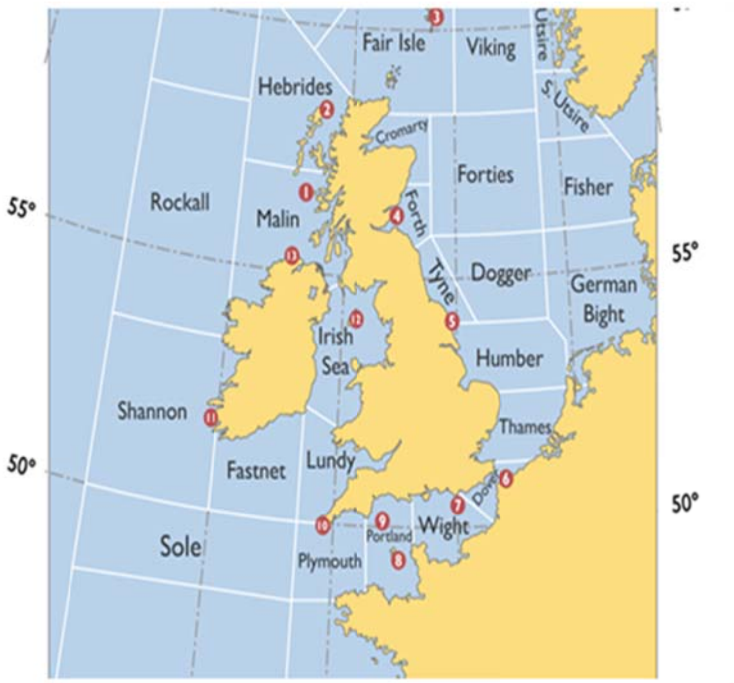


Overall, French fishers in Boulogne go to the closest fishing grounds available to them. They did not feel too constrained by other stakeholder activities at this point in time, though they worry about this changing in the future. Increasingly busy seas, especially with increased renewable energy activities and marine conservation were seen as the primary threats to their ability to fish in the future.

2.2 German Bight – the Dutch case

Introduction

Over 400 Dutch vessels fish the German Bight. The German Bight is confined by the northern coast of the Netherlands, the coasts of Germany and halfway Jutland in Denmark and at sea, east of the Doggerbank. Main ports are the Northern ports, like Urk; Texel; Harlingen; Wieringen; Den Oever; IJmuiden; Lauwersoog; and Scheveningen. Cutters of all sizes using a variety of gear: fly shoot; twin rig; beam trawl; pulse trawl; shrimp trawl, and other nets are targeting plaice, sole, shrimp, nephrops, other quota species and other non-quota species. Since 1989 cutters larger than 300 *hp* are not allowed to enter the Plaice box, situated along the coast of the German Bight (40,000 km2).



UK shipping forecast zones, with German Bight.

LEI developed an internet survey based upon the UK-FR survey developed by IFM-AAU (structured and open answers) and sent it out via the website and newsletter of two national Producer Organisations (POs). 103 people "looked" at the survey; 19 filled it out (25 vessels); 3 did not fish in the German Bight; 3 were incomplete and 2 were PO staff, so 8 were not valid. 11 Surveys were completed and delivered valid information. Of the respondents, 10 were male fishers, 1 female fisher, together fishing on 15 vessels of which 11 vessels were flying the Dutch flag, 1 a UK flag, and 3 vessels flying the German flag. The lengths of the vessels were as follows: 1 Cutter < 12m; 6 Cutters 12 tot 24m; 2 Cutters 24 tot 40m; and 4 Cutters> 40m. Various gear-types were used: Fly shoot; twin rig; beam trawl; pulse trawl; shrimp trawl and 'other nets'.

The low response rate can be explained, most likely, by two factors: the definition of "German Bight" and the length of the survey. Firstly, Dutch fishers define the German Bight differently from the way it is defined in the map above; to them, the plaice box *is* the German Bight. This becomes an issue for the survey since the plaice box is closed for the larger cutters. This definition problem was not tackled by publishing a map of the German Bight in the internet survey. Another explanation for the low response might be the length of the survey which took on average 40 minutes to complete.

The Plaice Box

Current competition for space in the German Bight

The German Bight consists of waters of 3 countries: The Netherlands, Germany and Denmark. 7 of the Dutch respondents fish in all the parts of the German Bight[5]

Where do you fish in the German Bight?		Response Total	Response Percent
Dutch part		11	100%
German part		8	73%
Danish part		7	64%
	Total Respondents (For this Question)	11	

The main reason to go to the German Bight is the 'season', but also important are the expected price for the catch, the distance to the port, previous catch and trip duration.

Why do you decide to go the German Bight and not to other fishing grounds like e.g. the Dogger Bank?		Response Total	Response Percent
Season		6	55%
Species price		4	36%
Regulations		1	9%
Fuel price		0	0%
Tradition		0	0%
Distance to port		4	36%
Previous catch		4	36%
Exchange of information		1	9%
Trip duration		4	36%
Other: "We are fishers of the Waddensea, we have no licence for deeper waters". "The best sole to catch".		4	36%
	Total Respondents (For this Question)	11	

[5] More than one answer to a question is often possible.

9 of the respondents think there are fewer square miles of fishing ground in the German Bight than 10 years before. This is mainly due to closed areas and wind mill parks.

If yes, due to what?		Response Total	Response Percent
Closed area		7	78%
Wind farms		7	78%
Natura 2000		4	44%
Shipping route		1	11%
Military		1	11%
Oil rigs		2	22%
Other: Musselseed catch installation		1	11%
Total Respondents (For this Question)		9	
(skipped this question)			2

This loss of space influences the fishing pattern of all 9 respondents. Now they have to fish more intensively and their trip length changed, too. It is stated that closed areas and parks are often situated in good fishing areas.

Seven respondents conflict with other users over space, especially with wind farms, Nature conservation, other fishers and rigs. Four were fined after (accidently) fishing in a closed area; unsafe situations occur near wind farms (4) and rigs (3) due to (weather) conditions and 3 mention crowdedness with other fishing vessels. Five of the respondents say there is more competition for space among fishers; however five also responded no to increased competition among fishers.

Only four of the eleven respondents note difficulties from non-human pressure, like changed fish distribution (3) and climate change (2) and only one mentions invasive species and outbreaks of jellyfish. Four do not notice any influence of non-human pressure. Three respondents think they have an advantage over changes caused by non-human pressures, but mainly see fluctuations as natural.

Restrictions/temporary closures

Eight of the eleven respondents themselves experienced an area restriction or a temporary closure in the German Bight of a relatively large size (5) or medium or small size (3). Nonetheless they still remain fishing in the German Bight, though as a consequence they catch less targeted fish (5) and earn less or it takes more effort to earn the same. The types of closure are mentioned in next bar chart:

What type of closure was it?		Response Total	Response Percent
Spawning area, like Plaicebox		4	50%
Temporary closure (e.g.real time closures)		4	50%
Natura 2000		4	50%
Wind farms		5	62%
Extension of military area		0	0%
Extension of shipping		2	25%

routes			
Riggs		3	38%
Other:		2	25%
	Total Respondents (For this Question)	8	
		(skipped this question)	3

Expectations on future competition for space in the German Bight

All respondents expect more area restrictions of a permanent character (10) in the near future in the German Bight. Only one respondent will quit fishing, others will continue, because they want to continue to go fishing. No respondent thinks they have any influence on these developments. Nine would like to try to have greater influence through their PO (9) or other organisations.

On their last trip to the German Bight respondents competed for space with a variety of activities:

Which other marine activities did you compete with spatially for your activities this trip?		Response Total	Response Percent
Other fishing vessels		5	45%
Gas/oil/sand extraction sites		4	36%
Maritime traffic		8	73%
Wind farms		6	55%
Natura 2000 areas		5	45%
Other closed areas		6	55%
Other:		0	0%
	Total Respondents (For this Question)	11	

Seven respondents went to the Dutch part, five to the German part and only one to the Danish part, this choice was, for 8, motivated by the catch possibilities and for 3, by proximity of the harbor. Although all kinds of other marine activities affect fishing in the German Bight, regulations also have a great influence on fishing practices:

Which regulations affect your fishing practices?		Response Total	Response Percent
Catch limits		6	55%
Days at sea limits		4	36%
Technical measures		6	55%
Plaice Box and/or other closed areas		6	55%
Area-based management (3-miles zone/6-miles zone/12-miles zone)		5	45%
NO REGULATIONS BUT Because it is a less crowded area		1	9%
Other: Fish prices Eel ban Gear restriction (art. 20)		4	36%
	Total Respondents (For this Question)	11	

Regulations and competition for space has for all respondents impact on the fishing practice:

What (activities) does this impact on?		Response Total	Response Percent
Fishing pattern		**8**	**73%**
Catch composition		**7**	**64%**
Gear use		**5**	**45%**
Length of trip		**6**	**55%**
Income		**9**	**82%**
Job satisfaction		**6**	**55%**
Other: "On everything"		**1**	**9%**
	Total Respondents (For this Question)	**11**	

Conclusion / Summary German Bight

Conflict / cooperation
1. There are fewer square miles of fishing ground in the German Bight than 10 years before.
2. Fishers have to fish more intensively now on less available fishing grounds.
3. Sometimes unsafe situations occur near oil rigs and wind farms.
4. Fishers do not think they have any influence on the increase of competition for space but would like to have more.

What limits activities?
- Spatially: Especially closed areas, wind farms and Natura 2000 areas. To a lesser degree rigs, shipping and mussel cultures. Other closed areas: Real time closures (RTCs).
- Regulations: Catch limits; Days at sea limits; Technical measures; Plaice Box; Area-based management (3-miles zone, 6-miles zone, 12-miles zone), Omega mesh-indicator.

Ranking of most important impacts on their activities
Fishers earn less and catch less targeted species. They have to adapt their fishing pattern. It is crowded now and less safe.

What has changed?
(Ranked) Income; Fishing pattern; Catch composition; Length of trip; Gear use; Job satisfaction.

Future views
Fishers expect more large area restrictions of a permanent character in the near future in the German Bight. But will continue fishing since they feel they have no choice.

3 Co-existence in busy seas: some insights from the primary sectors of activity

Section Authors
Delaney, A. (IFM-AAU), Degnbol, D. (IFM-AAU), Hoefnagel, E. (LEI), Jouanneau, C. (IFM-AAU), Piwowarczyk, J. (IOPAS)

Section Abstract
The pressure applied to the spatial usage of European regional seas by various stakeholder groups is intense. This has been investigated and compared across five regions: the Eastern English Channel, the German Bight, the Dogger Bank and the Gulf of Gdansk. In all case study sites, the majority of stakeholders feel this pressure

will only increase in the future, primarily due to proposals and plans for offshore wind farms, the newest entrants to these busy seas. In some case study areas, such as the eastern English Channel and Dogger Bank, applications have already been approved with construction planned; in the German Bight wind farms already exist and at least in the Dutch part new proposals have been made[6]. In others, such as the Gulf of Gdansk, such developments are further away- and unlikely to happen soon due to legal constraints - yet the uncertainty of impacts, such as on fishing, is cause of great concern. Of all the stakeholders groups, the fisheries group was the only one addressed by both Sections 2 and Sections 3 and thus can be compared across all case study areas: eastern English Channel, the Dogger Bank, the German Bight, and the Gulf of Gdansk. Fishing is one of the oldest activities in all four of the case study areas and though fishers in each area tend to use different gears and face different pressures, there are a number of similarities among them. These pressures include: regulatory pressures, competition with other users, and area restrictions.

3.1 Eastern English Channel

Introduction

This section presents an analysis of the activities and interactions of the main stakeholders making use of the eastern English Channel. The eastern Channel is a shallow (< 50 m) basin which extends approximately from the Cap de la Hague (FR)-Weymouth (U.K.) on its western limit to the Calais-Dover Strait on the eastern side. This equates roughly with ICES area VIId, an area delineated for fisheries management. A narrow, yet extremely congested spatial area, this channel continues to face a variety and large volume of maritime activities. Some activities are limited to the shallow, coastal areas (e.g. thermo-nuclear power generation, recreation) while others are focused more or less in deeper, offshore areas (e.g. aggregate extraction).

Historically, the main activities of importance in the Eastern Channel included shipping, transport and fishing. In addition to these on-going activities, many others have developed in the area. However the marine space has not been used in the same manner by France and England. The U.K. started developments of offshore wind energy whilst France started discussing the possibility to extend its renewable energy sector to the offshore area less than 10 years ago. Another activity pioneered by the UK is the exploitation of marine aggregates which started after World War II in the U.K. while it started in the late 1970's for France and Belgium. In addition to these numerous marine activities, there is a rise in coastal leisure activities on both sides of the channel (yachting, kite-surfing, etc.). All this increased use of the marine space goes along with a rise in marine conservation interests (MPAs, SSIs, etc) which can engender restrictions of harmful activities in some areas.

[6] There are, of course, many wind mill farms throughout the North Sea; there are simply none operational yet in the case study area of the Dogger Bank.

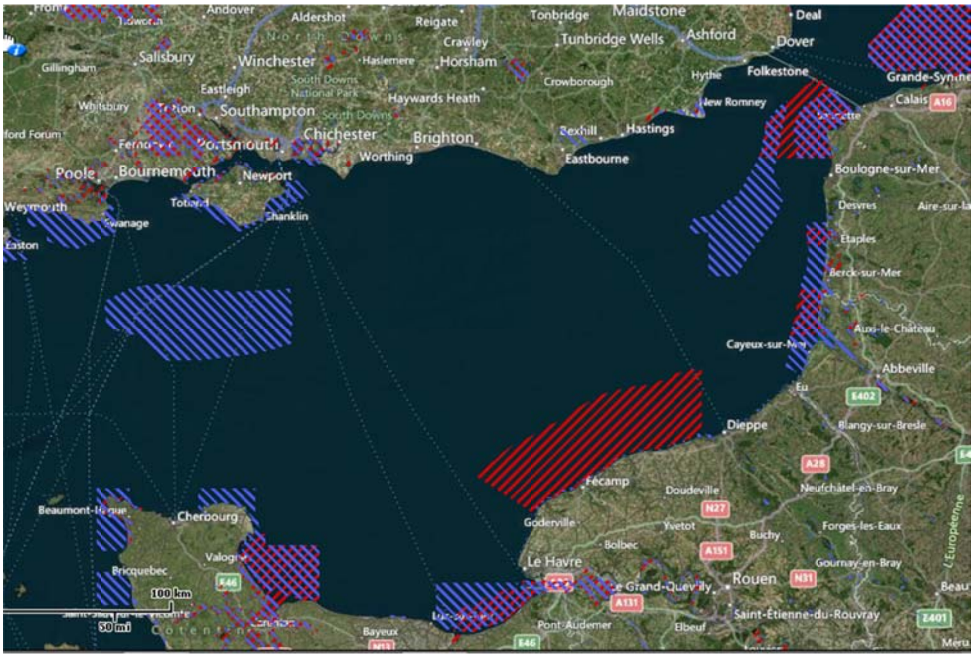


Figure 45. Natura 2000 Network Viewer (http://natura2000.eea.europa.eu/#).

The Eastern English Channel is a spatial area which is impacted by international transboundary issues since the area includes not only the sea territories of two EU Member States (MS), France and England, but it also includes international shipping traffic and fishing fleets from other MS, particularly the Netherlands and Belgium, as well as fleets from elsewhere in the UK such as Scotland and Ireland.

Bearing this in mind, a three-part analysis will be presented of activities and stakeholder interaction in the Channel: the French Case, the UK case, and a comparative analysis of the similarities between the two. As will be shown, and as one would expect from a number of sectors working actively in a small area, some conflicts do take place. Yet, at the same time, stakeholders have also learned to co-exist and at times, even work together for specific causes, even ones who would perhaps traditionally be considered at odds with one another.

The French side of the Eastern English Channel

The main activities currently undertaken- or being planned- on the French side of the eastern English Channel include:

- fishing;
- transport, shipping, and navigation;
- marine aggregate extraction;
- offshore renewable energy; and
- nature conservation.

Additional activities on the coast and in the inshore areas include recreation, nuclear power generation, defence (naval ports), and industry (including petrochemical and oil refineries). The Seine river has its estuary close to Le Havre with sea shipping going inshore up to Rouen (80km from the coast). In the last 15 years several local projects have been financed in the French regions bordering the Eastern Channel with the aim to implement at least partly the concept of integrated coastal management. Marine Protected Areas represent a new type of marine governance which tries to integrate all activities rather than creating no-take areas. The “Agence des aires marines protégées” in particular is the platform in charge to support the establishment and functioning of MPAs and natural marine parks, along with reinforcing French potential in international negotiations concerning the sea. This public administration was created in 2006 and has a specific Channel-North Sea branch since 2010.

Fishing

Fishing is one of the oldest activities in the region. The fishing sector is of great economic importance to France, with those registered in the Channel/North Sea comprising 40% of the value and 37% of the jobs in the French fisheries sector. The fisheries sector, however, is made of up a large number of subgroups. 90% are multi-use boats which switch between gears such as net trawls, and traps, with only 10% fishing outside of the coastal strip (12 nautical miles). Also the most important fishing port in France, Boulogne-sur-Mer, is located on this coastline with landings of 78m€ and 35,000 tons. The majority of French offshore boats land in ports close to their fishing grounds (e.g., in Scotland) and do not return to land, though Boulogne-sur-Mer does have the largest offshore fleet in France. There are some conflicts among the subgroups, particularly given the decrease in some species quota, such as squid and red mullet, which the fishers blame on Dutch seiners who are using efficient gear over a large area. Other fisheries-related concerns include an increase in competition with an increase in the number of gillnetters, as well as weather, toxins (scallop fishery), and a decrease in profitability. In terms of concerns regarding other stakeholders, fishers fear a reduction in the areas which may be induced by the proposed wind farms, Natura 2000 and marine protected area sites, as well as aggregate extraction with no foreseeable ability to adjust positively to the increased competition.

Shipping, transport, and navigation

Shipping and transport are private activities while the monitoring and surveillance of navigation is a part of the public sector. It is operated by the Maritime Rescue Coordination Centers (MRCCs) within the CROSS. CROSS continually monitors their areas of jurisdiction and are responsible for safety, surveillance, and traffic. Two CROSS monitor the Eastern Channel: Jobourg and Gris-Nez.

- CROSS Jobourg is present in the area of Cherbourg and monitors the maritime traffic on the Casquets TSS (Traffic Separation Scheme: obligatory passage for ships). In addition to two traffic lanes, there are passenger ships passing through the Channel Islands, and important traffic around the trading ports of Le Havre and Rouen. Other users who need to be taken into consideration include fishers, recreational boating and regattas.
- CROSS Gris-Nez operates around the Calais-Dover Strait, a particularly narrow and busy shipping route. The area is crossed by 25% of the world’s traffic, has the passenger line Calais-Dover, a LNG terminal in Dunkerque, is home to France’s first fishing port in value (78 million) and tonnage (35,000 tons) of Boulogne-sur-Mer, includes several sites of aggregate extraction, and will be home to new windfarms in 2017. In addition to these economic activities the area welcomes each year more than 1 million recreational vessels, kite surfers, and even swimmers crossing the channel. CROSS competences extend across all of these actors.

Marine Aggregates

Marine aggregate extraction is a relatively new activity in the French waters of the eastern English Channel. Though extraction began in the 1980s, permit applications have increased significantly in the last five years following a decrease in the number of exploitation sites and the volume of reserves of land-based aggregates because of increasing environmental pressure.
Current extraction rates in the area are approximately 2m tons annually. Overall, marine aggregates make up 2% of French construction material (360-370m tons). NE Channel deposits are especially prized for their quality, accessibility, and volume.

In France the authorization procedure for marine aggregate extraction requires three licenses: the mining title, a state authorization ("autorisation domaniale") and a prefectural order for opening of mining operations. In 2006, Decree No. 2006-798 brought together most of the regulatory requirements applicable to marine aggregate extraction in a single text, leaving the administration with only 38 months to study the issues and decide on the opening of new extraction sites. A consultative body was also introduced to associate elected local fisheries committees, eNGOs (environmental groups), renewable energy developers, etc. for better local governance.

Two aggregate extraction sites are located off Dieppe (2 companies); one is further located off St-Valéry en Cau and Fécamp (deposits 15-20km from the coast); the ”St Nicolas” site is along the watershed FR-UK; one other in

Seine Bay, 20km west of Le Havre; and a new site has been opened 30 km east of North Cotentin border. Dieppe is the historical site in the Eastern Channel, owned by the company Graves de Mer. The companies GSM Granulats and Cemex are also present in the Eastern Channel. Three authorisations were given in 2012-2013, for areas from 6-7km^2 to almost 100km^2.

The company Graves de Mer initiated a close partnership with scientists through the creation in 2003 of a scientific interest group (GIS SIEGMA[7]). The goal is to get more knowledge about the impact of aggregate extraction in the Channel area. Scientific studies are realised on environmental parameters (morphosedimentary bathymetry, benthic and fish, trophic networks, turbidity).

During the course of 2007-2013, a comparative study between an impacted area and a non-impacted one was undertaken in the Seine Bay. Outcomes have influenced the location of the area chosen for the extraction, its size, management decisions on months to avoid, the frequency of extraction, etc. The proactive involvement in the GIS might have helped the company to be attributed concessions by the State, an informant from Graves de Mer said. Other extracting companies in France are seeing the benefits they can get by showing they are virtuous in terms of environmental consideration, and in the Eastern Channel all companies are progressively getting involved in the GIS.

Through studies of the GIS, the consultation process and the approval by the State for new concessions, the chosen sites are supposedly the sites where the impact on both the environment and existing activities will be most limited. However some actors of the civil society underline the fact that marine aggregate extraction is an activity which can modify the marine environment (Desprez, 2000) and that its effects over the long term thus need more consideration.

Offshore renewable energy

Wind energy potential in France is estimated to be the second greatest in Europe, though, as of yet, quite limited in its exploitation. Fixed wind farms are being considered particularly for the Eastern English Channel given its shallowness. In 2009, with the view of offshore energy, an inventory of each area of interest was made, resulting in mapping of hydrological and geographic information as well as the presence of other activities such as shipping lanes, fishing areas, extraction zones, protected areas, etc. In 2011, a call for tenders was made for the building of 600 wind turbines by 2020 in 5 separate areas; three of these sites are to be in the Eastern Channel.

As seen with the marine aggregates sector, the development of the wind energy is currently a quite consultative one.

"Today there really is a desire to plan, the state identifies the areas and then offer them within call of tenders. … We are a newcomer in the sea. We first try to identify other actors in the marine environment … then we organise consultation to find the project with the least impact on their activities or perhaps how we can compensate for project impacts on their activities. Fishing is clearly the leading player with whom we have discussions. … Then we must also take into account activities which are more specific to the Channel : navigation rail (up and down) in which we obviously can not put a park. And then there are activities with which we are not necessarily interacting, e.g. aggregates, are also areas reserved for aggregates, obviously you can not have everything on the same zones. Also Natura 2000 zones on the Channel coast, and a natural marine park being created the Bay of Somme. Different activities, either exploitation of resources, or recreation, or protection of the environment come into play here in the windfarm project definition" (Wind energy developer, Dieppe).

Nature Conservation

There is also an increase in nature conservation in French waters, including the Eastern Channel. Depending on where you draw the line, there are at least 15 Natura 2000 sites, which include both Birds Directive sites (Special Protection Areas) as well as Habitats Directive sites (Special Areas of Conservation). The majority are in coastal areas, but also includes some in offshore areas (see map XX, above). The “Agence des Aires Marines Protégées” (MPA Agency) has a branch in the Channel North Sea since 2010. Among its responsibilities are:

[7] http://www.siegma.fr/;http://wwz.ifremer.fr/defimanche/content/download/39363/538002/file/Plaquette%20GIS%20SIEGMA.pdf

- leading the French MPA network and natural marine parcs, relying on concertation and several legal tools: Natural Marine Parc, Natura 2000 network, Natural Reserve, National Parc, public maritime domain of the "Conservatoire du littoral", prefectorial *order* for *protection* of the *biotope, "*Trame bleue" (Blue corridor)…
- Gathering scientific data on the marine environment
- Facilitating consultation between elected representatives, users and nature protection organisations
- Experimenting new governance or management models

The heavy anthropogenic pressure in the Eastern Channel has led to the progressive deterioration of the environmental quality of the water, particularly at the mouth of the Seine estuary. Over the last dozen years national and European measures have been designed with an eye towards developing an integrated management plan for the zone.

Several interdisciplinary scientific programs have also been implemented, both at the national and international level, to study all or parts of the eastern English Channel. During this same period, numerous qualified stakeholders have attempted to initiate integrated coastal zone management (ICZM) policies.

The UK side of the Eastern English Channel

Similarly to what is found on the French side of the English Channel, the main activities currently undertaken- or being planned- on the English (UK) side of the eastern English Channel include:

- fishing;
- transport, shipping, and navigation;
- marine aggregate extraction;
- offshore renewable energy; and
- nature conservation.

Additional activities on the coast and in the inshore areas include recreation, nuclear power generation, and defense (naval ports).

In the UK, there has been a significant effort in recent years to work on integrated management of coastal and marine waters. The Balanced Seas Marine Conservation Zone project is one notable example, another is the on-going work being undertaken to get all the users in one room to put together a plan for the next 20 years for the Eastern Channel: wind farms, shipping, fisheries, nuclear power stations, defense (MOD), leisure (yachting). As one attendee noted, "*Difficult to do, everyone vying for their own bit.*"

Fishing

Fishing is a varied and historical activity on the UK (English) side of the eastern English Channel. Activities have adjusted over the years and adapted to regulatory and legislative changes. Currently, the majority of fishers work on boats under 14m as it gives them the greatest flexibility to fish for a multiplicity of species in the inshore areas, as well as to save on operating costs. The offshore fleet has diminished in recent years and consists primarily of scallopers from Brixham, the West of England, and Scotland. There are also French boats which fish outside the 12nm limit, Belgian beamers, and French (stern trawlers) which fish right on the 6nm line.

There is some threat of increased fishing pressure due to displacement, e.g. boats entering new areas after being shut out of closed areas, such as Scottish boats shut out in Scotland and coming south; or conservation zones closed to fishing with boats then moving to new areas. Several of the fishers (not trawlers) pointed out the difficulties trawlers are facing with increased pressure/ competition for space and felt "sorry for them." One of the greatest impacts on fisheries comes from aggregate extraction—not only for current space they are closed out from, but also for previously used space as it no longer provides good fishing. Yet some subgroups accepted their (aggregates) presence as legitimate given their long history. Currently, fishers are also greatly concerned about the Dutch boats (fly shooting) and especially about the new proposed wind farms. As one long time fisherman noted

"*… 340.000 tons [spoil] dumped into 137sq km is pretty much going to bugger up all that habitat within the area. We are very concerned about that, very concerned about once we get over the construction phase, very concerned about the operational phase of on-going underwater noise, vibration and EMF effects for local stocks and migratory stocks that we produce seasonal fisheries forces, things like cuttlefish, black bream, bass, Dover sole and plaice. Although dover sole and plaice are available here in viable commercial quantities all year round, there are 2 distinct seasons per year where they are migrating from the southwest. Are they still going to do that the physical barrier of the wind farm? I don't know, I am not bright enough to tell you that and its not my job but somebody should tell us that.*"

They are also feeling a pinch from closed conservations zones. "… *Now we have the management zones the MCZ, which I was a supporter of, and the majority of the fishing in this district are [supporters of], as long as it is done sensibly. So what I am trying to say is areas of sand or mud, if we are doing it the right way (reef or habitat) that is defined and definitely there then everybody is willing to go along with it, I think it will work well, in the Eastern Channel… now in the Eastern English Channel you have got SACs, MPAs, MCZs, SSSIs (sites of special scientific interest) … All of which we didn't have ten years ago. In fact most of those we did not have 3 years ago. We have been squeezed for fishing grounds, that's for sure, no getting away from that."*

Pressure from large numbers of leisure crafts, especially yachts, also exists, though tends to be viewed as a pressure rather than a difficult issue.

Shipping, transport, and navigation

Much of the organisation and protection of transport (ferries), shipping and navigation on the English side of the English Channel is run by the Maritime and Coastguard Agency (MCA). MCA conducts research in such areas as environmental protection, navigation and seafarer/fishermen safety, and accident prevention. They also provide training and certification; weather and safety information; they work with partners in the shipping industry to promote the safe construction, operation and navigation of ships; and they provide emergency response.

The Channel has traffic on both the UK-Europe and North Sea-Atlantic routes, and is the world's busiest seaway, with over 500 ships per day. Following an accident in January 1971 and a series of disastrous collisions with wreckage in February, the Dover Traffic Separation System (TSS), the world's first radar controlled TSS, was set up by the International Maritime Organization (IMO). The Channel Navigation Information Service (CNIS), introduced in 1972, provides a 24 hour radio and radar safety service for all shipping in the Dover Strait, and is jointly operated by the UK and French Administrations from the Dover Maritime Rescue Co-ordination Centre (MRCC) and CROSS Gris Nez in France. The Dover Strait is a mandatory reporting area, meaning that vessels over 300 gross tonnes are required to report to either Dover MRCC (South West Lane) or CROSS Gris Nez (North East Lane) before proceeding through the service area. The scheme mandates that vessels travelling north must use the French side, travelling south the English side. There is a separation zone between the two lanes.

Stakeholders understand the safety issues involved with shipping and transport and understand the need for dedicated shipping lanes.

Marine Aggregate extraction

The eastern channel region is one of the most important for the English marine aggregate industry due to the licenses found here. Almost one-third of construction aggregates come from this region and one-third of UK construction takes place in this region (due to London). Though marine aggregate extraction has taken place for over 50 years in the English Channel, it has become a much larger industry in the last 15-20 years. As one informant described, "30 years ago it was one ship going in and out of one port 2-3 times a week; now it is multiple ships coming out of multiple ports 2-3 times a day." Consequently, it has become, in his words, "a huge industry compared to what it once was."

In addition to a larger industry, aggregate extraction has also moved further offshore compared to earlier years. Consequently, they must now interact with a greater number of different stakeholders (international fisheries, shipping, a greenfield site) than previously. Also, they tended to have closer relationships when interacting more with local stakeholders (e.g. port and inshore fisheries when compared with international fisheries).

In addition to being used in UK construction, marine aggregates are sent to the near continent (France and Belgium); sand and gravel are used in coastal defense and to protect environmental features and communities at risk.

The marine aggregate industry, as seen in the French case, also works diligently on outreach and public relationships. In the past, they would have had 50-80 fishermen in for a tense meeting on their activities, now they may only get one or two thanks to increased transparency on activities (e.g. on their website). All ships use a black box which reports positions at 30 second intervals; they also send out biennial reports to fishermen. Of course there are some tensions with fishers, as you would expect, but many in the industry feel they have a positive working relationship with fishers; they are a small industry and have similarities due to the location of where they work.

In 2012, they had 155km^2 of licenses, in which they were permitted to dredge in an area of 86km^2 and they actually dredged 35km^2 of area.

Current challenges stem from the increased number of other pressures: policy, windfarms, MPAs. The industry is advocating for the mapping of areas for better planning and development.

These sectors have worked together and signed joint statements at various times (e.g. with NGOs) on specific issues where some synergies exist, though the extent of agreement has varied. For example, the aggregate industry may hope for mapping and clarification of sensitive sites, while the NGOs would go a step further and actually want them designated.

Regional cooperation is advocated by many in the industry, pointing out that it makes no sense to have things done differently in France than the UK, they should work together.

Offshore renewable energy
Though still in the planning stages, offshore energy is already having an impact on the planning of other businesses (e.g., fisheries) in the English Channel coastal areas.

One of the proposed offshore wind farm developments by E.ON, planned for the Sussex coast, is known as Rampion. The wind farm will have a target zone capacity of 665 MW (enough for 450,000 homes) with up to 175 turbines. Development and construction costs are estimated at £2 billion. Rampion is to be located between 13 to 25 kilometres from the coast, lying off the towns of Worthing and Shoreham-by-Sea to the west, the city of Brighton and Hove in the centre and the towns of Newhaven and Seaford in the east. The wind farm would be in a zone that is an irregular elongated area, approximately 28 kilometres in an east to west direction and approximately 10 kilometres in the north to south direction. The wind farm itself would occupy an area of 167 square kilometres equivalent to two-fifths of the size of the Isle of Wight. The wind farm would be viewable from the bay between Selsey Bill and Beachy Head, as well as from the Isle of Wight. The Port of Newhaven will house the administration and engineering functions of the wind farm. The sites surrounding the Newhaven dockland will be used as storage for the landside construction of the various turbine components, before they are shipped for final construction on site.
In terms of potential impacts, at the moment, 137km^2 is set aside for a wind farm near Brighton and 100km^2 for one near the Isle of Wight. Impact assessments conducted by the wind energy firms estimate 1800 tons of seabed to be dug up for each turbine. This "spoil" (340 000 tons) is to be dumped within the boundaries of the wind farm, not a special spoil ground, which concerns fishermen.

The turbines have also been shown to impact various bird species (e.g. gannets around the channel island, France, and the UK) in terms of altering their foraging behaviours. There is also concern about the impacts of vibrations on marine life.

Nature Conservation
Much of the conservation work in the UK's English Channel areas are driven by the Marine Coastal Access Act (MCAA, 2009) as well as the EU's Habitats (1992) and Birds (1979) Directives which called for the designation of special areas of conservation (SACs) as well as Special Protection Areas (SPAs), and the Marine Strategy Framework Directive.

One of the most important aspects of the MCAA was the formation of the Marine Management Organisation (MMO). The MMO was established to *"make a significant contribution to sustainable development in the marine area and to promote the UK government's vision for clean, healthy, safe, productive and biologically diverse oceans and seas."* (http://www.marinemanagement.org.uk/about/index.htm). Critically, the MMO is a non-departmental government body (NPBD) which serves to basically coordinate decision-making regarding the coastal seas into one body.

Among the MMO's key responsibilities include:

- implementing a new marine planning system designed to integrate the social requirements, economic potential and environmental imperatives of our seas
- implementing a new marine licensing regime that is easier for everyone to use with clearer, simpler and quicker licensing decisions
- managing UK fishing fleet capacity and UK fisheries quotas
- working with Natural England and the Joint Nature Conservation Committee (JNCC) to manage a network of marine protected areas (marine conservation zones and European marine sites) designed to preserve vulnerable habitats and species in UK marine waters
- responding to marine emergencies alongside other agencies
- developing an internationally recognised centre of excellence for marine information that supports the MMO's decision-making process.

As seen in point four, working with Natural England and the Joint Nature Conservation Committee (JNCC) to manage a network of marine protected areas (marine conservation zones and European marine sites) designed to preserve vulnerable habitats and species in UK marine waters is one of the MMO's priority activities. The JNCC is a public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation, including the marine environment. They work closely with Natural England whose remit is to ensure sustainable stewardship of the land and sea so that people and nature may thrive. They view a key responsibility as seeing that England's rich natural environment can adapt and survive intact for future generations to enjoy.

The JNCC's primary work in the marine environment centers on:

- **Advice to offshore industries -** Well managed industries can minimise their biodiversity impacts.
- **Establishment of Marine Protected Areas -** The recent passage of the UK Marine Act and Marine (Scotland) Act has accelerated work on protected areas.
- **Marine Strategy Framework Directive -** Implementation of this new Directive will set goals for the state of our seas generally. We are working to see that these goals will meet the needs to conserve marine biodiversity.
- **Survey and monitoring -** We undertake surveys to identify potential protected areas. We are also currently developing a programme to advise governments on future monitoring needs to establish marine biodiversity status and trends and the pressures that act on them.
- **Assessment –** We bring together survey/monitoring information with new research and expert judgement to establish a comprehensive picture of the state of the seas.

These organisations always work closely with other statutory bodies such as Inshore Fisheries and Conservation Authorities (IFCAs), such as by serving as board members and working in their offices to provide data and expertise.

As seen with all of the organisations mentioned in this section, integrated management is a significant change and MCZ and MPS planning is a large part of their function. As opposed to EU designations, socioeconomic considerations *may* come into play when designating sites in the UK, and thus they work closely with more stakeholders and users. Their work is primarily driven by legislation and they view the primary hindrance as being time itself.

Comparisons and contrasts between France and England

UK and French fishermen fish with similar size boats and gear, they both have concerns about the Dutch fleets- fly shooting. In the Eastern Channel interactions take place with four nations using the same bit of sea: Belgium Dutch, French, and British. There are different styles of fishing among some boats. The indigenous French and British, those who live and work on these coasts, fish in similar ways, using towed gears, very similar scallop dredges, fishing very much seasonally (for scallop, dover sole), while Belgium have a fleet of beam trawlers and the Dutch trawl with fly shooters (earlier beam trawls).

There is a view that the local French and English together suffer from modern techniques used by "outsiders": ring netting/ fly shooting from the Dutch fleet http://en.wikipedia.org/wiki/Seine_fishing), which only materialised in the last 5 years and it is, in the words of a UK skipper, "*an incredibly efficient way of catching fish.*"

He further explained that,

"*If you have got an area of seabed, if you go through with a traditional boat you would scare 70 percent of the fish. With this method, because it herds it all together before pulling the trawl through, you catch a much higher percentage and what we've noticed in the UK part of the Eastern Channel is that certain species such as red mullet, gurnards, cuttlefish, squid, all historical fisheries that have been going on for decades, probably centuries, have really, really diminished when these ring nets came along. When you see their landings: cuttlefish, red mullets, squids, gurnards… it can't be coincidence. I am not a scientist and don't pretend to be but it cannot be coincidence. The French get very excited about it because that is their area and their fishing force.*

So that is a new pressure that has come along and it's a consequential pressure because the only reason why the Dutch have gone to ring netters is because of the pressure put on by environmentalists to get away from beam trawlers (biggest beam trawling fleet in Europe). So whether it is a bigger problem to have that is not for me to answer. You go from one problem to another."

An additional 14 licenses were created by the Dutch government for ring netting recently so that issue will increase in the near future.

French aggregate extraction is a new industry, possibly without the same level of legitimacy as seen in, for example, the UK. In the UK the industry is seen as an "old player" and thus has more legitimacy in terms of having a "right" to operate in the area. Also, the aggregates (UK) ally themselves at times with other industries—e.g. fishing or conservation, depending on the issue at hand.

Shipping separation zones are now less of an issue since there are fewer trawlers than in the past.

Since 2003, a platform of cooperation (*Channel Arc*) gather both UK and French actors into a more holistic programme to exchange best practices and discuss about maritime issues:
http://www.arcmanche.com/en/the-channel-arc/what-is-it/

Overall, the conflicts among stakeholders from various sectors is not as severe in France as in the UK. Given the relative youth of the renewable energy and aggregate extraction sectors in France, however, it can be anticipated that conflicts will increase in the future as they expand their activities.

3.2 The Dogger Bank

Introduction

The Dogger Bank is a major sandbank below sea level rising off the sea bottom in the middle of the North Sea. The bank stretches through the Exclusive Economic Zones (EEZs) of four member states: Denmark, Germany, the Netherlands and the UK. EEZs are the zone from the boundary of territorial waters, 12 nautical miles off the coast to 200 nautical miles off the coast to which member states enjoy exclusive rights to resource exploitation.
Dogger Bank extends over approximately 17,600 km^2, with dimensions of about 260 km long and up to 97 km wide. The water depth ranges from 15 to 36 metres which is about 20 meters shallower than the surrounding sea. A big part of it is a productive fishing bank.

Each member state has had to consider whether the Dogger Bank in their EEZ is a sandbank habitat type requiring protection according to the EU's Habitats Directive and, if so, designate a protected area – or Special Area of Conservation (SAC) as it is termed under the Habitats Directive. Germany, the Netherlands and the UK have all designated Dogger Bank SACs in their respective EEZs. In the Danish part of the Dogger Bank, which is the deepest end of the bank, it has been argued that it is not a "shallow" sandbank, and thus does not merit conservation status under the Habitats Directive.

Germany and the Netherlands have also made harbour porpoise, and grey seal added features which require particular protection on their respective SACs. The UK formerly had both species added in an early version of their SAC, but removed them from the final proposed site.

As the German part of the Dogger Bank is in rather deep waters, which makes it both less productive as a fishing bank and less useful for wind farm development, it is important only for a small group of stakeholders. In the Dutch part of the Dogger Bank, the water depth varies between 24 m and 40 m. This area is generally shallower than the German part of the Dogger Bank and hence a more productive fishing site – however, it is still too deep for wind farm development. The UK part of the Dogger Bank is the shallowest part – a major part of it is less than 20 meters deep.

Users and conflicts

The Dogger Bank is an important site for a range of different users, just as it is featured for its ecological qualities. In the following we give an overview of the different uses, including how they coexist and conflict:

Fishing ground

Due to its shallowness and the high hydraulic activity on the bank, the Dogger Bank is a very productive fishing ground, especially when it comes to flatfish and sandeels. Hence, it has been a popular fishing site for more than a century and has been named after the *dogger*, a particular type of Dutch fishing vessel. The shallower areas of the Dogger Bank in the UK and Dutch parts of the bank are the most productive, particularly because the shallowness allows the sunlight to reach the sea bottom, allowing for processes of photosynthesis, which again feeds the fish. For the same reason, the deeper areas in the German and Danish part of the Dogger Bank are less popular fishing grounds than the rest of the bank.

The main fisheries stakeholder on the Dogger Bank is a major Danish fishing fleet going mostly for sandeel, but also for plaice, sole and mackerel. Incomes vary depending on the yearly quota, but during the latest 5-6 years Danish fishers, if taken together, earned about 43 million EUR per year[8]. Dutch fishers are also very active on the bank, earning app. 11 million EUR per year[9]. There are very few German and UK fishing vessels operating on the Dogger Bank.

The management plans are not expected to consist of complete closures of the areas, but rather to restrict particular activities. However, they are expected to have major impacts on particular fisheries activities in the area. Hence, the fishing industry has been and still is heavily involved in the process of designating SACs on the Dogger Bank and developing management plans for the areas. Particularly through their engagement in the North Sea Regional Advisory Council.

Source of aggregates, such as gravel and sand

Very small areas of the seabed are licensed for the extraction of sand and gravel from the seabed. This is an important material for construction. However, if you ask members of the sand and gravel industry, they will argue that the Dogger Bank is not a sandbank, but sand over hard substrata. This makes it a less important site for sand and gravel extraction than other 'plain' sandbanks. Hence, the sand and gravel industry has not been particularly engaged in the process of designating SACs on the Dogger Bank – instead, they have focused their efforts on other SAC designation processes concerning sandbanks important to the industry.

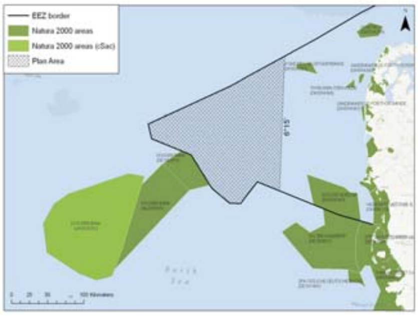
Drilling area for crude oil and natural gas

There is limited oil and gas activity on the Dogger Bank. The UK, for example, is developing a gas field through Cygnus Alpha, a permanently manned hub that consists of three bridge-linked platforms providing drilling,

[8] Interview with Danish fisheries representative.

[9] Ibid.

accommodation, processing, and export. According to the Cygnus Field Development Environmental Statement Summary (Dept of Energy & climate change n.d.), ten gas production wells are planned, three of which may require hydraulic fracturing to improve flow rates. Constriction is scheduled to begin April 2014 with first gas expected in September 2015.



Map: The Danish portion of the Dogger Bank with surrounding designated conservation areas

Additional sites are found along the Danish-German line, as noted in one environmental blog[10] "As we cross to the east of the large block [of the Dogger Bank] we enter Danish waters, which are crowded with gas platforms, especially along the boundary between Danish and German jurisdiction."
In Denmark, according to an environmental report prepared for the Danish Energy Agency, oil and gas activity in the area may increase if current applications for exploration are approved. The areas of discussion bound the German sector the Dogger Bank which is a Natura 2000 site. The impact assessment expected impact on the local wildlife to be minimal; fishing would be impacted by constraining fishing activities in the area.
According to some assessments[11] "the biological and physical structure of the Dogger Bank has been impacted locally by a small number of oil and gas installations. Recent pipeline laying on the western edge has experienced high levels of sediment mobilisation by tidal currents (Mark Tasker, pers. comm.)" (JNCC 2011: 12).

Location for offshore wind turbines

The shallow depth in the UK part of the Dogger Bank makes it suitable for offshore wind turbines. And while shallow areas closer to the coast tend to be controversial sites for windfarming because – according to some citizens – they scar the sealine, a shallow area so far from land makes it less controversial in that respect. Moreover, the fact that the shallow area of the Dogger Bank is so large enables a major windfarm in one spot, reducing the costs of the expensive infrastructure between the wind turbines and land. Taken together, this makes the Dogger Bank an extremely ideal spot for wind farm development, and the world's biggest windfarm has been projected here. The wind farm zone extends over 8,660 square kilometres. It is expected to be able to supply the UK with 10 per cent of its total energy consumption – two thirds of the UK's commitments to the EU strategy for a fast transition to renewables by 2020 (the EU 20-20-20 plan).

Shipping

The North Sea is also an important area for shipping. Major harbours are located along the coastline of the North Sea and it serves as a transit area to and from the Baltic Sea. It is estimated that at any time there are at least 500 vessels with more than 100 gross register tonnages present in the North Sea (Lange, 1991[12] ; Mærsk Olie og Gas, 2011[13]). Given that shipping lanes are subject to change, it is difficult to get an image of precisely where shipping and its impacts take place.

Conflicting activities

As one would expect given the variety of activities taking place on the Dogger Bank, some activities conflict with one another.

[10]IFAW 2011. http://www.ifaw.org/united-states/news/dogger-bank-journal-its-wednesday-so-we-must-be-dutch-waters%E2%80%99

[11] JNCC 2011 "Offshore Special Area of Conservation: Dogger Bank SAC Selection Assessment Document." *jncc.defra.gov.uk/pdf/DoggerBank_SelectionAssessment_v_9.pdf*

[12] Lange, R. (ed.) 1991. *Environment Northern Seas*, p 63.

[13] Mærsk Olie_og Gas as, 2011:Vurdering af virkningen på miliøet fra yderligere olie- og gasaktiviteter i Nordsøen.

Windfarms and conservation

In this light, the prospects of a Special Area of Conservation on the UK part of the Dogger Bank raise concerns, particularly with the UK Department for Energy and Climate Change, the Crown Estate and the wind farm developer Forewind (a consortium comprising Statoil, Statkraft, SSE and RWE power). As the management plans are still negotiated, it is still not clear which implications this will have for the wind farm. First of all, the drilling required in the construction phase will generate a lot of noise, which can affect the harbour porpoises in the area, as these are particularly sensitive to sound and depend on their hearing abilities for navigational and communication purposes. Some NGOs suspect that this is why the UK, unlike the Netherlands and Germany, ended up not making the UK SAC a special conservation area for harbour porpoise.

Windfarms and fisheries

The prospects of a major wind farm on the Dogger Bank also raise concerns among fishermen. Each turbine will have a safety zone, and likewise powerlines along the seabottom will obstruct bottom trawling in particular areas. The main impact on fisheries will be the loss of important fishing grounds and, on other grounds, restrictions of fisheries. There will also be safety issues and increased steaming times to fishing grounds, just as fishers are concerned about the eventual negative impact of the wind farms on the abundance of commercial species.
As part of the initial phase Forewind is consulting with all users in the area in order to ensure as smooth coexistence as possible. Among the mitigation measures taken to reduce impacts on fisheries, Forewind mentions "regular Notices to Mariners; the establishment of safety zones of up to 500 metres during construction or significant maintenance work; installation of adequate safety lighting, and ensuring construction vessels follow international regulations in respect of fishing routes." (Forewind 2013, p. 12)

Windfarms and shipping, oil and gas

As the area is very shallow, only few vessels transit through the area. Hence, the wind farms are not expected to cause major changes in shipping routes.
There are oil activities close to the proposed landfall for the wind farms. Mitigation measures will include comprehensive mapping, proximity agreements and to place underwater structures as close as possible in order to minimise the affected area.

Windfarms and prehistoric sites

There are several prehistoric and historic sites on the Dogger Bank. As part of the planning phase Forewind has been screening the area and identified a number of sites which will be exclusion zones.

<u>Nature conservation area</u>

Due to its shallowness and the high hydraulic activity on the bank, the Dogger Bank is in some areas highly productive and provides physical habitat for species such as harbour porpoises and seals. It is a feeding ground for seabirds, and in some areas there are high densities of sandeels, which serve as an important food source for a long list of species. The purpose of the SACs on the Dogger Bank is to protect its function as a habitat, just as harbour porpoises and seals are added as protected features on the German and Dutch SACs.

Conservation and stakeholders

The management plans for the three SACs on the Dogger Bank are still negotiated. In order to ensure a coherent management regime on the bank, Germany, the Netherlands and the UK are striving to have joint management plans. Rather than being a complete closure, the management will restrict or exclude particular activities. Several stakeholder groups are taking part in the negotiations, particularly fisheries representatives and NGOs. In the UK, the wind farm developer Forewind, the Department for Energy and Climate Change and the Crown Estate are also consulted continually about the eventual implications of the management plans on the wind farm development.

<u>Nursery ground, diversity of species and ecological functions</u>

The diversity of species living above and in the Dogger Bank plays many different roles, for example helping to remove carbon dioxide from the atmosphere and remove waste products from the water. Moreover, Dogger Bank as a habitat plays a role in populating the wider North Sea.

The SAC management plans

The Dogger Bank is a highly productive area and a habitat for a number of species, hereunder harbour porpoise, seals and a range of commercial species (e.g. sandeel and plaice). At the same time, it is an important site for a range of industries, particularly fisheries (mainly in the Dutch and UK area) and wind farm development (only in the UK area). Other industries, which are less important, however still active, are oil and gas, sand and gravel extraction and shipping. Moreover, the Member States have different agendas for their bit of the Dogger Bank. All this makes the process of developing management plans for the Dogger Bank SACs highly problematic.
The Dogger Bank Steering Group is coordinating the negotiations. The North Sea Regional Advisory Council, consisting of NGOs and fisheries industry representatives, has been given an important role in the process. Asked by the Dogger Bank Steering Group to make joint zoning proposals, a focus group was formed in the North Sea RAC, which came up with a position paper proposing the contours of a management plan. Main elements were co-management, adaptive management and zoning. However, the Member States wanted a full management plan proposal. Hans Lassen was hired as a consultant and developed three management scenarios which were presented at a North Sea RAC meeting. None of these were supported by the RAC – many members found that very few elements in their first position paper were included.

The Dogger Bank Steering Group then asked the North Sea RAC to develop a new proposal, this time with a very short timeframe. They were provided with new Terms of Reference, which were a mix of different Member States' agendas, for example Germany wanted at least 50% of the SAC area to be protected. The main issue in this process was about zoning – how many percentages of the areas within the SACs should be closed or regulated, and where within these SACs should these regulated zones be, that is, which areas are ecological hotspots. Whereas the starting point for the NGOs was that they would not go below 35%, the fisheries industry wanted less. Another issue was which fishing gears should be allowed and banned respectively. Particularly, the regulation of bottom trawling, otter trawl and especially seines have been discussed.

When they reached the deadline, the working group in the North Sea RAC informed the Steering Group that they could not reach an agreement, and they were given an extension with the clause that the chair and vice chair of the North Sea RAC was involved. It was still impossible to reach an agreement – they disagreed about the percentage and the location of zones, and in the end they had to give up on coming up with a joint proposal but submitted a proposal with minority reports. Hans Lassen was asked once again to refine the proposal, and the North Sea RAC was invited as an observer in the Steering Group. A proposal has now been sent to ACOM for final advice, and ACOM has asked independent reviewers to review the proposal.

More recently, the involved NGOs have sent a letter to the European Commission, the Dogger Bank Steering Group, the Member States and the North Sea RAC. The letter detailed their frustration with the process, which they had found to be longwinded and, for the NGOs, costly but without results and with too many compromises in favour of the industry and at the cost of the conservation goals. They will not participate in more processes until they can see an opening and things moving forward. (Pers. comm., NGOs representatives)

Forewind, an energy group, has been taking part in the process since 2012 when they joined the North Sea RAC focus group. The Forewind wind farn-approved area is also taken into consideration in the proposals.
Due to the many stakes in the Dogger Bank, the process of first designating SACs and later of developing management plans has been longwinded and full of conflicts. The different stakeholder groups have been negotiating closely, both during Forewind's wind farm planning phase and in the SAC process, however as of yet, no agreement has been reached.

3.3 Gulf of Gdansk

Short description of the case study area:
The Gulf of Gdansk, part of the Southern Baltic Sea, is delimited by the shores of the Pomeranian Region in Northern Poland and by the coast of the Kaliningrad Oblast in Russia. The total surface area of the Gulf is 4,296 km^2 and its volume is 236 km^3. The bottom of the Gulf is stony close to the coast, muddy further away in deeper parts, and sandy, especially in the sheltered Puck Bay (the western part of the Gulf), where it is coved by macrophytes. The western and eastern regions of the Gulf were included in the NATURA 2000 network and belong to HELCOM Baltic Sea Protected Areas. The coastal zone of the case study site is mostly low sand

beaches – an excellent place for tourism development. The Gulf is also an important area for fishing, shipping, and to a limited extent for extraction of natural gas, sand and gravel.

Methodology

The research methodology involved using qualitative, semi-structured interviews that were conducted with the three predefined user groups: fishers, environmentalists, and representatives of shipping industry. At least two representatives of each sector were interviewed, using face-to-face interviews that lasted between thirty and sixty minutes. The questionnaire was designed to capture spatial conflicts, potential barriers and solutions, and changes in the sector within the last decades.

Results

Fishing

Fishing is the oldest and the most traditional use of the marine resources, but its overall importance is decreasing. In 2007 the Polish fleet had over 860 fishing vessels, but in 2011 this number dropped to 790. At the same time in 2011 the fishing quota assigned to the Polish fleet had not been used (apart from the quota for herring; Kalinowski et al. 2012). It is expected that fishing quota will be reduced and the number of vessels and employment possibilities will decrease, causing further changes in the fishing sector. The consequences of these changes, however, will be different for coastal or off-shore fisheries, and for vessels owners and fishers who do not own the ships.

Fishers in Poland are aware of these changes. All the interviewed fishers agreed on the four important reasons for the challenges they face: (i) the technical and technological development, (ii) change in the political situation (transformation from socialism to free market), (iii) Polish accession to the European Union, and (iv) changes in the marine environment.

Technical and technological progress led to the development of fishing gears and other on-board equipment. Overall, the work at sea became easier and safer. All the fishers thought that these improvements lead to increased fishing capacity, but a few underlined that this might be relevant only on an individual level. These fishers noted that the overall fishing capacity will not increase due to the market mechanism or EC regulations and further reductions in fishing quotas. Polish accession to the EU had two important consequences. First, the Polish fishing sector has to follow European regulations, including the Common Fisheries Policy, which Poland was not prepared for, and as a result made a lot of mistakes, especially in quota division. Second, the accession brought a lot of funding opportunities for modernization of the fishing vessels and investments in large infrastructure, e.g., fishing harbours or fish sale centres,but only a few respondents believed this funding was properly designed to meet their needs. For example, it was not possible to purchase modern engines for fishing vessels and to replace old engines with more powerful ones. This continues to be a big problem, because many vessels were under-equipped in post-war Poland. One respondent noted that the level of co-financing for similar investments was lower in Poland than in other EU countries. Bureaucracy and paper work was commonly criticized.

The combination of these factors not only exacerbated the existing problems but also brought new challenges. Perhaps the most important ---and widely discussed by all the fishers--- is the issue of discards and quota division. The respondents complained that a division system is practically non-existent, and therefore, they cannot plan their activities and investments in the long term. They continue to be surprised by the limits and division criteria. Every year there is a political bargain between various fishers organizations, and also within these organizations---between fishers representing smaller and larger vessels (cutters). As a result, there are vessels that receive cod quotas that are too small, but more often the limits are far too large. Small vessels are not only sensitive to weather conditions, but are also subject to navigation restrictions. They are not allowed to go further than 12 or 30 nautical miles from the coast, yet cod can rarely be fished in shallow waters close to the coast. This is a major conflict between the small boat and large boat owners. Smaller boat owners argue for higher cod quotas, but some of them are only interested in selling their quotas on the market and not in actually fishing them out. Therefore, Poland is not able to use approximately 30% of the granted cod quotas. Many of the respondents noted this fact and considered it outrageous, especially considering the fact that this surplus is lost and cannot be transferred to the next year.

The fishers were not able to provide a ready-to-use solution and could not agree how this problem could be solved. Some fishers suggested that the fishing organizations should have a bigger influence on the quota division, but others were convinced that it would only increase the chaos as the community is too divided to reach a compromise. One respondent noted the poor division system will end only if a long-term system is prepared. This person believed that such a system should not be created by the fishers themselves, but by experts in fishing economics and the marine environment. Management of fisheries cannot be separated from the management of all marine resources. But a proper management system cannot be prepared unless there is interest from fisher's organizations and relevant agencies. Agencies dealing with fishing often lack people who have relevant qualifications or are able to communicate and negotiate with the fishing community. This view was shared by other respondents when they discussed the involvement of various institutions.

A few respondents underlined that improper quota division has more general social implications. The general uncertainty prevents not only coastal fishers but also large boat owners from considering fishing as a reliable source of income. The fishers believed that an indirect result of the Common Fisheries Policy is the reduced solidarity among them, withdrawal of the young people from the profession, and increased costs of running the fishing business. The respondents also complained about reporting requirements, improper organization of the sale of fish, and excessive port and registration fees. They also underlined that there is no vision of how the fishing sector should develop and no support from the central government. The fishers were, however, aware that these problems are not particular for the fishing sector, and are relevant for other sectors of the Polish economy.

There was no agreement on how changes in the marine environment influence the fishing sector. The majority of the fishers noted the marine environment gets worse, especially the quality and size of the fish population. Some fishers, however, especially those fishing close to the coast, see positive changes in the environment. For example, they now catch fish species that were not seen for a long time. All the fishers showed their concern for the environment, and also called for the protection of the fish stocks, but at the same time, they were convinced that the fishing sector is in conflict with the protection of the environment, at least as it is commonly defined by the activities of the environmentalists.

In general, the fishers did not observe many conflicts in the marine realm around the Gulf of Gdansk. One of them noted that, basically, there are no conflicts over the marine realm, but every square meter is already being used and there is no space for new uses. And since there are pressures from new sectors or from the expansion of traditional sectors, clashes are likely to occur. Other interviewees shared this view, although the majority also mentioned tensions between the environmental sector and off shore wind farms. This tension is dominated by a lack of knowledge and uncertainty. A few respondents added a conflict between commercial and recreational fisheries and one mentioned issues related to aquaculture.

No-one currently knows how off-shore winds farms will influence fishing in the Polish Marine Areas. Such investments are not currently planned in the Gulf of Gdansk, and it is not clear where they will be placed. The fishers worry about this lack of knowledge---not so much about a massive conflict for space, but the effect on marine ecosystems---the influence of off-shore on the sea bottom and of the noise generated by wind turbines, and possibly also the electromagnetic field itself on fish. They call for more detailed research before any permissions are granted. The spatial dimension of placing wind farms off-shore was also discussed, but the main worry here was the increased use of fuel if the shipping routes change to go around the farms.

Nevertheless, the main conflict in the Gulf of Gdansk areas is between fishers and environmentalists, especially concerning the protection of marine mammals (harbour porpoises and seals) and birds (cormorants). All the fishers underlined that they are not against the protection of the environment, not even against the protection of these particular species. They do, however, protest against excessive protection measures. Unlike some environmental NGOs or scientists, the fishers do not believe the Baltic subspecies of harbour porpoise exist. According to the fishers, the individuals present in the Baltic Sea, and especially in the Gulf of Gdansk, migrate here sporadically from the North Sea. One of the respondents also recalled the theory according to which the Baltic subspecies must be extinct, if it ever existed at all. There were years in the Baltic Sea history when the whole sea was frozen so it was impossible for the harbour porpoises to survive. Another fisher mentioned that it was in the early 1980s when the last harbour porpoise was seen by any fisher, and that only a few harbour porpoises were observed in this region since WW2. Nevertheless, a prohibition of fishing with drift nets to prevent by-catch of these animals was introduced, and the fishers were exposed to losses of up to € 125,000 each. No financial compensation was proposed.

Similar problems are related to the presence of seals and cormorants. Seals cause considerable destruction in fisheries. In November and December 2011, individual fishermen's losses in salmon and trout fishing ranged from 50 to 90% of the total fish caught. Seals not only eat out the fish directly from the nets but also destroy the nets. There is hardly any research to measure the losses in fisheries caused by the seals, while this is crucial for any plans of compensation by the Ministry of the Environment. The respondents are also worried that no-one wants to talk about the maximum number of seals that can live in the Polish waters. The environmentalists are never willing to discuss these issues, even though in the Northern Baltic, in the Gulf of Bothnia, seals are regularly shot. They constitute such a danger in some parts of the Baltic Sea that the fishers have to use extra protection for fyke nets.

Cormorants are even more of a problem. They are almost a plague. Once there were only present in the Mazurian lakes district, in the Vistula Lagoon, and perhaps in the Szczecin Lagoon. Now the range of their occurrence includes the Puck Bay, the Bay of Gdansk, and even open sea harbours. The damages caused by cormorants are enormous not only for individual fishers, but also when restocking is concerned. Cormorants eat out small fish, including juveniles, so restocking fails. In addition, stocking has to be done after dark, otherwise the fry would be almost completely eaten out. In Poland cormorants are under strict protection and there are no actions that would aim at controlling their population. Such activities are undertaken for example in Germany, where shooting cormorants is allowed.

The fishers have also reported that environmental NGOs are difficult to talk with. One fisherman mentioned that environmental NGOs are impossible to deal with because they consider themselves "the only saviours of the Earth, while the rest of the society is only interested in destroying it," and they believe that fishers "do not have the appropriate societal skills to be involved in decision-making". This is slowly changing and the situation is improving but a compromise still seems to be rather distant.

Shipping

Shipping routes, anchorages and harbour approaches claim about 7% of the Polish Marine Areas (Węsławski et al. 2010). Out of three major Polish ports, Gdansk, Gdynia, and Szczecin, the first two lie in the Gulf of Gdansk. Gulf of Gdansk is intensively used, and the number of ships visiting these ports increases every year. In 2010, cargo turn-over increased by over 40% in Gdansk and over 8% in Gdynia, while passenger transport by over 6%, and 16%, respectively (Kalinowski et al. 2012).

The representatives of the shipping sector are aware of this positive trend and they connect it to globalisation and increasing demand for imports in Poland. They notice that the economic crisis only slightly influenced the Baltic Sea routes, while its effect on other sea routes was more severe. The respondents noticed that they work in branches of international companies, and many decisions are taken elsewhere, with related organizational problems. The companies work together when dealing with ports, depots, and freight forwarders---rather smoothly, although it of course depends on a particular person and company. They consider current safety regulations and port-related regulations as relatively friendly and justified. They understand the environmental issues involved with transportation, but these are mainly related to requirements concerning ships and ship equipment, and these issues are not at the discretion of local representatives.

The respondents do not see any conflicts over space that might refer to their sector. They see that the use of the marine realm is increasing but the shipping lanes are regulated under international agreements, and ports and other infrastructure will probably be supported at the central level. Shipping is too important to be ignored.

Nature Conservation

Protection of the environment is based on national legislation, international conventions, and EU legislation. The three most important forms of spatial protection of the environment present in the Gulf of Gdansk are:
NATURA 2000 special bird protection areas;
NATURA 2000 special habitat protection areas;
Coastal Landscape Park.

Baltic Sea Protected Areas are an additional form of spatial protection. Their creation has been proposed by an intergovernmental agreement -- Baltic Sea Action Plan – but they are established and managed according to national legislation and other voluntary actions (such as research projects). The Bay of Gdansk is also subjected to national and international legislation concerning species protection----there are regulations concerning seals and harbour porpoises, and commercial and rare fish species.

Currently there are no protection plans for marine NATURA 2000 sites in the Gulf of Gdansk, but the first plans should be ready early this year. Although specific measures are not in place, it is forbidden to undertake any actions that can negatively affect the state of natural habitats, protected species, or the integrity of NATURA 2000 areas.
The respondents agreed that there were two important changes in the nature conservation sector. First, Polish accession to the EU allowed for a new way of thinking---a new paradigm---in conservation. NATURA 2000 areas allowed for a clear definition of the objects and objectives of protection. Before they were introduced, everything was protected indiscriminately. NATURA 2000 introduced more specific evaluation criteria, including numerical indicators and defined reporting periods. EC environmental legislation brought considerably more work for environmental agencies but it also introduced better and more flexible tools, and for some time the NATURA 2000 network was practically the only tool that could be applied in marine areas. Second, European legislation brought forward the need for more active stakeholders and society involvement. This involvement, again, requires more workload from responsible institutions, but can potentially bring more legitimacy to environmental protection. As an indirect effect, transformation and Europeanization allowed for more active involvement of environmental NGOs. Bottom-up initiatives are now quite common in Poland and some of them have proven to be rather successful.

Discussion
Overall, the respondents believe that the marine environment is threatened by too many users. The main conflicts are between conservation and fishery, and conservation and tourism. One respondent noted that shipping and large oil platforms pose a significant danger to the marine environment, and was surprised that this issue is not widely discussed, in contrast to threats coming from tourism and fishing. By-catch and overfishing are important, but a lack of proper fishery management makes things complicated. Ineffective management focuses on each fish stock separately and trophic relationships are ignored. The respondents were surprised that fishers do not call for more marine protected areas. One respondent noted that individual fishers may lose, but the sector as a whole will gain if they are introduced---and the public interests should prevail. In some cases, compensation measures for lost profit could be introduced for a transition period. Effective management of all sectors, including fisheries, would be enhanced if marine spatial plans are prepared. The second important conflict is between conservation and tourism. The respondents believe that mass tourism is enhanced by local governments and is not properly regulated. Restrictions of surfing, kitesurfing, motor sports, and coastal urbanization are needed. Unauthorized coastal work, including tourism infrastructure, are difficult to deal with. Related judicial and administration proceedings take too long to be able to restore the areas to the desired or natural state.

3.4 Synthesis

3.4.1 Comparative summary of the Eastern English Channel, German Bight, the Dogger Bank, and the Gulf of Gdansk

As has been shown, the pressure applied to the spatial usage of European regional seas by various stakeholder groups is intense. In all case study sites, the majority of stakeholders feel this pressure will only increase in the future, primarily due to proposals and plans for offshore wind farms, the newest entrants to these busy seas. In some case study areas, such as the eastern English Channel and Dogger Bank, applications have already been approved with construction planned; in the German Bight wind farms already exist and at least in the Dutch part new proposals have been made[14]. In others, such as the Gulf of Gdansk, such developments are further away-

[14] There are, of course, many wind mill farms throughout the North Sea; there are simply none operational yet in the case study area of the Dogger Bank.

and unlikely to happen soon due to legal constraints, yet the uncertainty of impacts, such as on fishing, is a cause of great concern.

Of all the stakeholders groups, the fisheries group was the only one addressed by both Section 2 and Section 3 and thus can be compared across all case study areas: eastern English Channel, the Dogger Bank, the German Bight, and the Gulf of Gdansk. Fishing is one of the oldest activities in all four of the case study areas and though fishers in each area tend to use different gears and face different pressures, there are a number of similarities among them. These pressures include: regulatory pressures, competition with other users, and area restrictions. Stakeholder conflicts as perceived by stakeholders are synthetized in the Table below.

Spatial Conflicts	Fishing	Conservation / Closed areas	Shipping / transport	Oil and gas	Wind farms*	Aggregates
Fishing	EC; GB; GG	EC; DG; GB; GG	GB	DB; GB	EC; GG; GB	EC
Conservation	EC			DB	EC; DB; GG	
Shipping / transport	GB					
Oil and gas		DB				
Wind farms*	EC	DB				
Aggregates	EC					
EC	English Channel	GB	German Bight		* viewed as a potential conflict	
DB	Dogger Bank	GG	Gulf of Gdansk			

3.4.2 Summary of competition fisheries are subject to

Regulatory pressures
In all case studies, the fishing industry faces regulatory pressures. A large number of fishers catch quota species and, with the TAC limits imposed in recent years, combined with high operating costs and uncertain futures, are in decline. In the Gulf of Gdansk, given their status as a relatively new MS, Polish fishers face additional pressures resulting from the "growing pains" associated with recently coming under EU regulations such as the CFP.
Furthermore, many area closures in the case study areas, especially the English Channel, the Dogger Bank, and the German Bight, are driven by MS and EU policies such as the Habitats and Bird Directives and the new Marine Strategy Framework Directive (EU) and the Marine Coastal Access Act (UK), limiting the area available for fishing.

Competition with other users
In all case study areas spatial competition with other users was viewed as a concern for fishers, including in regards to the unknowns associated with future users. Currently, in the German Bight, competition stems from wind mill parks, maritime traffic, other fishers and area conservation closures, both temporary such as spawning sites as well as those of a more permanent nature such as Natura 2000 sites. Competition with conservation area closures is also found in the English Channel and the Dogger Bank.
Competition for space is also found among different groups of fishers themselves. This was particularly an issue in the eastern English Channel where boats using different gear come from further afield (e.g. Belgium and the Netherlands), competing with local (UK and FR) boats for space, but is also an issue in the German Bight. In the Gulf of Gdansk this competition is present but arises mainly from the way the quotas are divided. Competition for

space is less important in this dispute. Competition among differing fishing subgroups is not an issue in the Dogger Bank.
The marine aggregate industry has its longest history in the UK portion of the English Channel and there they are viewed as being the greatest limiting factor for fishing, after conservation. The issue with aggregates is the seabed is altered thus, even once a space opens up again it is no longer suitable for the same fishing activities to take place.

Future concerns
The concern for the future stemmed from the view that the seas are already fully exploited (e.g. Gulf of Gdansk), leaving no room for new industries (e.g., renewable energy in the Channel, Dogger Bank and Gulf of Gdansk), or rather, meaning space awarded to new industries would come from areas where old industries had been operating, thus constricting their activities.

3.4.3 Summary of competition, outside of fisheries

In some areas, competing stakeholders have found ways to work together for integrated spatial management, such as in the English Channel and the Dogger Bank, in others such as the Gulf of Gdansk, they are only now learning how to work together. In the UK, especially, a great deal of effort has been put into stakeholder involvement such as with their Balanced Seas project. The primary complaint with this was the timeline was too short; once stakeholders learned to communicate and work together, then the time was up. Additionally some stakeholders, in this case conservationists and aggregate extraction, came together to push for similar aims, showing that some alliances can take place even between traditional “competitors.”

In the Dogger Bank groups have also come together to manage the area, in this case with the special area of conservation (SAC) management plan, with negotiations taking place with relevant stakeholders in a Dogger Bank Steering Group and with management scenarios proposed to the North Sea RAC. The primary difference with the Dogger Bank is some groups became disillusioned with the process, in this case, conservationists, and they have refused further participation in the process given the expense, and what they view as too many compromises in favor of industry.

In the English Channel, groups in general seem to compromise and come together, despite differences. The UK also has formed statutory bodies whose role is to liaise with industry to help minimize impacts on the environment.

In contrast, on the Dogger Bank and in the Gulf of Gdansk, conservationists and other groups appear less willing to compromise, making integrated management much more challenging. *“[..] Recent marine spatial plans in European countries, e.g., Belgium, Germany, the Netherlands, and the UK, focus on managing the multiple uses of marine spaces as whole. While marine protected areas in these countries remain an important aspect for marine conservation, they are considered in the wider context of an MSP strategy designed for the entire area that balances them with the need to ensure economic growth and stability and biodiversity considerations outside the protected area”* (Douvere 2008). In the Dutch situation most consultations are with other federal agencies, major marine industry sectors, and public review of plan documents. The Dutch respondents however don’t think they have any influence on these developments.

B. Forecasting the behaviour of human agents operating in a common maritime domain

1. Short-term effect of windfarms and MPAs on fishing fleets: individual stress level analysis in the North Sea:

Section Authors: Hamon, K.G., Schulze, T., and Simons, S. Individual Stress Level Analysis.

Section Abstract
In this study we used the spatial data of the Vessel Monitoring System (VMS) coupled with logbooks to assess the stress potentially caused by the closure of fishing areas. The stress was expressed in financial terms as the percentage of current revenue obtained from catch coming from areas to be closed. It is therefore not a precise prediction of the real loss, but rather a measure of the maximum loss that would occur under the respective scenario if no compensation through effort relocation occurs.

We used the A2 and B1 scenarios as applied in other VECTORS WPs to design potential closures due to wind farms, nature conservation areas and maritime traffic in the North Sea and we calculated the stress caused by the closures on the Dutch and German 2010 fishing fleets. We here developed a method to estimate the potential stress for the fishing fleet that would result from area closures expected with the respective scenario. In this, "stress" is measured as potential loss of revenues per individual vessel, eventually aggregated per harbour or fleet. The scenarios investigated envisage large closures leading to stress levels of 7 to 15% for the Dutch fleet and 0.5 to 3% for the German fleet. Almost all of the Dutch vessels would be impacted by the closures (more than 90% of vessels in both cases) while the German fleet would be considerably less impacted (around 45% of vessels impacted for A2 and 55% for B1). All Dutch harbours will have seriously impacted vessels (loss of >15% of revenue on average/ per vessel) for both scenarios, although the proportion of impacted vessels is higher in B1 scenario, especially in the southern harbours. The German harbours are less impacted with Büssum hosting most vessels that would experience reduced revenues.

Introduction

General background
With the development of new marine activities such as energy (wind farms, oil and gas extraction), maritime traffic and the increase of areas reserved for nature conservation (e.g. natura 2000 areas) the space available to fishing is shrinking. Because the closure of marine areas has a strong impact on their livelihood, the fishing industry wants to be part of the discussions on the selection of areas allocated to other activities than fishing. Areas can be very heterogeneous in terms of productivity, catch rates and catch composition making them more or less profitable for exploitation.

In the North Sea, we expect to see an increase of energy and nature conservation related closures and fishing restrictions in shipping lanes. Those closures will largely affect the marine activities as we currently know them.
For decision makers, the knowledge of the outcome of a change in the access to a maritime area on the different users is crucial for successful management. However, the exact outcome is difficult, if at all, to determine. But some techniques exist to estimate the outcome of different management scenarios. Models like FISHRENT (Section 2.2) give the possibility to test different scenarios against each other and aim at forecasting the overall resulting economic parameters of the fisheries and the status of biological compounds taking into account the spatial redistribution of effort at the ICES rectangle level. In contrast, the approach of an individual stress level analyses (ISLA) used here presents a method at a much higher spatial resolution, which allows for comparing fishing effort and revenues depending on management scenarios, thereby estimating the potential impact of spatial closures on the fisheries sector.

Aims and objectives
In this approach logbook, landing and vessel monitoring system (VMS) data of commercial fisheries are used in a multi-step method to calculate the "stress level" (SL) of the fishing sector. SL is defined as percentage of

revenues of total revenues coming from areas that will be closed in the future. So SL reflects the maximum negative effect on fisheries, since displacement of fishing effort is not considered.

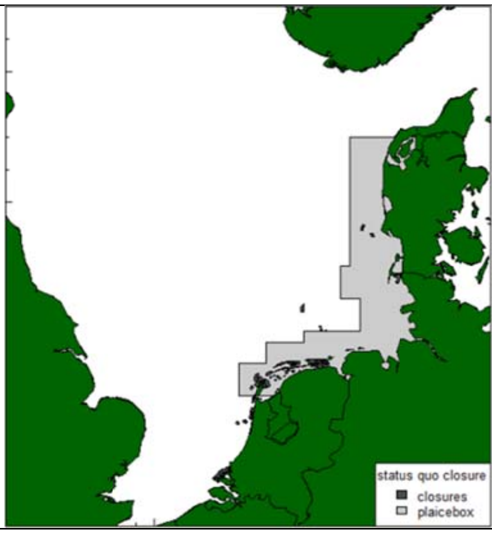
To achieve this task the information on fishing effort per individual trip and landings of individual trips are as a first step combined to allocate landings and with that, revenues to a fine spatial grid in a dataset defined in this work package (eflalo++). In a second step, the revenues of each individual fisherman in areas to be closed in the future are compared to the overall revenues of these fishermen at a certain time (reference time span). Then, in a third step, this calculated "individual stress level" (ISL) can be aggregated at different levels: producer organisation, harbour community, segments or fishery with a specific gear used or a total national fleet. This aggregation (e.g. $ISL_{revenues}$ profiles) is often obligatory not only to simplify the results but also to take account of confidentiality issues of individual data. In the present study data from the fishery of The Netherlands and Germany and management scenarios for the Dutch, German, British and Danish waters were used to test the impact of different management scenarios on the fishery.

To test the outcome of future management excluding fisheries, 7 scenarios (S1 to S7) were investigated (Fig. 1). Those scenarios were drawn from the Vectors wide scenarios A2 and B1 with the following assumptions for the development of wind farms, nature conservation areas and maritime traffic:

	A2	B1
Wind farms	50% wind farms DE+NL+DK → coexist scenarios UK → phase 1 and 2 of current plans	100% wind farms DE+NL+DK → coexist scenarios UK → phase 1, 2 and 3 of current plans
Nature conservation	Some MPA closed DE+NL → areas for mobile gears closed (coexist) DK → all closed UK → close offshore planned MPAs	All MPA closed DE+NL → all closed (COEXIST*) DK → all closed UK → close offshore + inshore planned MPAs
Transport	No extra closure	Closure of area exclusively for maritime traffic

Please note that these scenarios are not politically authorized but based on a previous EU project (COEXIST), IPCC scenarios A2 and B1 and expert knowledge on the long term future of those activities.

Status Quo
Exclusion in nature conservation areas and existing wind farms or construction sites of Germany, Netherlands and Denmark.
And exclusion of the larger vessels in the plaice box



S1: Wind farmA2 (50% of wind farms) Exclusion in 50% of planned wind farm areas in Germany, the Netherlands and Denmark (scenario COEXIST). And exclusion of phase 1 and phase 2 areas of British wind farm development. For these areas, exclusion of all types of fishing activities is assumed.	
S2: : Wind farmB1 (100% of wind farms) Exclusion in 100% of planned wind farm areas in Germany, the Netherlands and Denmark (scenario COEXIST). And exclusion of phase 1, 2 and 3 areas of British windmill development. For these areas, exclusion of all types of fishing activities is assumed.	
S3: NatConA2 (Nature Conservation A2) Exclusion of all gears from Nature 2000 areas: for Germany and the Netherlands areas closed for mobile gears closed in COEXIST, all Danish areas closed and British offshore planned MPAs	

S4: NatConB1 (Nature Conservation B1) Exclusion of all gears from all Nature 2000 areas: for Germany and the Netherlands all Nature 2000 areas in COEXIST, all Danish areas closed and British inshore and offshore planned MPAs	
S5: Shipping B1 Exclusion of all gears from the traffic separation scheme designed by the Leibniz Institute for Baltic Sea Research Warnemuende	
S6: NatConWindA2 (National Enterprise) S1 + S3	

S7: NatConWindB1 (Global Community)

S2 + S4 + S5

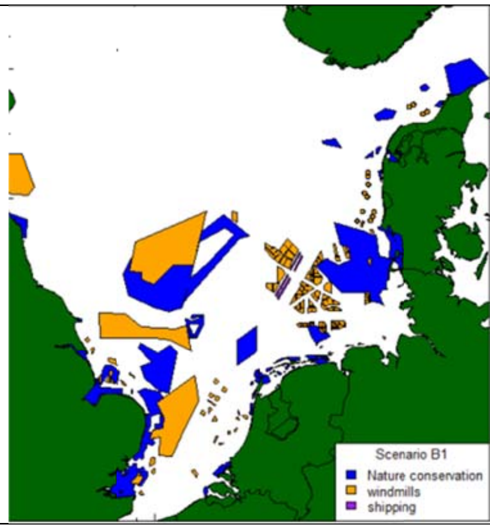


Figure 46. “Revenue stress level” = max. % of revenues lost if no compensation in other areas occurs; relative to the revenues of the year analysed

Material and methods

Data

Data for the year 2010 from the Netherlands and Germany were available for this analysis and used to analyse the scenarios S1 to S7. Information of the logbooks, landings and fisheries vessel register was aggregated to EFLALO format. Vessel Monitoring System (VMS) data were formatted according to TACSAT specification. In Europe, all fishing vessels over 15m length are required to have VMS, but smaller vessels are exempted, resulting in only a partial coverage of the fleet. VMS provides position and speed of a vessel with a 2 hour interval between the “pings”.

Analysis steps & software

Most of the existing methods used to handle VMS data and run analysis to link VMS and logbook data have been compiled in an R package (R development team, 2012) called “vmstools” (for documentation see Hintzen et al., 2012 and http://code.google.com/p/vmstools/wiki/Introduction). The analyses conducted in this study used extensively the available tools and methods that have been peer reviewed and published. The steps used to link the datasets EFLALO and TACSAT into EFLALO++ were those used for the Dutch fishery and defined with the fishing industry (Hintzen et al. 2013):

- Cleaning-up of raw data EFLALO and TACSAT using vmstools guidelines (http://code.google.com/p/vmstools/wiki/Practicals2) to correct for wrong data (e.g. positions on land, high speeds, headings above 360 degrees)
- Identifying trips in both datasets using vessel identifiers and dates with method “mergeEflalo2Tacsat” to combine logbook (e.g. information on gear used, fish caught) and VMS data (geographic position, speed, heading) via vessel identification code and time stamp in both data.
- Identifying the vessel state as “fishing” or “steaming” depending on the speed of the vessel retrieved from VMS data. For each vessel, the methods “activityTacsatAnalyse” and “activityTacsat” are used to identify speed boundaries and identify the state of each vessel when sending a VMS ping. With that, the area where a vessel was fishing can be identified. Please note that the use of the speed profile of the vessels works relatively well for active gears but the performances of the method are quite low for passive gears where vessel movements are less strictly correlated to fishing effort.
- Allocating the catch and revenue of the trip to the position of the pings using method “splitAmongPings”. With that, based on the effort of each trip, the catch of each trip can be allocated to the area which was fished during the trip.
- Once effort, catch, and revenue are allocated to the individual pings, data is aggregated at the grid of 0.05 degree pixels to make EFLALO++

The fishing activity is then compared to the area closures. Indicators were calculated at different levels of aggregation. First the “revenue stress levels” were calculated for the national fleets as the percentage of the 2010 revenue in areas that would be closed in the future following the scenarios described in Figure 46 (“revenue stress level” = max. % of revenues lost if no compensation in other areas occurs; relative to the revenues of the year analysed). Then, individual revenue stress levels ($ISL_{revenues}$) were calculated for every vessel in the analysis using the same method as for the national fleets. ISL were categorised into 11 classes (0%, >0 to 10%, >10 to 20%; ...) used to visualize the stress profile of national fleets and harbour communities.

To investigate whether some fishing activities were more likely to be impacted by closures than others, the main gear used by a vessel within the year (for at least 50% of its effort) was used to classify vessels into fleets (see Table 19). Vessels for which no main gear could be identified were classified as “others”, OTH. Dutch vessels were assigned to their port of origin. The harbour is used to explore the potential impact of area closures on coastal communities.

Table 19**.** Gear definitions and aggregations used. Numbers of vessels for the Netherlands (NLD) and Germany (GER) in italics.

MBC	**Mobile bottom contact gears**				
		TBB	*NLD: 108* *GER: 7*		Beam trawl targeting mostly flatfish
		TBS	*NLD: 37* *GER:174*		Beam trawl targeting brown shrimp
		DTS	*NLD: 53* *GER:44*		Demersal trawlers and seiners
				OTB	Otter trawls targeting mostly flatfish
				SSC	Fly shooting seines
				SDN	Danish seines
				PTB	Bottom pair trawl
				SB	Beach seines
PG	**Passive gear**		*NLD: 204* *GER:5*		
		GNS			Gill nets
		GTN			Trammel nets
PEL	**Pelagic gears**				
		PTS	*NLD: 37* *GER:6*		Pelagic trawl and seine
OTH	**Other gear**		*NLD: 20* *GER:7*		

Results

Stress levels per country and fishing gear

About 8% of the 2010 revenue of the Dutch fleet and less than 1% of the German fleet would be potentially affected by wind farm closures and 7% and >3% by nature conservation area closures (Figure 47). Shipping lanes would hardly affect the Dutch and German fishery. The total cumulative revenue affected by the A2 and B1 scenarios amount to 7 and 15% for the Dutch fleet and 0.5 and 3% for the German fleet.

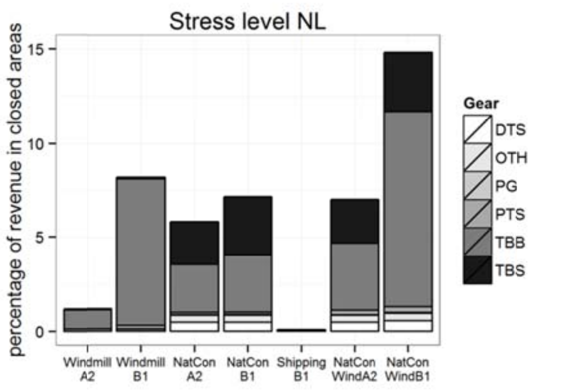
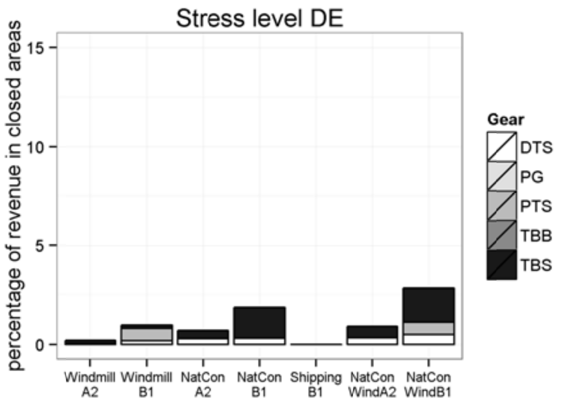
NETHERLANDS	GERMANY
	

Figure 47. Average $SL_{revenue}$ (% loss of revenues if no relocation of fishing effort occurs) for the national fleets for the 5 scenarios. Different gears contribute differently to the national level of stress. DTS: demersal trawl and seine, OTH: other gears, PG: passive gears, PTS: pelagic trawl and seine, TBB: beam trawl targeting mainly flatfish and TBS: beam trawl targeting brown shrimp.

Stress profiles of national fleets by main gear

In the Dutch fleet different activities (or gears) are affected differently by area closures (Figure 47). The Dutch shrimpers (TBS) are quite severely affected by the closure of nature conservations areas (S3 and S4) representing more than 40% of the Dutch fleet revenue affected by the natural conservation area closures. In contrast, wind farms (S1 an S2) do not affect the shrimpers since they are more active in areas closer to the coast with less wind farms. The stress levels of flatfish trawlers (TBB) show the different trends, in B1 scenarios they are affected by wind farms more than by nature conservation. The B1 wind farm closures have a greater impact on the flatfish trawlers corresponding to about three times as much as the B1 natural conservation closures. This is according to high efforts off coast where most of the wind farms will be built (see Figure 46). In A2 scenarios, the wind farm closures have a limited impact on the Dutch fisheries as a whole (about 1% of total revenue impacted) but most of it is sustained by the flatfish trawlers, which corresponds to half of the impact of the nature conservation areas.

Both A2 and B1 scenarios (S6 and S7) would severely impact the Dutch fishery as less than 10% of the vessels would not be impacted by the closures. The fisheries would be more severely impacted in the B1 scenario where 60% of the fleet would be impacted on more than 10% of their revenue against 50% for A2. Other fleets such as demersal trawlers (DTS) are affected in the same way as the bean trawlers.

In the German fleet nearly all vessels will be impacted by the A2 and B1 scenarios. For A2 about 45% and for B1 around 55% of the fleet will be impacted. In contrast to the A2 scenario the B1 scenario resulted in further increased ILS for the German fleet. TBB and DTS are both severely impacted vessel groups under the A2 and B1 scenarios (see Figure 48).

NETHERLANDS	GERMANY

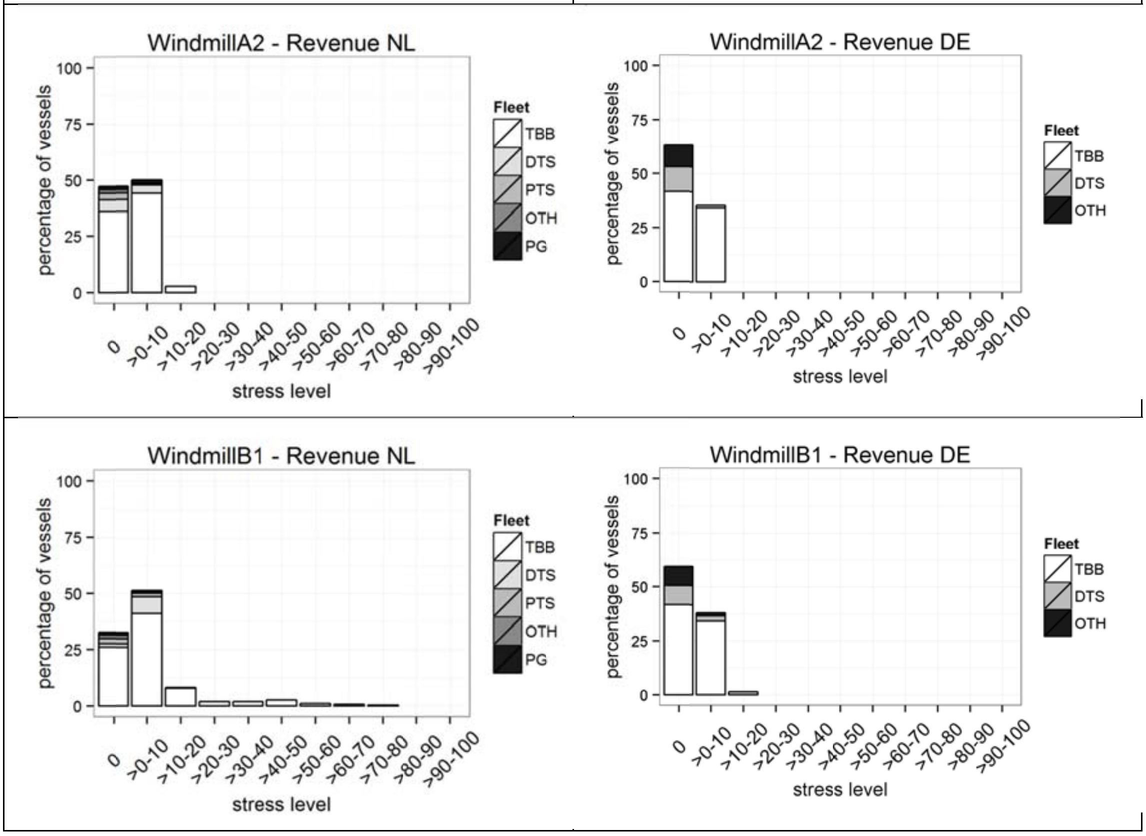
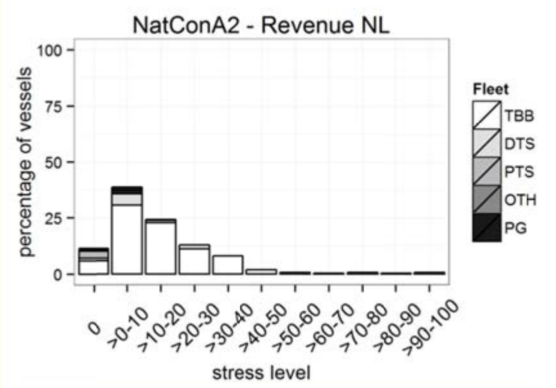
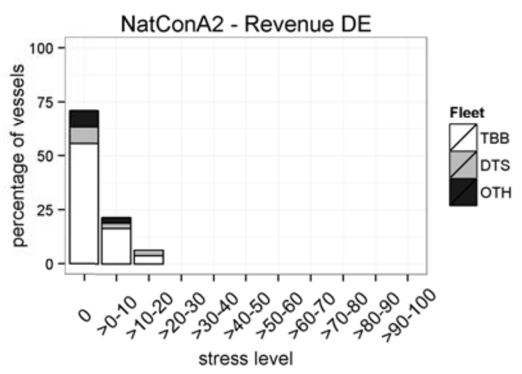
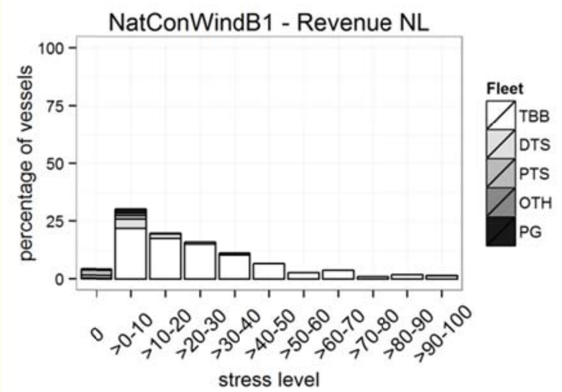


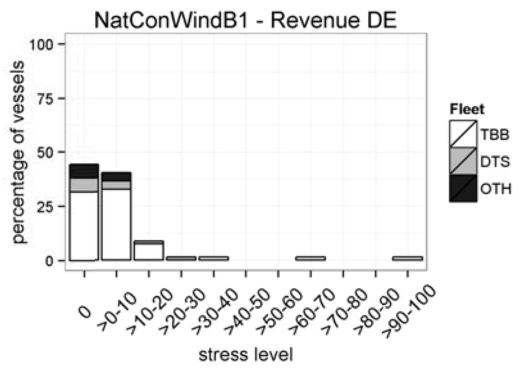
Figure 48. $ISL_{revenues}$ profiles for the Dutch and German national fleets. The vessel percentage is calculated as the percentage of the total national fleet. DTS: demersal trawlers and seiners, OTH: other fleets, PG: passive gears, PTS: pelagic trawlers and seiners, TBB: beam trawlers.

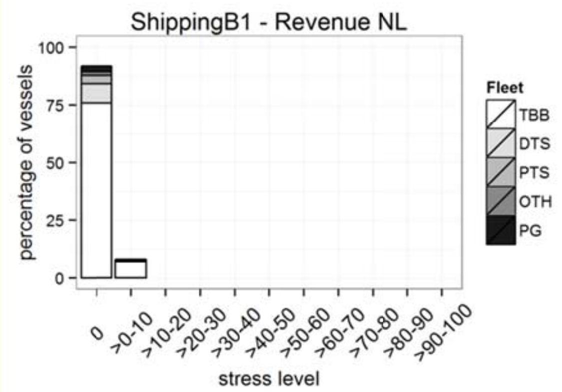
NETHERLANDS	GERMANY











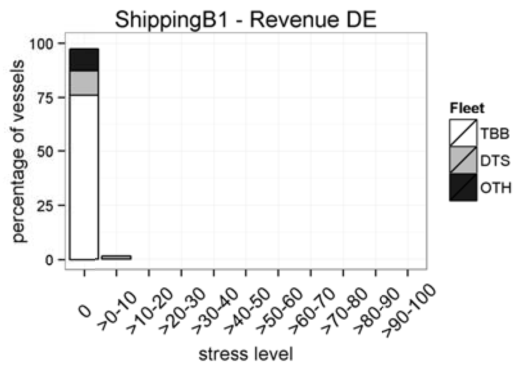


Figure 48 continued.

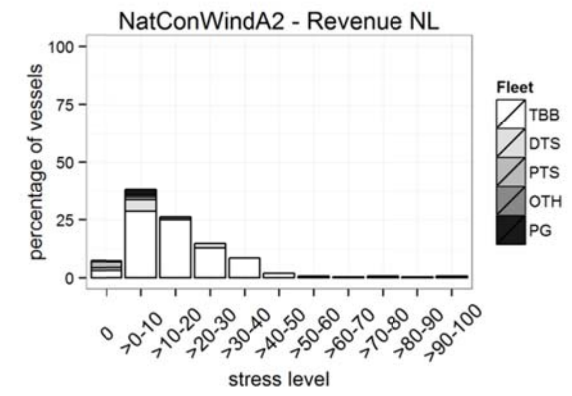
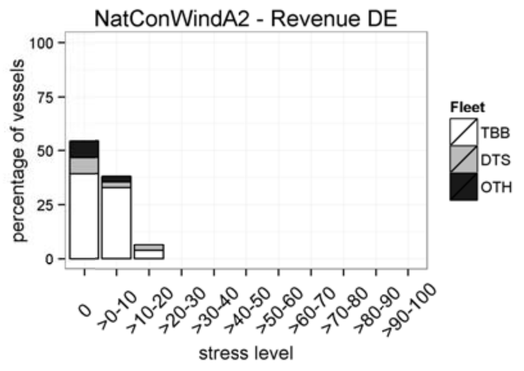
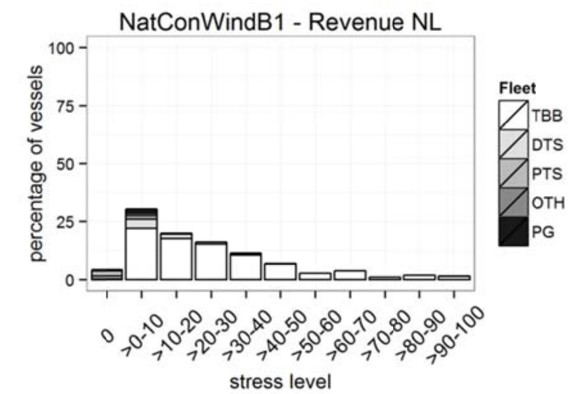
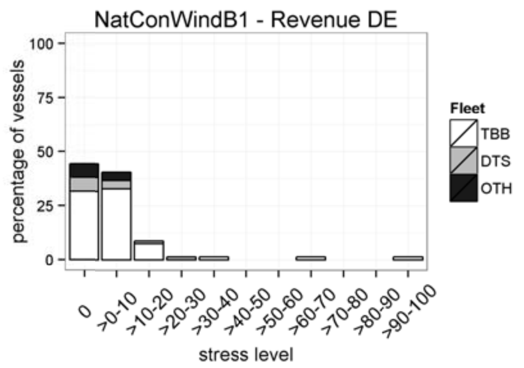
NETHERLANDS	GERMANY
	
	

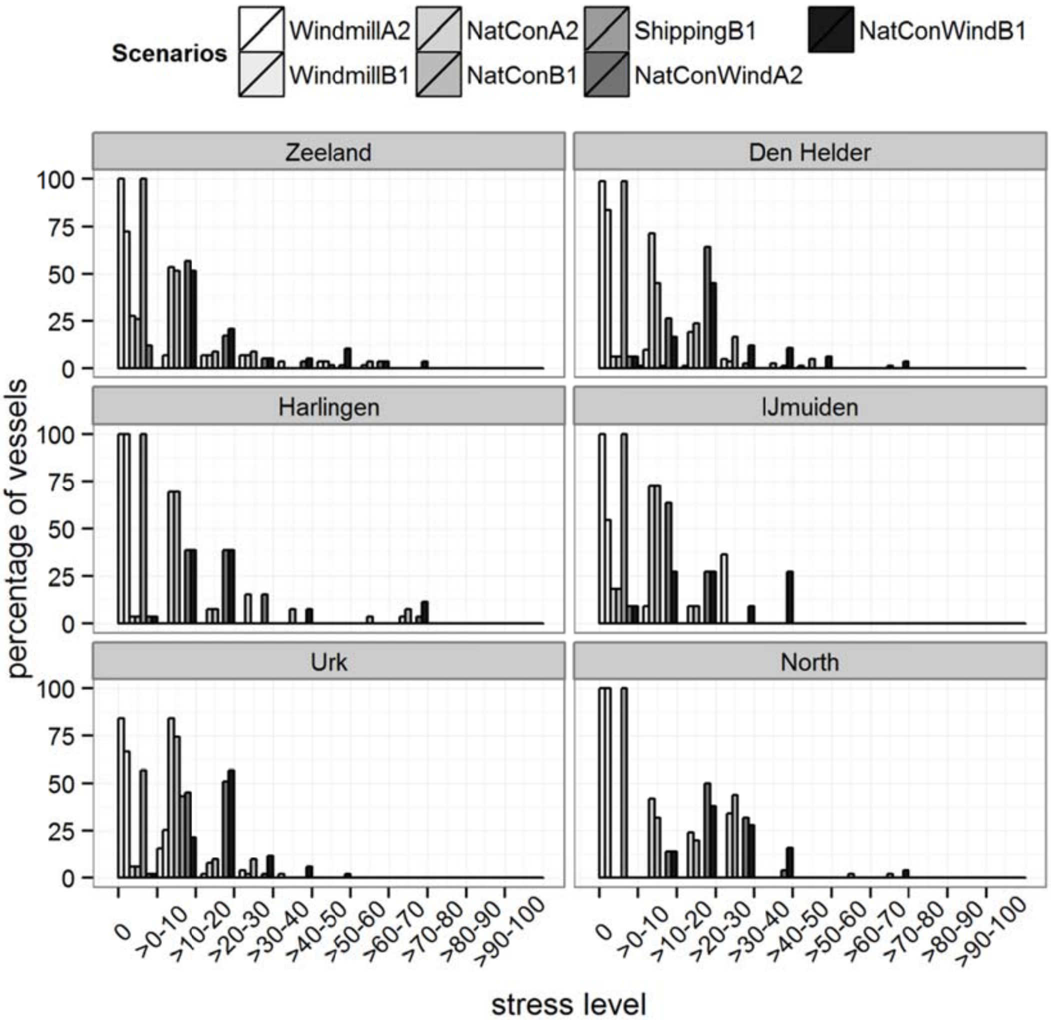
Figure 48 continued.

Stress profiles of harbour communities

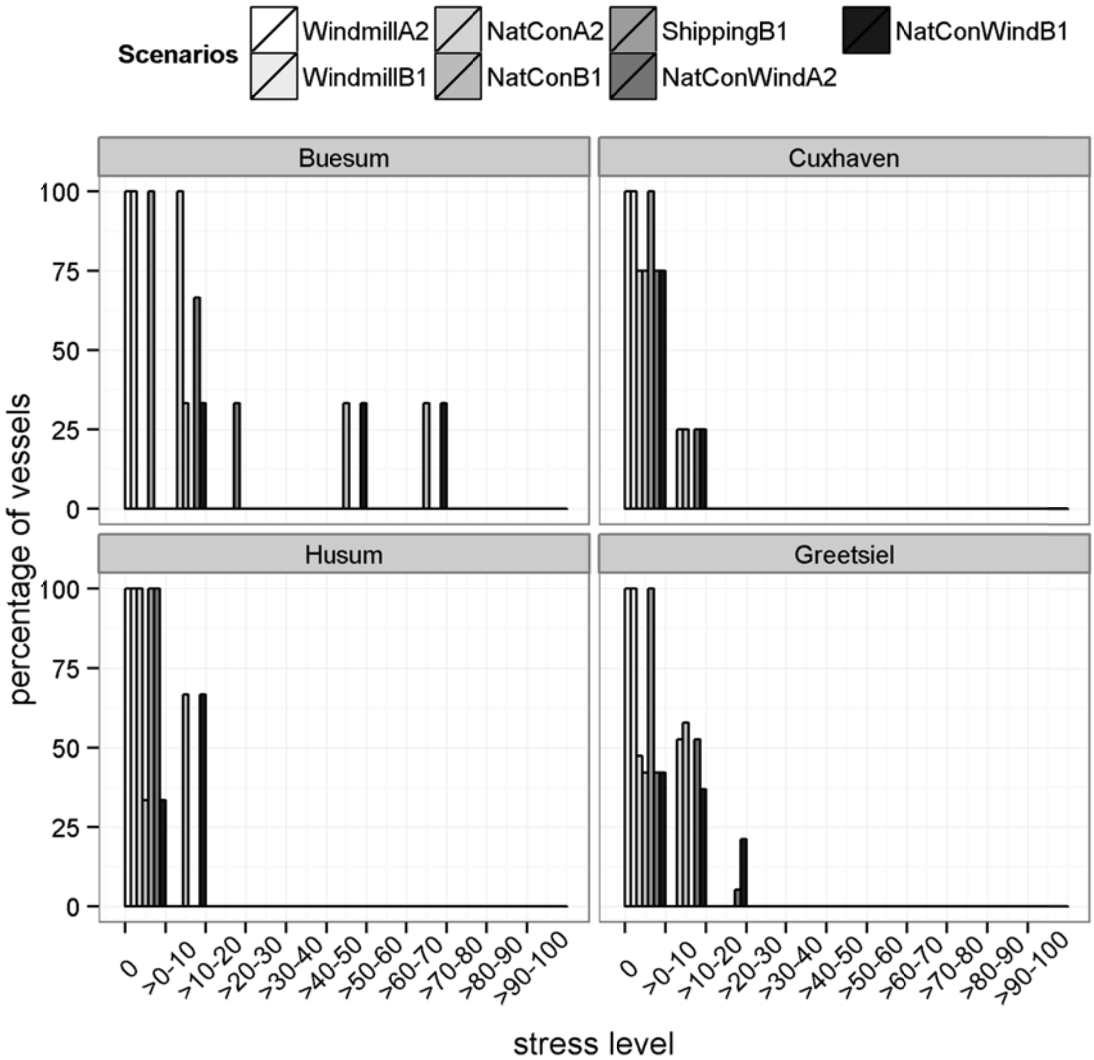
Along the Dutch coast from north to south, North, Harlingen, Den Helder, Urk, IJmuiden and Zeeland have a different proportion of flatfish trawlers and shrimp trawlers which affects the level of impact from each closure scenario (Figure 48a). The shrimpers are more present on the Wadden Sea (in the northeast of the Netherlands), where beam trawl used for flatfish is forbidden, while flatfish trawlers are dominant in IJmuiden, Urk and Zeeland (southern harbour). The impact of closures is linked to the spatial distribution of the main activity of the harbour. For the wind farm closures, flatfish trawlers are mainly affected (Urk, Den Helder, IJmuiden) while the shrimpers ("North" and Harlingen) are the ones mainly affected by the Nature conservation area closures. If all A2 or B1 closures were happening, all harbours would be massively impacted as for most harbours more than 50% of the vessels have 15% or more of their current revenue in an area that would close.

Most of the German harbours will be affected by the closure of certain areas and the impact cannot simply be concluded from the geographic distance between a harbour and an area that is considered to be closed. For example, the stress for Husum is rather low in spite of this harbour being in the close vicinity of the nature conservation areas (i.e. the Natura 2000 site "Sylt outer reef").

The impact on Büsum and Greetsiel would be the heaviest of the included harbours (Figure 48b) since their fishermen community had high effort in the areas which were modelled as being closed. Though in Greetsiel also about 60% of the vessels would be affected, about 20% of the influenced vessels would have a stress above 10%. In Büsum all the vessels would be influenced and 67% of the vessels in Büsum would have a stress level higher than 15%.


Scenarios
WindmillA2
WindmillB1
NatConA2
NatConB1
ShippingB1
NatConWindA2
NatConWindB1
Zeeland
Den Helder
Harlingen
IJmuiden
Urk
North
percentage of vessels
100
75
50
25
0
0
>0-10
>10-20
>20-30
>30-40
>40-50
>50-60
>60-70
>70-80
>80-90
>90-100
stress level

A)



B)

Figure 49. $ISL_{revenues}$ profiles for selected harbours in the Netherlands (A) and Germany (B).

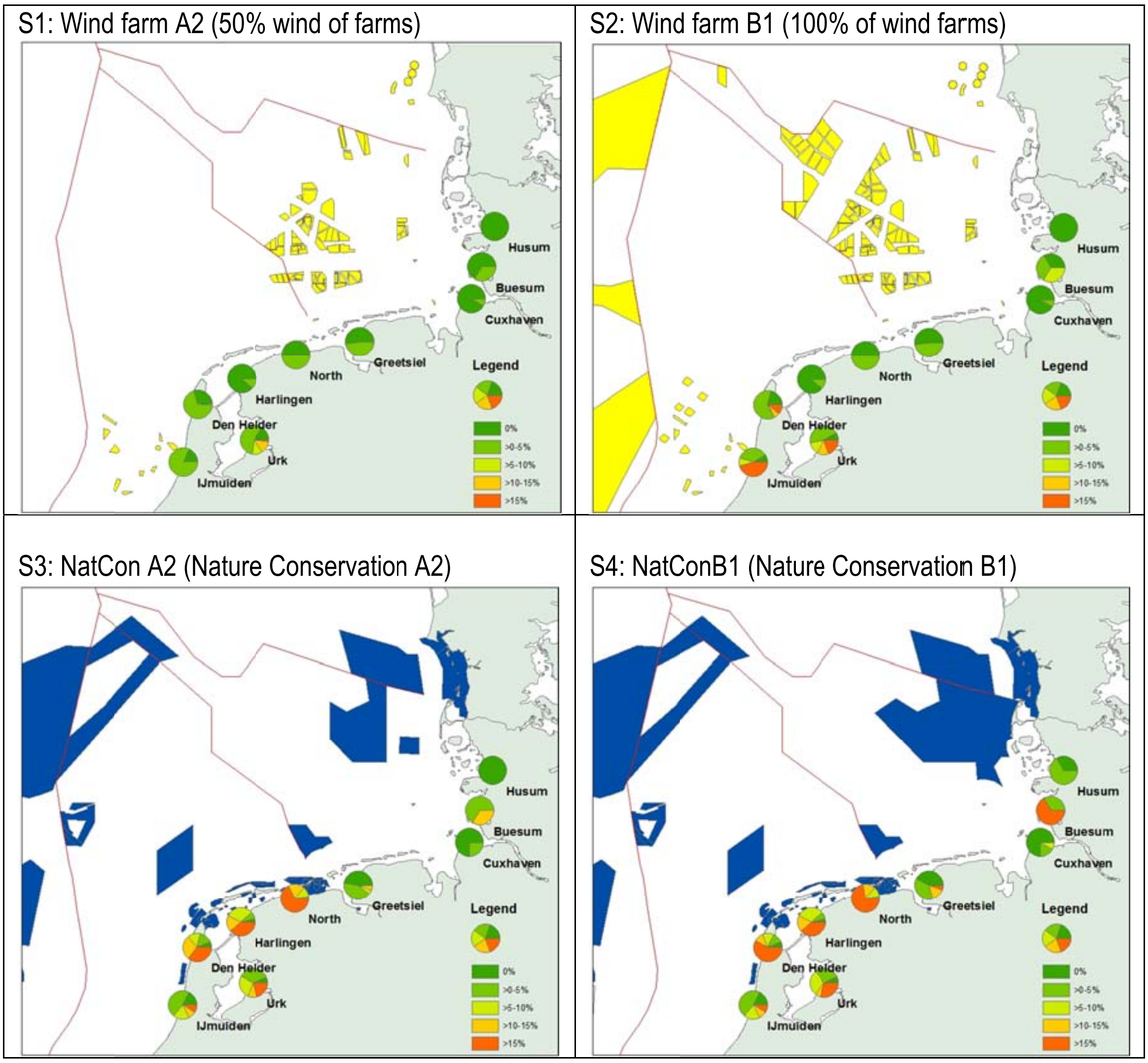


Figure 50. Simplified $ISL_{revenues}$ profiles for selected harbours of the North Sea. Five different scenarios are on display. Harbours displayed (from north to south, clockwise): in Germany Husum, Buesum, Cuxhaven and in the Netherlands “North” Harlingen, Urk, Den Helder and IJmuiden.

S6: NatConWind A2 (National Enterprise) | S7: NatConWind B1 (Global Community)

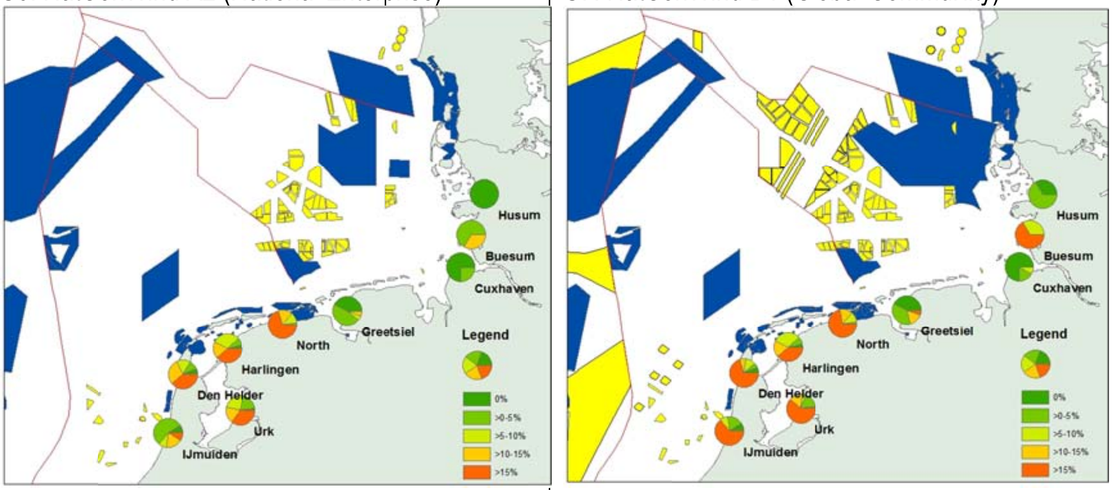


Figure 50 continued.

Discussion

The individual stress level analyses (ISLA) revealed that the Dutch and the German fleet will be affected differently by a potential loss of fishing grounds due to wind farms and nature conservation areas. Whereas more than 90% of the Dutch vessel will lose at least some fishing ground in the full A2 and B1 closure scenario (S6 and S7), several German vessels will be not affected at all in the harbours Greetsiel, Cuxhaven and Husum. However, the vessels in Büsum will all loose areas which were fished in 2010. Please note that potential closures in the German coastal zone (Wadden Sea) have not been considered in these scenarios. It can be expected that such closures would exert a high stress level on the local, especially German, shrimp fishers, but not on the fleets of larger vessels that operate further offshore.

With coverage of more than 85% in both of the data sets, the major part of the revenues is covered. For the Dutch fleets, area closures will have an effect on the fishing activities and likely lead to the redistribution of effort of shrimp and flatfish trawlers. However, both fleets will not have the same opportunities to reallocate their effort as shrimps are only found in shallow waters and area closure will probably lead to higher competition for space as coastal areas are also used for other activities.

A calculated stress level does not imply that all the earlier revenues of the area are lost in future since it (SL) is defined as percentage of effort/landings/revenues of total effort/landings/revenues which will be “lost” in worst case due to a closure of an area for a specific industry. By changing fishing grounds the fisherman might compensate these losses from area closures. Further, competition for space, and increased fishing effort in the remaining areas, will most likely reduce the catch per unit effort and therefore reduce profits for all other gears. Also, longer steaming times to circumvent closed areas are likely to increase fuel costs. The described investments and costs to react on the future management are exactly the stress which is captured by the presented approach. On the other side, increased catches due to the spill-over effect of marine protected areas (MPA) may also compensate for some of the losses and are not covered by the presented approach.

This approach should be compared to a bioeconomic model approach (see FISHRENT) as the individual stress level analysis (ISLA) cannot account for changes in economic processes and behaviour. However, ISLA enables the analyses of the impact of management on individual companies on a very small spatial scale rather than the analysis of fleet segments and the spatial management according to ICES squares (see FISHRENT).

In conclusion, the stress level can be used as one static element in a set of indicators to estimate the effects of future management on fisheries based on the closure of fishing grounds, but cannot foresee profit or revenue losses of individual fishermen or fishing communities. Subsequently, the stress level calculations can be useful in Marine Spatial Planning exercises.

2. Medium-term effects of spatial or resources restrictions on fleet dynamics: towards integrated models

2.1 Fishing fleets competing for quota in the Eastern Channel: an IBM, bio-economic, approach

The following study is due to be published as a paper with the following reference:
Batsleer, J., Poos, J.-J., Marchal, P., Vermard, Y., and Rijnsdorp, A.D. 2013. Mixed fisheries management: protecting the weakest link. Marine Ecology Progress Series, 479, 177-190.

Section Abstract
North Sea cod (*Gadus morhua*) is outside safe biological limits and total allowable catch (TAC) management has proved ineffective to rebuild the stock. The European Commission is considering imposing a discard ban to preserve vulnerable and economically important fish stocks. We explore the potential effects of a discard ban in mixed fisheries management using the French mixed fisheries in the Eastern English Channel as a model system. We examine in particular the performance of two different management scenarios, (i) individual quota management with a tolerance for discarding and, (ii) individual quota management in combination with a discard ban, using a dynamic state variable model. The model evaluates a time series of decisions taken by fishers to maximize profits within management constraints. Compliance to management was tested by applying a tax for exceeding the quota, which is varied in the study. We then evaluate the consequences of individual cod quota in both scenarios, with respect to over-quota discarding, spatial and temporal effort allocation and switching between métiers. Individual quota management without a discard ban hardly influenced fishers' behaviour, as they could fully utilise cod quota and continue fishing other species while discarding cod. In contrast, a discard ban forced fishers to reallocate effort to areas and weeks where cod catch is low, at the expense of lower revenue. In general, a restrictive policy for individual quota for cod needs to be combined with a discard ban and a high tax to reduce over-quota discarding.

Introduction
Fishing is an important socio-economic activity providing food and employment (FAO 2008) but is criticized because of its adverse impact on exploited fish stocks and marine ecosystems. In this context, throwing overboard dead fish that has been caught in the net ("discarding") is often considered a wasteful practice that has adverse effects on fish stocks while not contributing to the harvesting of food (Alverson et al. 1994, Kelleher 2005).

The practice of discarding is mainly driven by economics and management. From an economic perspective, low valued fish of quota species are discarded (high-grading) in the expectation to catch more valued fish later (Gillis et al. 1995b), while regulation of mesh size and minimum landing size determine the discarding of undersized fish (Cappell 2001, Graham & Fryer 2006). TAC regulations also create an incentive for fishers to discard fish caught over-quota, especially in mixed fisheries (Daan, 1997; Reis, 2010), and they have often proved unable to control fishing mortality around sustainable levels (Daan 1997, Rijnsdorp et al. 2007, Ulrich et al. 2011).

The European Commission is considering a discard ban in combination with individual, and possibly transferable, quota to prevent the waste of food, to reduce fishing impacts on the ecosystem, to preserve vulnerable and economically important fish stocks and to improve scientific advice (Anon. 2011, Buisman et al. 2011). Under a discard ban, all catches of both target and by-catch species should be landed and will be deducted from the individual quotas. At present, a discard ban is under consideration and pilot studies on its ecological and economic impacts have started (Catchpole & Gray 2010, Buisman et al. 2011).

Fishers are expected to adjust their behaviour to maximise their utility, given prevalent management regulations (Gordon 1953, Hilborn & Kennedy 1992). Hence, fishers may respond to management regulations by trading-off economic gain against the cost of non-compliance. Adaptive behaviour of fishers, e.g. reallocation of effort to other species, fishing grounds or seasons, is an important management concern (Salas & Gaertner 2004, Poos et al. 2010). Further studies on the adaptive behaviour of fishers may be useful to explore the scope for responses that undermine the effectiveness of a certain management system. A fisheries manager needs to trade-off socio-economic benefits of a fishery against protection of the weakest links in the ecosystem. Understanding these trade-offs will support fisheries management.

This study will investigate how a discard ban in combination with individual quota may improve the regulation of fishing mortality, for a depleted stock that is exploited in a mixed fishery. Using a dynamic state variable model (DSVM (Clark & Mangel 2000)), we study the over-quota discarding of cod (*Gadus morhua*) in the eastern English Channel and the southern North Sea. Despite a recovery plan imposed in 2003 (EC 2004), there have been no sign of recovery and the stock has remained the weakest component of a demersal fish assemblage (Ulrich et al. 2011). We will compare the performance of (i) TAC management that allows over-quota discarding and (ii) TAC management in combination with a discard ban, using the French otter trawl and net fisheries as a case study. The consequences of individual quota for cod in both management regimes will be studied based on a number of indicators of the fishery system such as the catch of cod, the spatial and temporal distribution of fishing effort, the changes in métiers and the economic performance of the fishery.

Material and Methods

The English Channel mixed fisheries

The English Channel is a corridor between the Atlantic and the North Sea. The eastern English Channel (ICES division VIId) is the narrowest part of the Channel and it is an important fishing area (Vaz et al. 2007). The French fishing fleets are most active in this area with a total of 641 vessels in 2005, landing over 90,000 tonnes of fish with a total value of 218 million euros. Boulogne-Sur-Mer is the main French fishing harbour, both in number of vessels and total landings (Carpentier et al. 2009).

Data

Effort and landings data obtained from logbooks and sales slips were available over the period 2001 – 2005. The data set included information by fishing trip on vessel length, vessel tonnage, engine power, gear type, mesh size, fishing ground (ICES rectangle, 1° longitude x 0.5°latitude, which approximates 30 x 30 nautical miles), fishing effort (hours fished for trawlers, days absent from port for netters), weight and value of the landings per species. We selected the French otter trawlers and netters fishing in the eastern English Channel and most southern part of the North Sea between 49°N, 2°W and 52°N 4°E, for which most data is available (Figure 51).

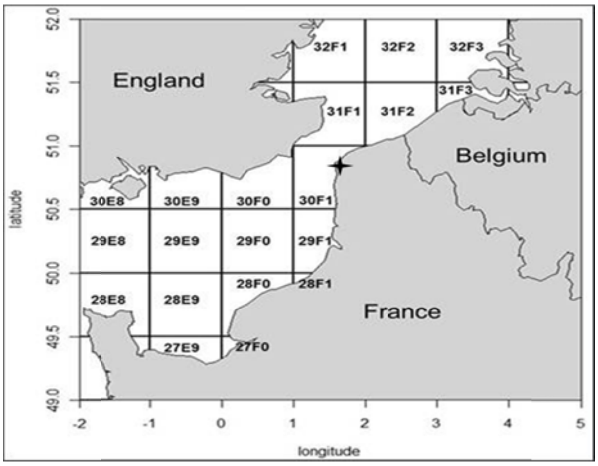


Figure 51. Map showing ICES-rectangles in the eastern English Channel (i.e.27E9 up 30F1) to and southern North Sea (i.e. 31F1 up to 32F3), where both fleets may fish. The star indicates the location of the port of Boulogne-Sur-Mer.

Otter trawlers

The otter trawl fleet is one of the main demersal fishing fleets operating in the eastern English Channel. Vessels in this fleet are predominantly rigged with 80 mm mesh size nets. The dataset consists of 120 vessels with an average engine power of 440 kW and average vessel length of 21m.

The otter trawl fleet operates two separate métiers using: (i) demersal otter trawls (OTB_D, 25591 trips) and, (ii) mixed demersal/pelagic trawls (OTB_M, 725 trips). Both métiers land a mix of species, consisting of ca. 60% of whiting, cod, plaice, sole and mackerel. Whiting and mackerel contribute to the bulk of landings of OTB_D and OTB_M, respectively (Table 20). Fishers are capable of switching métiers during the year. Both métiers are operated inside and outside the 12 nautical mile zone (Carpentier et al. 2009), with fishing grounds in ICES rectangles 30F1 and 29F0 being the most frequently visited.

Table 20. Proportion of five commercial species in the catch composition of both fishing fleets, separated by métiers.

	Otter trawl		Static net	
	OTB_D	OTB_M	TN	GN
Sole (%)	0.4	0	54.9	14.8
Plaice (%)	4.1	2.1	15.4	15.7
Cod (%)	5.3	2.6	8	45.3
Mackerel (%)	15.6	44.9	0	0
Whiting (%)	29.4	12.1	0.9	2.7
Other (%)	45.2	38.3	20.8	21.5

Static netters

The netting fleet in the study area consists of 107 vessels, with an average engine power of 160kW and average length of 12m. The most common gear is the trammel net (TN, 10449 trips), being used interchangeably with gillnets (GN, 632 trips). Both nets are anchored to the bottom but differ in their structure and target species. Trammel nets have three sets of netting, whereby the outer nets have a large mesh and the inner net has a small mesh size, whereas gillnets have only one net. This difference makes trammel nets less selective in terms of size and variety of fish species caught (Carpentier et al. 2009). The most commonly used mesh size for both nets is 90 mm, used mainly to catch sole; however, larger mesh sizes (100mm – 180mm) may be used when plaice or cod are targeted. Although sole, plaice, and cod are the main target species and account for approximately 80% of the landings, sole is the main target species for trammel nets, whereas cod is the primary target species for gill-netters. Most netting activities occur close to the port of Boulogne-Sur-Mer (30F1, 31F2).

A few (2.7 %) observations in the data set consisted of multiple aggregated, and these were not included in the analysis.

Statistical analysis

Our aim is to parameterize a simulation model by estimating the spatial and temporal distribution of landings per unit effort (LPUE) (l_i) of five species: plaice (*Pleuronectes platessa*), sole (*Solea solea*), cod (*Gadus Morhua*), whiting (*Merlangius merlangus*) and Atlantic mackerel (*Scomber scombrus*), targeted by the French fleets. Our dataset contains measurements of landings (y_i) in weight (kg) by species and effort in hours fished for trawlers and days absent from port for netters (E_i) per trip ***i***;

$$l_i = \frac{y_i}{E_i} \qquad [1]$$

We apply Generalized Additive Models (GAMs) to allow for non-linearity in the relationships between the response variable and multiple explanatory variables (Zuur et al. 2009). The actual value of the landings per trip is used as the response variable while the log (E_i) serves as offset. We use the negative binomial distribution with a logarithmic link function.

$$y_i \sim Negative\ Binomial(\pi_i, \theta) \quad [2]$$
$$\mu_i = l_i E_i = e^{\eta_i} E_i = e^{\eta_i + \log(E_i)}$$

Here, μ_i is the expected landings per trip and θ is the dispersion parameter, which accounts for under- or over-dispersion. The expected LPUE (l_i) is modelled as e^{η} whereby η is the linear predictor.

$$l_i \sim m\acute{e}tiers + year + engine\ power + mesh\ size + area * DoY \qquad [3]$$

Métiers and years were entered as discrete variables; engine power, mesh size, area (i.e. geographic midpoint of the ICES rectangle) and day of the year (DoY) were entered as continuous variables (Table 21). The interaction between area and DoY was included to model the seasonal changes in distribution. Because vessel length and engine power are highly correlated (0.9), we decided to only include engine power due to its presumed larger influence on the catch efficiency (Rijnsdorp et al. 2006). Mesh size was included as it may indicate the target species, for example the 90 mm mesh size in trammel nets is used to target sole, while larger mesh sizes (120mm-180mm) are fitted when targeting cod. Finally, the variable year was used to capture differences in landings per unit of effort between the years.

The next step is to select a model, using forward selection based on the Bayesian Information Criterion (BIC). Forward selection starts with an empty model, fitted with the intercept only. Then covariates are added sequentially based on the BIC in order to obtain the “best” model. When the best covariate structure is found, we applied a GAM to come to a final model. This final model was used to predict the spatial and temporal patterns in catch rates for each of the species and vessel–gear combinations.

Table 21. Model components used to describe variation in catch rates. “te” stands for tensor product smooth. Variables métier and area (i.e. geographic midpoint of the ICES rectangle) are discrete variables and engine power, mesh size, year and day of the year (doy) are continuous variables.

Explanatory variable	Model component
Métier	factor(GE_UNI)
Engine power	te(ve_hp, k=4, by=factor(tactic))
Mesh size	te(GE_MSZ, k=4, by=factor(tactic))
Year	factor(FT_YEAR)
Spatio-temporal interaction	te(lon,lat,doy, bs=c("tp","cc"), d=c(2,1), k=5)

Simulation Model

Our model is based on Dynamic State Variable Modelling (DSVM) (Houston & McNamara 1999, Clark & Mangel 2000). The DSVM is an individual based model that has been used to predict the behaviour of animals (Mangel 1987, Clark & Butler 1999) as well as fishers (Gillis et al. 1995b, Poos et al. 2010, Dowling et al. 2012). We expanded the model of Poos et al. (2010) to two fishing fleets targeting a mix of species that were constrained by annual individual cod quota. A discard ban was modelled by incorporating a tax to discourage over-quota discarding. Each individual vessel in the model has a set of choices, allowing it to respond to management regulations and economic opportunities. In each time-step a fisher can choose simultaneously: (1) to go out to fish or to stay in port, (2) a métier, (3) a fishing ground and (4) to discard.

A vessel evaluates its optimal annual strategy in terms of biweekly behavioural choices, based on a utility function. This utility function describes the result of choices in a single currency. We use the annual net revenue (φ) as the currency that a fisher wants to optimize (Gordon 1953, Poos et al. 2010).

$$\varphi(L_{1-5}, E) = \sum_{i=1}^{5}(L_i p_i) - (Ep_e + D) \qquad [4]$$

The net revenue is defined as the total quantity landed of each species (L_i) weighted by each species price (p_i); minus the variable fishing costs. Variable fishing costs consist of total fuel cost; i.e. total effort (days) (E) times fuel costs per day (€/day) (p_e); and a tax for overshooting the quota (D). Compliance to management was tested by exploring the effect of different tax values. Fines increased from one to twenty times current cod price. These fines are equivalent to those imposed for catching abalones illegally, i.e., ten times landing price (Bose & Crees-Morris 2009).

Parameterisation of the model was based on individual vessels, assuming Boulogne-Sur-Mer was their home harbour. For each time step, a vessel chooses a métier and one fishing ground (out of 20). Each combination of métier and fishing ground is characterized by a mean (μ) and variance (θ) of the catch rates for each species estimated by the GAM. Also, the combination of métier and fishing ground determines the amount of effort required for the fishing operation. The unit of total effort in the model is days at sea and consists of the summed actual fishing time and travel time required to reach the fishing ground. The fishing time was estimated from the 2001 data at 3.1 days for a trawler and 3 days for a netter. Travel time depends on the distance from port and was calculated from the distance in nautical miles (Nm) in a straight line from the harbour of Boulogne-Sur-Mer to each fishing ground. Assuming a steaming speed of 10 nautical miles per hour for an otter trawl and 6 nautical miles per hour for a netter (Messina & Notti 2007) and taking account of the number of trips observed per time step (2-week period), we calculated the travel time needed to reach a fishing ground. If a fisher decides to stay in the harbour, nothing is caught and no effort is used.

The costs associated with using fishing effort depend on the fuel use in the model. Fuel costs per day are estimated to be 1800€ for trawlers and 1300€ for netters and are equivalent to approximately 35% of the gross revenue (Taal et al. 2009). The final element for the parameterization is the market value of the target species. We choose to use fixed market values for each species, determined by the average price per kg within our dataset. Table 22 includes detailed information on the parameters and their values used in the model.

Table 22. Summary of parameter values included in the model.

	Trawl	Net
Engine power (kW)	440	160
Mesh Size (mm)	80	90
Fuel costs per day (€)	1800	1300
Fishing effort (hours)	75	72
Market value (€ per kg)		
Sole		9.42
Cod		2.43
Plaice		1.99
Whiting		1.40
Mackerel		0.99

Results

Statistical analysis

The GAM models best explaining the variation in LPUEs included all covariates (Table 23). The variable engine power was selected and added as first variable in explaining the spatial and temporal variation in distribution of whiting and plaice, while métiers was the first variable for sole and mackerel. The selection of métiers within all five models reflects our classification of both fleets into two métiers. Within the cod model, mesh size was added as the first variable, which confirms our expectations that larger mesh sizes are preferred when fishing for cod. The last variable that was added in all the models was the year. Further analysis for cod shows that landings are significantly ($p < 2e-16$) lower in the years 2004 and 2005. Lower landings are likely to be related to the low abundances and weak recruitments of cod during that period (ICES 2010).

Table 23. Final model results for all five species. All covariates are selected for all five species. LPUE = mesh size + area*DoY + year + engine power + métier + offset.

Species	Log-likelihood	Dev.exp	Theta (θ)
Cod	-169261	31.0%	0.185
Whiting	-210053	28.3%	0.252
Sole	-124632	97.8%	0.192

Plaice	-205433	43.0%	0.391
Mackerel	-173594	46.1%	0.234

Cod catch

The cod catch depends on the fishing fleet and the management scenario (Figure 52). For trawlers, cod catches are still high (> 10 tons per year) if the individual cod quota (IQ) is set to zero and discarding is allowed. No cod is landed, but cod catches are discarded. Individual quota lower than 10 tons per year result in full utilization of quota by almost all vessels, while over-quota catches are being discarded. The variability in the cod catches in the model causes some fishers to be more or less successful at catching cod than others. Successful fishers will fully exploit their quota and discard their over-quota catch, while less successful fishers will land all their cod catches and will not use all quota. Increasing the IQ above 10 tons results in trawlers progressively being unable to use all of their quota: all cod catches are landed and none are discarded.

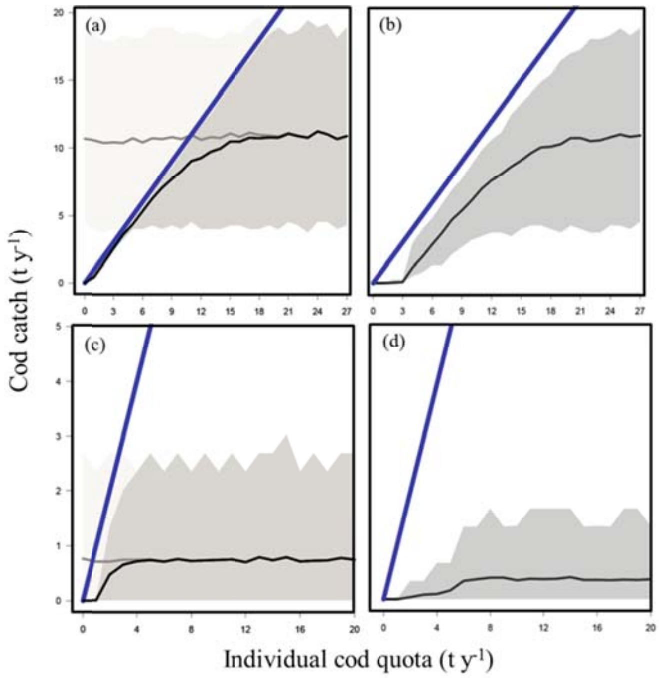


Figure 52. Modelled average annual cod catches (i.e. landings plus discards) per vessel for both trawlers and netters in relation to the available individual cod quota (blue line). Upper panels (a) and (b) are for trawlers; lower panels (c) and (d) for netters. In the left panels (a) and (c) discarding is allowed, while in the right panels (b) and (d) discarding is banned. Average annual landings (black line) with confidence area (dark grey shaded area) are separated from average annual cod catches (light grey line) with confidence area (light grey shaded area), depicting the amount of cod discards.

When a discard ban is introduced, individual cod quota may reduce catches considerably. At an individual cod quota below 4 tons per year, the cod catch is less than 0.5 tonnes per year. Increasing the IQ results in an increase in landings, but vessels rarely utilize their quota completely. As for the first scenario, the catches level off towards ca. 10 tons per year. There are two main periods, during which cod is caught by trawlers (Figure 53). The first period is around the end and beginning of the year, while the second period occurs halfway through the year. Fishers constrained by a discard ban switch to other fishing grounds during these periods, resulting in lower annual cod catches.

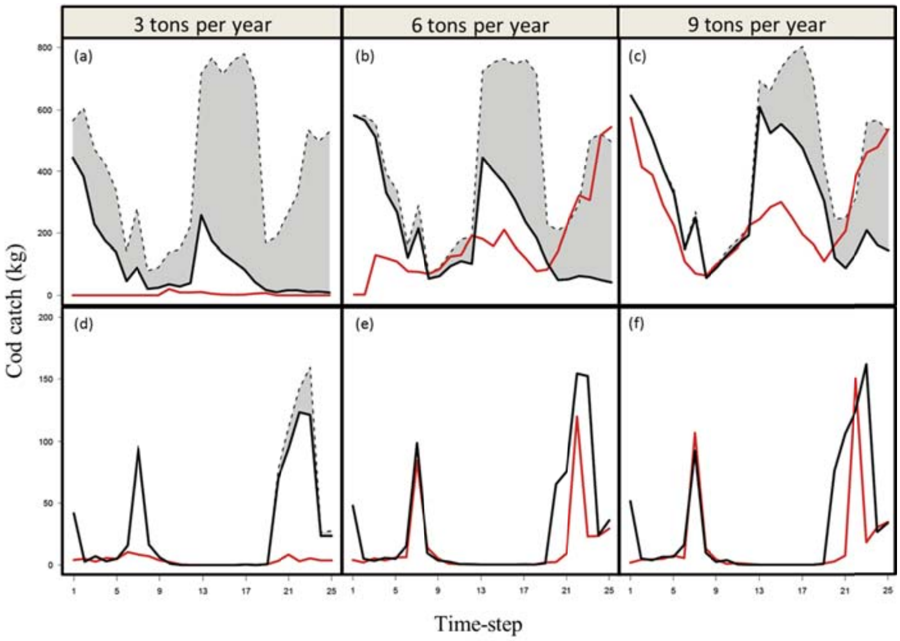


Figure 53. Modelled temporal variations in average cod catches (t.y-1) per vessel between both management scenarios. Upper panels (a-c) are results for trawlers and lower panels (d-f) are for netters. Differences between scenarios are observed by comparing average cod catches when discarding is allowed (dashed line) with catches under a discard ban (red line). When allowing discards, differences between average cod catches and average landings (black line) quantify the amount of discards (shaded area) per time step.

Similar results are observed for netters (Figure 52c & d), but cod catches are much lower (< 3 tons per year) compared to trawlers. A similar comparison for the netting fleet shows more spatial overlap under both management scenarios. However, similar to the trawling fleet, deviations of the choice of fishing grounds occur during periods when cod is more frequently caught. So, netters also switch fishing grounds to avoid catching cod.

When IQ for cod are reasonably high (~ 9 tons), trawlers only become limited in landing cod at the end of the year, and only discard when quota are almost fully exploited. When less quota is available, the amount of cod being discarded increases and fishers discard earlier in the year as well. When the quota are low (~3 tons) cod is discarded throughout the year, with the highest amounts of discards occurring during both periods when cod is mainly caught. Compared to the trawlers, netters barely discard cod due to the low amount caught. However, if cod is discarded, it occurs at the end of the year during the period when cod catches are higher. These results show that fishers are able to regulate their catches either by discarding the over-quota catch or, when discarding is banned, by switching fishing grounds and targeting other species.

Effort

If discarding is allowed, the annual allocation of fishing effort is independent of the cod quota (Figure 54).

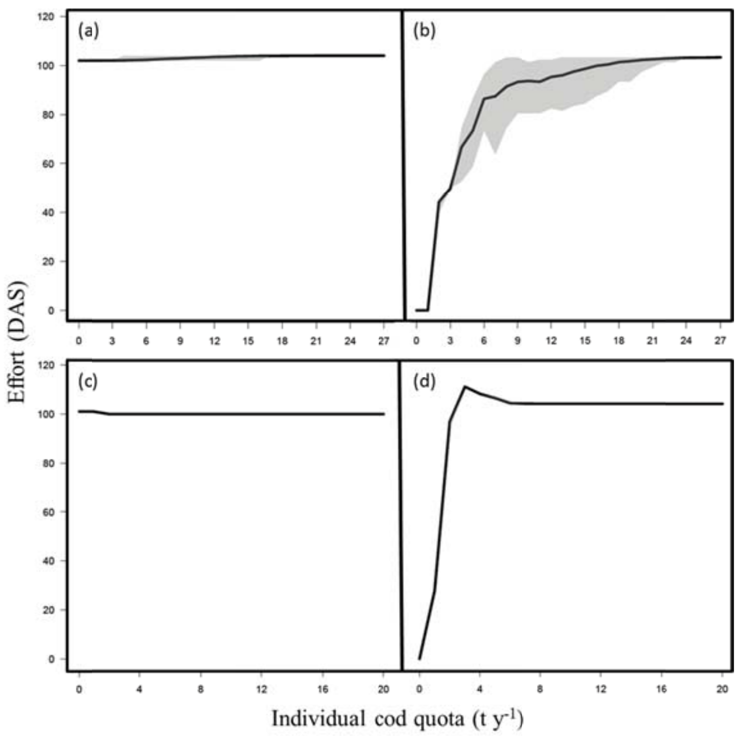


Figure 54. Modelled average annual effort per vessel for both fleets and both management scenarios. Upper panels (a) and (b) are for trawlers; lower panels (c) and (d) for netters. The left panels (a) and (c) allow discarding, while the right panels (b) and (d) ban discarding. The area between the upper (95%) and lower (5%) confidence intervals is shaded.

The total days at sea (DAS) increase only marginally from an average of 102 days to 104 days when more quota becomes available. Effort is mainly allocated near the English coast and in the southern North Sea where the most frequently fished fishing grounds are ICES rectangles 30F1 (36% of trips) and 32F1 (28% of trips) (Figure 55).

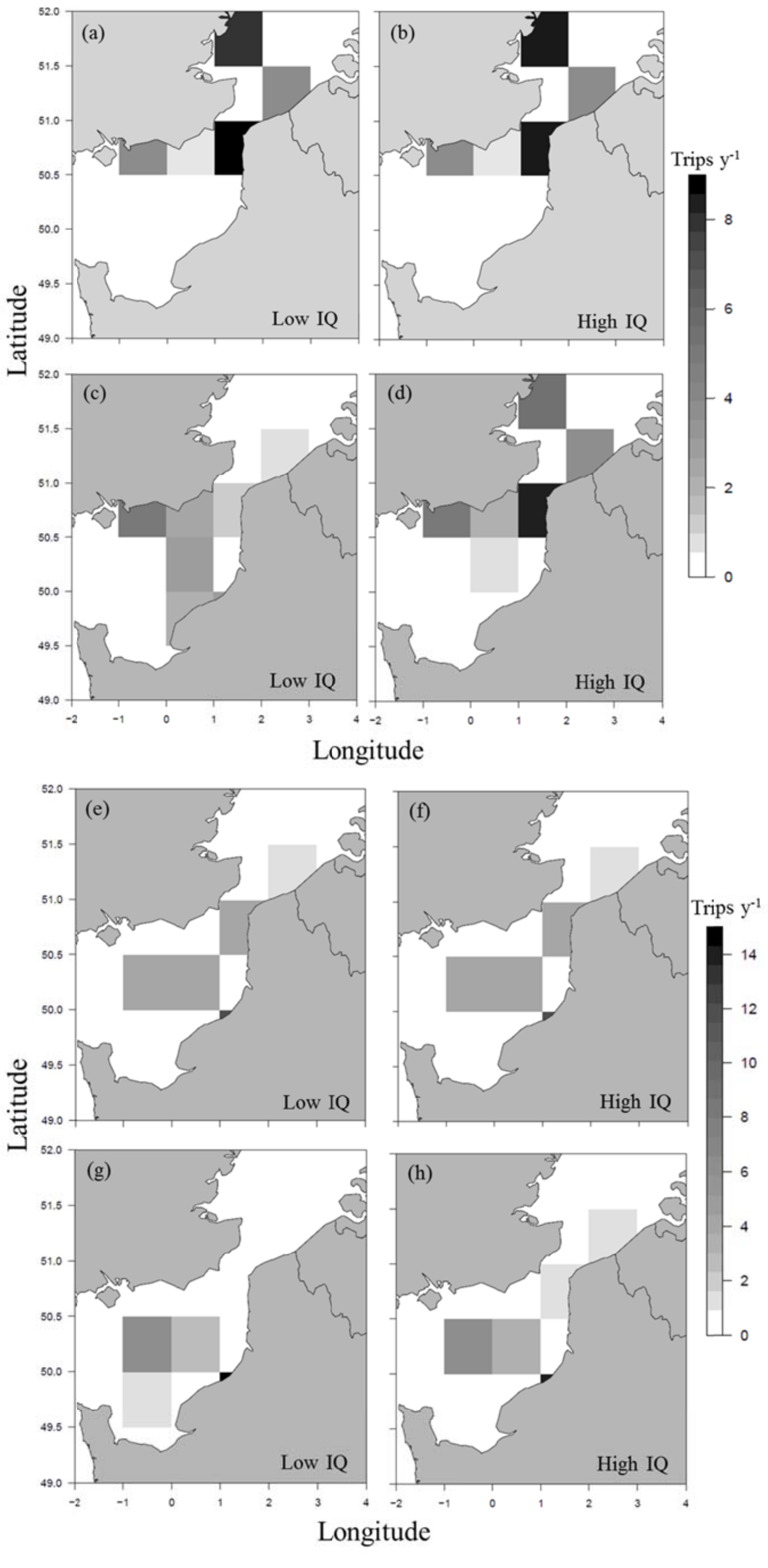


Figure 55. Modelled spatial allocation of effort by average number of trips per year for trawlers (a-d) and netters (e-h) at low (5 t.y-1) and high (15 t.y-1) individual cod quota. Upper graphs (a-b and e-f for trawlers and netters, respectively) are based on the first management scenario (discarding), while lower graphs (c-d and g-h) are based on scenarios with a discard ban.

Imposing a discard ban in combination with low IQ has a clear impact on the effort and setting the IQ to zero results in a complete stop of fishing. At a quota of below 6 tons, there is a steep increase of effort with increasing quota. As more quota become available the increase in effort slows down and stabilizes towards an average effort of 104 DAS. Introducing a discard ban causes a spatial shift in the distribution of fishing. At low IQ levels, trawlers make fewer trips (16 trips) and effort is concentrated in more southern and distant fishing grounds such as 30E9, 28F1 and 29F0. At a higher IQ level, the spatial distribution resembles that found when discarding is allowed.

Similar results for netters are observed. In the absence of a discard ban, netters spend 100 days of the year at sea, regardless of the quota. As for trawlers, cod quota management on its own has no influence on the spatial distribution of netters that predominantly fish in the eastern English Channel, in particular ICES rectangle 28F1 (48% of trips). With a discard ban, effort is only influenced at low (< 8 tons) quota. Fishing stops when IQ is null, but rapidly increases up to 111 DAS when IQis set at >3 tons. Yet effort gradually decreases again and remains fixed at an average annual effort of 105 DAS. The peak at low quota may reflect a reallocation of effort away from the southern North Sea to more distant fishing grounds in the eastern English Channel (29E9), although rectangle 28F1 is still the most visited fishing ground. At higher IQ levels, spatial distribution of fishing effort slightly shifts away from the North Sea area towards fishing grounds 28F1 and 29E9.

The shift in spatial distribution of fishing effort from the southern North Sea to the eastern English Channel is related to the spatial distribution of cod. Cod is more frequently caught in the southern North Sea fishing grounds compared to the Channel. So when cod quota is high a fisher can continue to fish in the northern fishing grounds until the cod quota becomes depleted. Implementing low cod quota and a discard ban, however, make the Channel fishing grounds more attractive, because of the reduced risk of catching cod, while targeting other commercial fish species.

Besides spatial effort allocation to reduce cod catches, trawlers constrained by a discard ban change their preference for a métier in response to the IQ (Figure 56). When IQ is below 4 tons, there is no fishing at all or trips are done only choosing OTB_M. As IQ increases, OTB_D is more and more operated. For an IQ of 8 tons, only 4% of fishing effort is operted with OTB_D. Increasing IQ to 27 tons results in 36% allotted to OTB_D fishing, similar to the scenario where discarding is allowed. Netters choose, regardless of the management scenario, to fish using TN throughout the year.

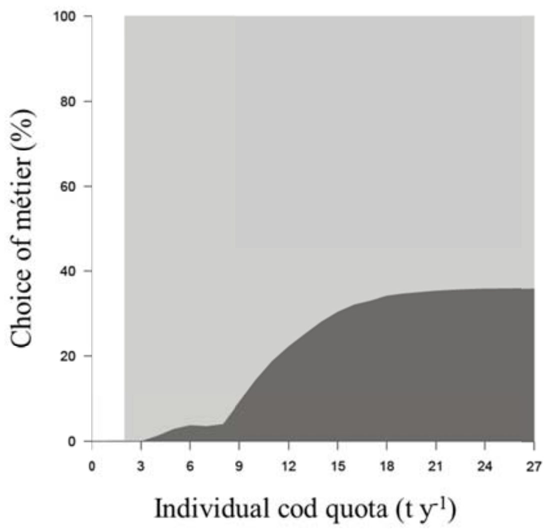


Figure 56. The proportion of effort allotted to each métier operated by trawlers, when constrained by a discard ban (light grey: OTB_M, dark grey: OTB_D).

Catch composition

The catch compositions of trawlers and netters constrained by a discard ban are shown in Figure 57. For trawlers, mackerel is the most dominant (98%) species in the catch at low individual cod quota. With increasing IQ, the catch of whiting increases and becomes dominant. The increase of whiting with increasing cod quota indicates that both species co-occur. When quota is not a limiting factor, whiting (54%) and mackerel (42%) represent the main components, while cod and plaice contribute marginally to the total landings. For netters there is virtually no change in the catch composition with changing IQ. Netters mainly catch sole (> 80%) and plaice (~19%), while cod is caught in small quantities and contributes less than 1% to the entire catch. Hence, introducing a discard ban on top of individual cod quota has little impact on the catch composition of netters.

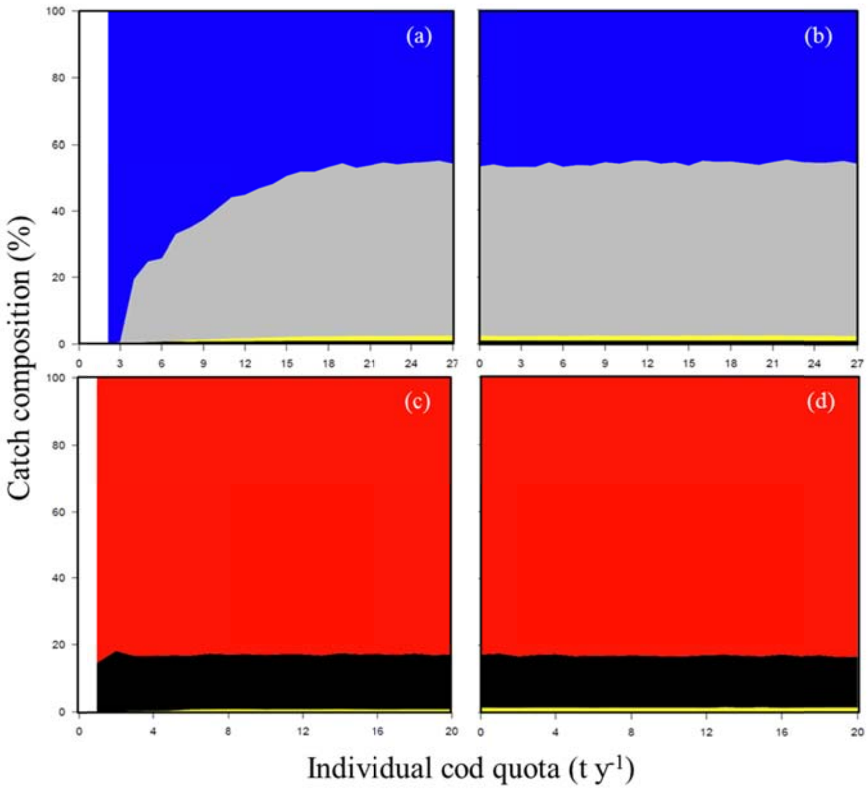


Figure 57. The proportion of each of the five species contributing to the total catch for trawlers (a & b) and netters (c & d). Right panels (b) and (d) are modelled catch compositions for the first management scenario and left panels (a) and (c) for the second scenario. Color-coding: yellow (cod), black (plaice), grey (whiting), blue (mackerel) and red (sole). Note the white bars in (a) and (c) where no fish was caught, because fishers remained in port.

Allowing discards eliminates the effect of low IQ on the catch composition. For trawlers, whiting and mackerel are the main contributors, whether a low or a high cod quota is implemented. The catch compositions resemble those of the scenario with high IQ (> 18 ton) combined with a discard ban. Similar results were seen for netters, although the proportion of cod is slightly higher (1.5%), compared to that observed with a discard ban (< 1%).

Trade-offs

Here, two indicators of fishery, i.e. effort and net revenue, are weighted against cod catch (Figure 58). Allowing cod discards, a trawler continues to fish despite a decrease in IQ. Therefore, effort (> 100 DAS) and cod catch (> 10 tons) remain unchanged (Figure 58a). Reducing the IQ, however, results in a slight decrease (from ca. 350.000€ to ca. 313.000€) in net revenue. This decrease is related to the reduced cod landings.

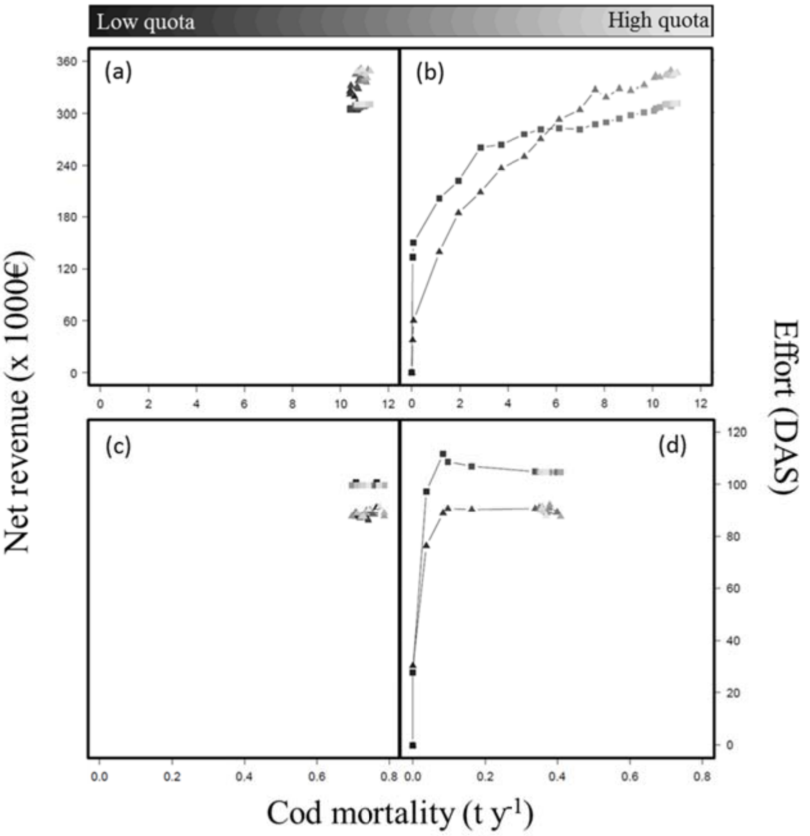


Figure 58. Trade-offs between (▲) net revenue, (■) effort and cod mortality (t y-1). Panels (a) and (b) present results for trawlers, and (c) and (d) for netters. Left and right panels refer respectively to discard and no-discard scenarios. Note the changing colours of the points from black to light grey, as individual cod quota increases from low to high levels.

In contrast, imposing a discard ban clearly affects both indicators and cod catch (Figure 58 (b)). When IQ is below two tons, trawlers stay in port and do not generate revenue. Setting a low IQ ensures that fishers avoid cod catches by targeting other commercial species with lower market value (e.g. mackerel) in more distant fishing grounds. Consequently, a fisher generates less revenue (ca. 38.000€) in proportion to the amount of fishing effort (ca. 44 DAS at an IQ of 2 tons). At an IQ of 4 tons, trawlers allocate some fishing effort to cod fishing grounds, increasing the catch of cod from an average of approximately 74 kg to approximately 1 ton. Effort slightly increases, while net revenue doubles. As more quota is made available, effort increases and levels off at about 104 DAS. This increase in effort leads to an increased cod catch, because gradually more cod fishing grounds are fished. In addition, landings of commercially valuable and co-occurring species such as whiting increase likewise and contribute substantially to the revenue. Hence, while effort levels off, net revenue continues to increase until the point where IQ are no longer constraining i.e. 18 tons.

Trade-offs as seen with otter trawlers are less observed for netters using trammel nets, for which whiting and cod are by-catch species. When discarding is allowed, cod catch, fishing effort and revenue remain unchanged (ca. 750 kg) (Figure 58c). When introducing a discard ban in combination with a zero IQ, fishing completely stops, and no revenue is generated (Figure 58d). Increasing IQ to one ton results in zero cod catch, while fishing (28 DAS) resumes and some revenue (ca. 92.000€) is generated by fishing for sole and plaice. For an IQ of 3 tons, effort strongly increases up to 111 DAS. With higher IQ, effort slightly reduces and levels off to approximately 105 DAS. Net revenue increases likewise to ca. 270.000€. This revenue is maintained regardless the height of IQ, indicating that netters are to an extent economically independent of whiting and cod catches. In relation to effort and net revenue, cod catches remain low (< 170 kg), but slightly increase up to a maximum of approximately 400 kg when IQ exceeds six tons.

In general, permitting cod discarding, fishers will uphold effort and maintain their net revenue at the expense of cod conservation. In contrast, with a discard ban, fishers avoid cod but maintain a reduced fishing effort targeting lower valued species such as mackerel to compensate the loss in revenue.

Over-quota tax

The results above assumed that the discard ban was fully enforced, corresponding to a very high tax. The response of the fishers in terms of over-quota discarding of cod for a range of different fines is shown in Figure 59. With a low tax equal to the market value of cod (2.43€ per kg) trawlers start discarding when IQ are below nine tons. Above this level, fishers have sufficient quota available to uphold their revenue and switch to other target species when their quota is fully exploited. Increasing the tax shifts the threshold IQ below which fishers start discarding the over-quota catch towards a lower level. In our model, the tax needs to be sufficiently high, e.g. 20 times the price of cod, to reduce discarding of over-quota cod below 6 tons.

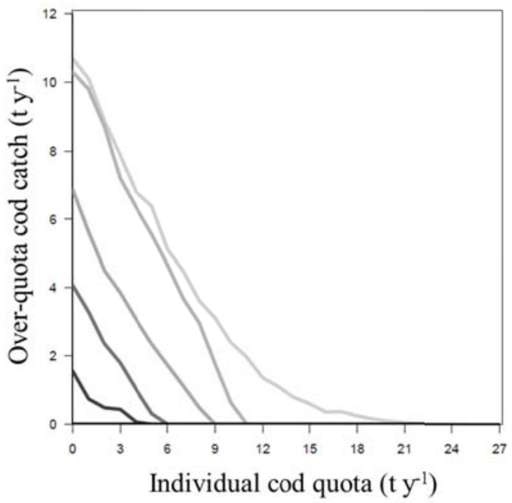


Figure 59. Average over-quota cod catches in relation to tax levels. The upper light grey line represents a free-fishing situation (tax = 0). The darker the line the higher the tax, varying from the market value of cod (2.43 €) up to 20 times that value (48.60 €). The black line with no over-quota catches represents a situation with an extremely high tax (3000000 €) for overshooting the quotas.

Discussion

This study explored the effects of a discard ban in combination with individual quota in mixed fisheries. It was shown that under a management regime that allows over-quota discarding, quota for by-catch species such as cod may have little effect on the effort allocation, and catch composition of fishing fleets. Fish that is caught without quota provision are discarded. IQ management with a discard ban can reduce over-quota discarding of cod when properly enforced. In that case, fishers will reallocate effort to fishing grounds and weeks when the cod catch is low at the expense of lower revenue.

Our model showed that, even when forced by a tax, fishers have, to some extent, the ability to avoid over-quota discarding by reallocating their effort in space and time. Empirical support comes from a study of Branch et al (2009), who showed that when TACs were increased for some species and reduced for others, fishers were able to adjust the species mixture in their catches by reallocating their fishing effort. In the eastern Channel, landings of non-regulated species such as striped red mullet (*Mullus surmuletus*), sea bass (*Dicentrarchus labrax*) and squid (*Loligo spp.*) have increased following the decline of cod landings and may reflect a response of fishers to the change in resource composition (Carpentier et al. 2009).

The compliance of the fishery to restrictive quota is influenced by the tax for overshooting the IQ. We showed that this tax should be set at several times the market value of cod to remove the economic incentive of over-quota discarding. The tax needed to reduce the probability of over-quota discarding will be dependent on the difference in maximum revenue that can be obtained and the revenue of the alternative fishing ground where the by-catch of cod will be negligible. An important consideration when exploring management regulations is the compliance of fishers to these regulations. Our results show that to be efficient, fines should be much higher than fish price.

Hence, imposing a high tax would be a contributing factor to deter fishers from rule-breaking behaviour (Bose & Crees-Morris 2009, Jagers et al. 2012). In our model, we assume a 100% detection rate while realistically rule-breaking behaviour of fishers may not necessarily be detected. Some fishers may trade-off economic gain and the risk of paying a high tax. This implies even higher fines should be considered to obtain full fisheries compliance. Yet, assessing the risk of being detected is beyond the scope of this paper.

In this study we have focussed only on one component of the discard problem, the over-quota discarding. Fishers in the EU, however are forced to discard catches below the minimum landing size (MLS) and discard non-commercial species. These discards are particularly high in mixed fisheries that target multiple species with different selectivity characteristics relative to the minimum landing size, such as in the roundfish, flatfish and Norway lobster fisheries (Rijnsdorp & Millner 1996, Cappell 2001, Catchpole et al. 2005). Also high-grading may occur when fishers discard part of their less valuable marketable catch to increase their revenue. By ignoring these other types of practices, we will underestimate the overall level of discarding in these fisheries (Gillis et al. 1995a, Poos et al. 2010, Depestele et al. 2011).

The DSVM approach is particularly appropriate to address these issues and could also be applied to the problem of high-grading as well as discarding undersized and non-commercial fish. A study of Dowling et al (2012) showed that by including price dynamics into a stochastic dynamic programming model the behavioural response of fishers towards market value fluctuations may be studied. Due to lacking knowledge, however on processes underlying fish price setting, our model assumes a fixed market value for each species throughout the year. The strong numerical power of these models demands high computational resources. Therefore, key descriptors such as abundance, catch and market price were not classified into different size classes, because this would increase complexity and drastically increases the dynamic programs' computational requirements, i.e. curse of dimensionality" (Clark & Mangel 2000). Hence, each species was modelled as a homogeneous group of marketable fish.

Discard reduction is on top of the agenda of EU fisheries managers. At the time of writing the EU is considering a mandatory discard ban as part of the reform of this policy (Anon. 2011). In 1987 Norway introduced a discard ban causing younger and smaller species to be landed. Our first management scenario corresponds to the initial Norwegian regulations before they implemented a discard ban. Fishers would land their total catch, but discards are confiscated without being deducted from the individual quota, and without receiving a financial compensation for landing discards. The second scenario resembles a complete discard ban on marketable fish, whereby all catches are landed and are deducted from the quota. In Norway the introduction of a discard ban reduced the waste of resources (e.g. finding alternative use), improved estimates of fishing mortality and scientific knowledge, which in turn supported the recovery of Northeast Arctic fish stocks(Diamond & Beukers-Stewart 2011). Up to now, it is unclear how the EC intends to implement a ban and the Commission could also adhere to alternative ways of discouraging discards.

Many fishers' behaviour studies have presumed that fishers are entirely driven by economic interests (Gordon 1953, Hilborn & Walters 1987, Poos et al. 2010). The relevance, however, of tradition, past experiences and information exchange on fishers' behaviour has been studied (Holland & Sutinen 2000, Little et al. 2004, Marchal et al. 2009) and could be taken into account when modelling multi-annual management scenarios. Because we only explore the consequences of our management scenarios over one year, our model assumes opportunistic behaviour towards maximizing expected profit.

Our model ignores vessel aggregations hereby excluding interactions. These interactions, through information sharing, exploitation and interference competition may affect catch rates of vessels. Information sharing among vessels about local fishing grounds for example, may increase catch rates. By contrast, exploitation competition due to an increased density of vessels with a shared exploitation of common resources may reduce catch rates, as does interference competition due to direct, physical hindering of a fishing operation or indirectly, due to local depletion of target species (Gillis 2003, Poos and Rijnsdorp 2007b). The effect of information sharing and both elements of competition were beyond the scope of this study and will be investigated in depth in a companion study.

The methods and results of this study will be generally relevant to other mixed fisheries systems. The specific results depend on the parameterisation for a specific case. A fisher will choose the most profitable fishing ground, characterized by low fuel costs, high catch rates of the most valuable species and sufficient quota availability (especially under the discard ban). In our model, fuel cost is approximated at 35% of gross revenue. However, in the English Channel operating costs of gillnetters and beam trawlers are estimated to be 20% and 50%, respectively (Marchal et al. 2011). If costs are higher fishers may spend less time at sea or fish closer to port (Poos et al. 2010). Hence, differences in fuel costs may influence the catch composition and discard rate. Also, we considered the study area as a single management unit, although it belongs to two different management units (subdivisions IVc and VIId). Since 2009 the eastern English Channel (subdivision VIId) was allocated a separate cod TAC (i.e. 1600 tons in 2011) from the North Sea (subdivision IV) cod TAC (i.e. 26800 tons) (ICES 2011) and the French fleet receives a larger proportion of cod TAC (ca. 84%) VIId, compared to that in IV (ca. 4%). The results of our model should therefore be adapted before being used by managers.

Mechanistic models are increasingly being used to analyse vessel fishing behaviour (Little et al. 2004, Poos et al. 2010, Dowling et al. 2012). These models are independent of historical patterns and have strong predictive power, making them ideal tools to analyse fisheries responses to new management regulations (Dowling et al. 2012). Commonly, fishers behaviour is based on economic interests while alternative utility functions with less emphasis on economic interests, such as tradition or information sharing could be included (Little et al. 2009). However, this would require a more extensive understanding of the rationale of fishers' behaviour. Fisheries management is a complex system, whereby a manager must take interests and concerns of many stakeholders into account. Our spatially explicit effort allocation model proves to be a useful tool to evaluate conservation and economic trade-offs and enables managers to visualize consequences of new management scenarios, such as a discard ban.

2.2 Fishing fleets competing for space with other sectors of activity in the North Sea: application of the FISHRENT bio-economic model

2.2.1 Northern North Sea (saithe fishery) application

The following study is due to be published as a paper with the following reference:
Simons, S. FishRent: a bioeconomic model of fleet dynamics in the North Sea saithe fishery. Submitted to ICES Journal of Marine Science. In review.

Section Abstract

Regulations and changes in market and environmental conditions may change the profitability of one fishery and can lead to reallocation of fishing effort. The extent of this effort displacement will depend on the relative profitability of the alternative options for the fleet segments affected. When fishing areas and fleet segments are heterogeneous, simple aggregate effort models such as those based on the ideal free distribution theory, may provide inaccurate predictions. A bio-economic optimisation and simulation model is applied to explore how the different conditions of A2 and B1 impact the fishing effort allocation and the distribution of benefits across fleet segments from different nations. In the model the optimization of net profits determines the effort adjustment and the investment behaviour of fleet segments, which in turn affect the level of catch rates. This tool was applied to the North Sea saithe fishery. For B1 and A2 there was a spatial heterogeneity of the fishing effort observed with shifting effort through the year. As profit was maximised, effort aggregated in those areas where the costs of fishing (e.g. fuel cost) were low. The simulations demonstrate that A2 and B1 will have heterogeneous impacts on individual fleet segments from different nations and home ports. Even when A2 or B1 did result in little change in overall net profits, there were winners and losers, and the distribution of gains and losses may not be intuitively obvious.

Introduction

Regulations and changes in market and environmental conditions may change the profitability of one fishery and can lead to reallocation of fishing effort. The extent of this effort displacement will depend on the relative

profitability of the alternative options for the fleet segments affected. When fishing areas and fleet segments are heterogeneous, simple aggregate effort models such as those based on the ideal free distribution theory may provide inaccurate predictions (Hilborn and Ledbetter, 1979; Campbell et al., 1993; Gillis and Peterman, 1998).
The approach is based on a bio-economic optimisation and simulation model called "FishRent" (Salz et al., 2011). It includes the economics of multiple fleet segments and their effort distribution which is based on optimizing the profit of the whole fishery. The model includes 5 fleet segments of the North Sea saithe fishery. A basecase scenario is contrasted with the A2 and B1 scenarios to forecast the effects on fleet dynamics. In particular, simulations explore how the different conditions of A2 and B1 impact the fishing effort allocation and the distribution of benefits across fleet segments from different nations.

Materials and Methods

The North Sea saithe fishery as a case study
Saithe (*Pollachius virens*) is of major economic importance for North Sea fisheries, with annual landing values of around 15 million Euros (Anderson and Guillen, 2009). It is targeted by Norwegian, French, German, English, Danish, and to a small extend Swedish trawlers (ICES, 2012). 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 recruitment is impaired with a high probability (ICES, 2010; Lassen and Medley, 2001). B_{pa} is the precautionary reference point for SSB, below which the stock would be regarded as potentially overfished (ICES, 2010; Lassen and Medley, 2001). F_{tar} is the average fishing mortality for age class 3-6 that is set as a target (ICES, 2010; Lassen and Medley, 2001). In the long-term management plan F_{tar} is set to 0.1 ($F_{tar-low}$), when SSB is estimated to be below the minimum level of 106 thousand tons (B_{lim}) (ICES, 2013). Usually fishing mortality is around 0.4, a F_{tar} of 0.1 is hence a strong reduction. Where SSB is above 200 thousand tons (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}) (ICES, 2013). In the case where SSB is estimated to be between B_{pa} and B_{lim} the target fishing mortality rate ($F_{tar-mid}$) is calculated as

$$F_{tar-mid} = F_{tar-up} - \left(F_{tar-up} - F_{tar-low}\right) * \frac{\left(B_{pa} - SSB\right)}{\left(B_{pa} - B_{lim}\right)}$$

Scenarios
The North Sea and Skagerrak were subdivided by the grid of ICES rectangles (30 x 30 nm²) (Figure 60). 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 three zones, covering the spawning and partly the feeding grounds of North Sea saithe as well as the main fishing grounds of the modelled fleet segments (Figure 60 and Figure 61).

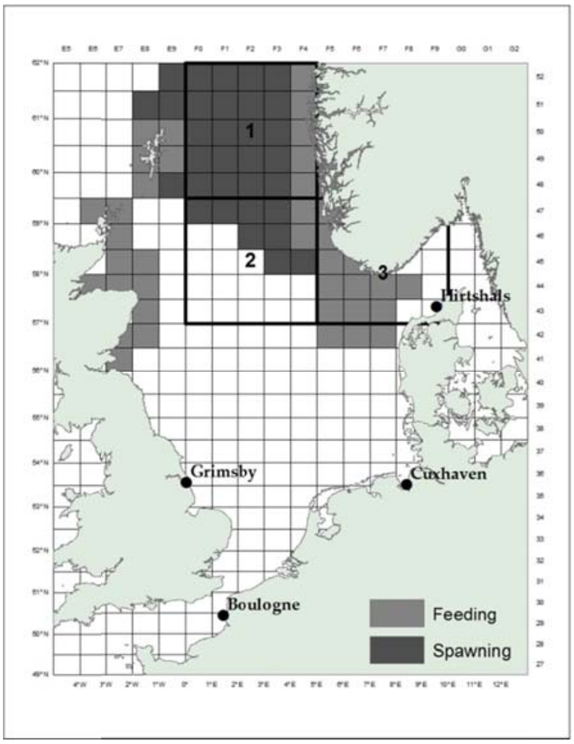


Figure 60. The spatial layout for simulations of the North Sea saithe fishery. The North Sea is subdivided by the grid of ICES rectangles with a focus on three zones, covering partly the feeding grounds (grey) and the spawning ground (black) of North Sea saithe. Main home port for the Danish (Hirtshals), English (Grimsby), French (Boulogne) and German (Cuxhaven) fleet segment are shown.

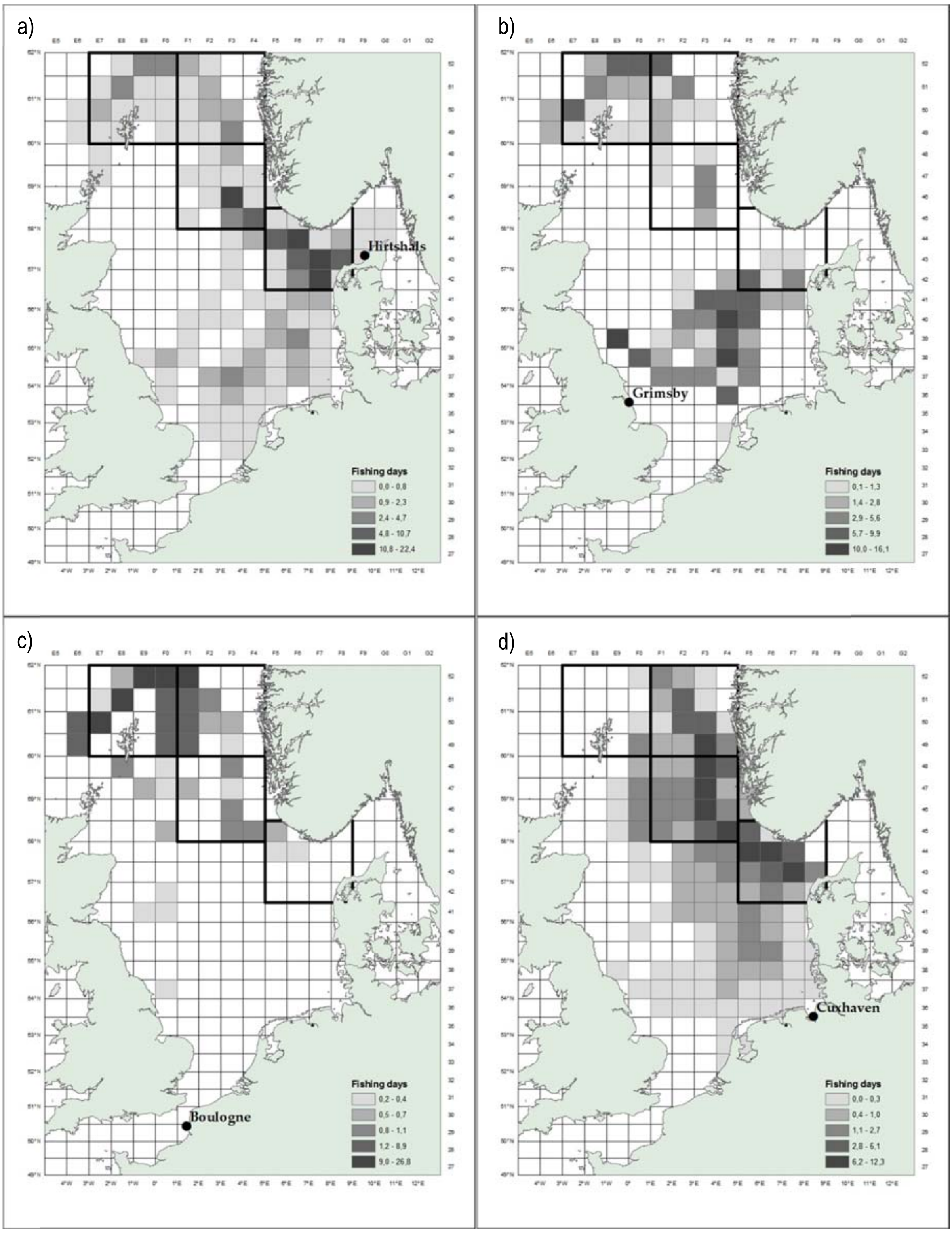


Figure 61. Initial distribution of annual fishing days per vessel for the Danish fleet segment (a), the English fleet segment (b), the French fleet segment (c) and the German fleet segment (d).

For A2 the annual TAC was allowed to change only within 15% (Table 24), keeping the annual volume of catches rather stable. Moreover, fuel prices were assumed to increase by 214% and fish prices by 135% from 2010-2050, respectively (Table 24). For B1 fuel prices were increased by 176% and fish prices by 116% from 2010-2050, respectively (Table 24). For B1, a HCR option was applied that included a 15% constraint for the annual change of the TAC if SSB was at or above B_{pa} (Table 24), facilitating a more immediate response to stock development, especially when SSB is declining below

B_{pa} (200 000 tons). A temporal area closure of the spawning ground of North Sea saithe was applied for B1 during the first quarter of the year (Table 1).

Table 24. Description of the scenarios

Scenarios	Fuel prices	Fish prices	HCR	Area closures	Varying recruitment
Basecase	-	-	Annual TAC can change by more than 15% when SSB $\leq B_{pa}$	-	Yes
A2	214% change	135% change	Annual TAC can change only within 15%	-	Yes
B1	176% change	116% change	Annual TAC can change by more than 15% when SSB $\leq B_{pa}$	Spawning ground	Yes

Settings

The model was run from 2007-2050. For the years 2007-2009 the low recruitment values from the official assessment from 2012 (ICES, 2012) were used (Figure 62). For the following years recruitment was predicted based on stochastic simulations applying a Beverton and Holt stock-recruitment relationship (Figure 62). This kind of sochasticity was added to the originally deterministic model, as a failure of recruitment is an important driver of the North Sea saithe fishery right now. The model accounted for four fleet segments with North Sea saithe either as a main target or important by-catch species, covering vessels from Denmark, England, France and Germany (see main home ports Figure 60). According to the Data Collection Framework (DCF) fleet segments were classified by vessel length and predominant gear type (COMMISSION DECISION, 2009). The calibration of the model was based on average biological and economic data for the period 2005-2007 (ICES, 2012; Anderson and Guillen, 2009).

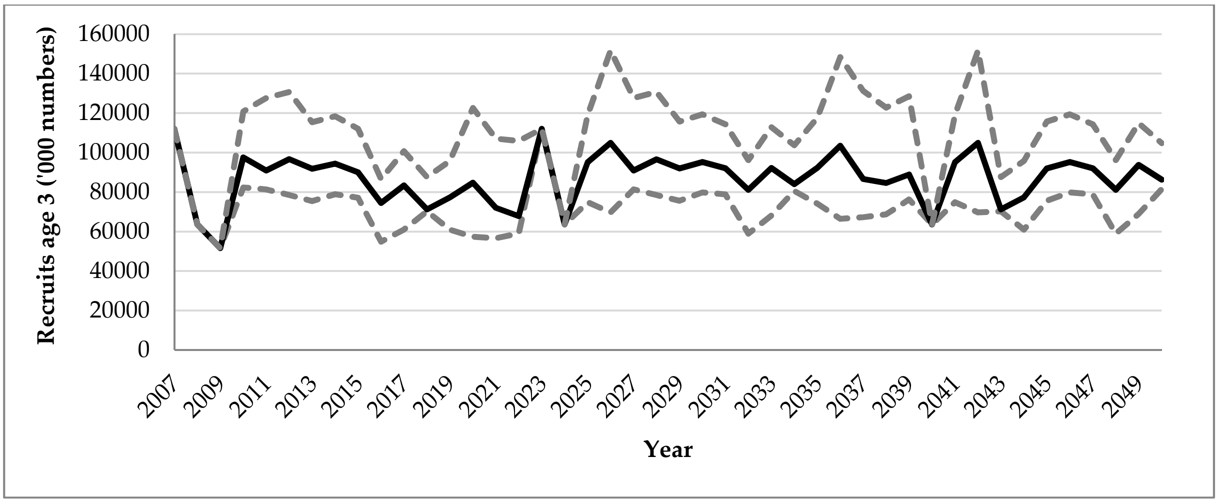


Figure 62. From 2007-2009 observed recruitment values. From 2010-2050 onwards median recruitment values (solid lines) with 5 and 95% intervals (dotted lines) based on 1000 iterations.

Model description

The presented modelling approach is based on a bio-economic optimisation and simulation model called "FishRent" (Salz et al., 2011). It is a dynamic feedback model and is composed of six sub-modules (Figure 63). The individual fish growth, fishing and the movement of species is modelled on a monthly time step. The profit maximisation, the ageing of fish, the spawning and recruitment event, the calculation of costs and the fleet size adjustment are modelled on an annual time step. It is a model of a fishery system which focuses on the economic drivers, among which the profit earned by the fleet segments is the main driver. Profit depends on the amount of landed fish, prices for the landed fish, and the costs of fishing. Profit, furthermore, depends on the interest rate for capital invested in the fleet. Each year, the applied CONOPT solver (for the detailed description of the CONOPT algorithm (seeDrud, 1991) finds the optimum levels of fishing effort for each fleet segment within the historical minimum and maximum values of fishing effort that maximise the total net profit of the fleet. In particular, the solver finds not only the optimal level of fishing effort, but also its optimal spatio-temporal distribution. Thereby, it is assumed that the fishers have a perfect knowledge about potential catch rates in each ICES rectangle. Based on the calculated profits from two years ago, the model determines the level of investment or disinvestment in the fleet (for details see (Salz et al., 2011)). Any fleet segment that is highly profitable will become bigger and hence the profit of the individual vessels would dissipate in the long-term, given that free access in the fisheries is allowed. Thus, it is assumed that fleet segments maximise the overall annual profit by setting an optimal level of fishing effort, which in turn impacts the commercial fish stock. In the model, management constraint activities affect the stock and control the fishery. Simulations of changes in stock biology (e.g. changes in stock productivity), fisheries economics (e.g. changing fuel costs) and/or policy (e.g. alternative management strategies) can be conducted by the model. A full description of the basic version of the model can be found in (Salz et al., 2011).

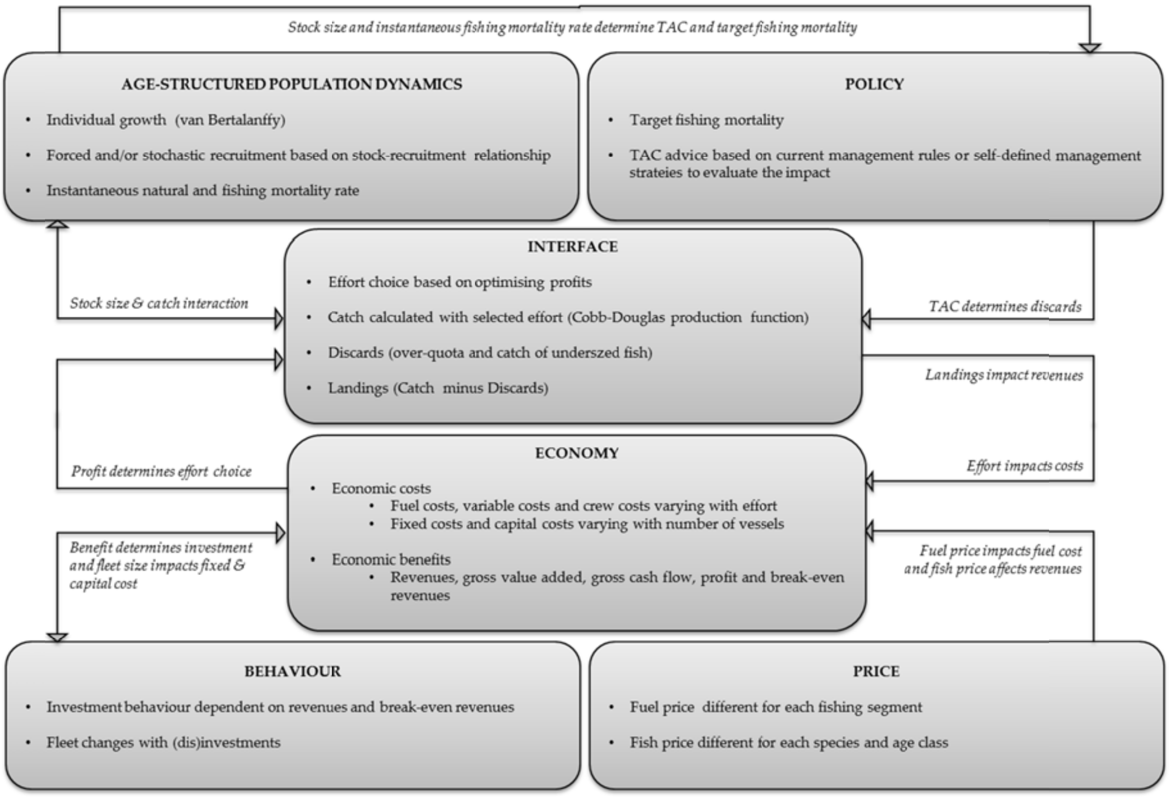


Figure 63. Conceptual model design with arrows that explain the interaction between the six sub-modules (age-structured population dynamics, policy, interface, economy, behaviour and price module).

Results

Effort aggregation

In the model the solver finds the optimal level of fishing effort as well as its optimal spatio-temporal distribution that maximises the overall net profit. To investigate the impact of A2 and B1 on the spatial distribution of fishing effort, ICES rectangles fished each year were ordered by the amount of predicted fishing effort (days at sea), and the cumulative percentage of the total annual effort expended in each of the rectangles fished each year was then calculated. These results were then averaged over the modelling period between 2007 and 2050, and used to plot the cumulative effort against cumulative area fished (Figure 64). For B1 and A2 there was a spatial heterogeneity of the fishing effort observed (Figure 64). As profit was maximised, effort aggregated in those areas where the costs of fishing (e.g. fuel cost) were low. In particular, as costs (i.e. fuel costs due to longer distance from port) associated with each area differed between fleet segments, profit rates varied also considerably between fleet segments and areas, resulting in the spatial heterogeneity of fishing effort. On average, around 90% of fishing effort of A2 occurred in only 41-50% of the ICES rectangles fished, with about 30% of the fishing effort in the top 10% of fished ICES rectangles (Figure 5). As a perfect knowledge about potential catch rates in each ICES rectangle was assumed, effort for B1 (including a closure) was even more aggregated with around 90% of fishing effort occurring in only 21-30% of the ICES rectangles fished (Figure 64).

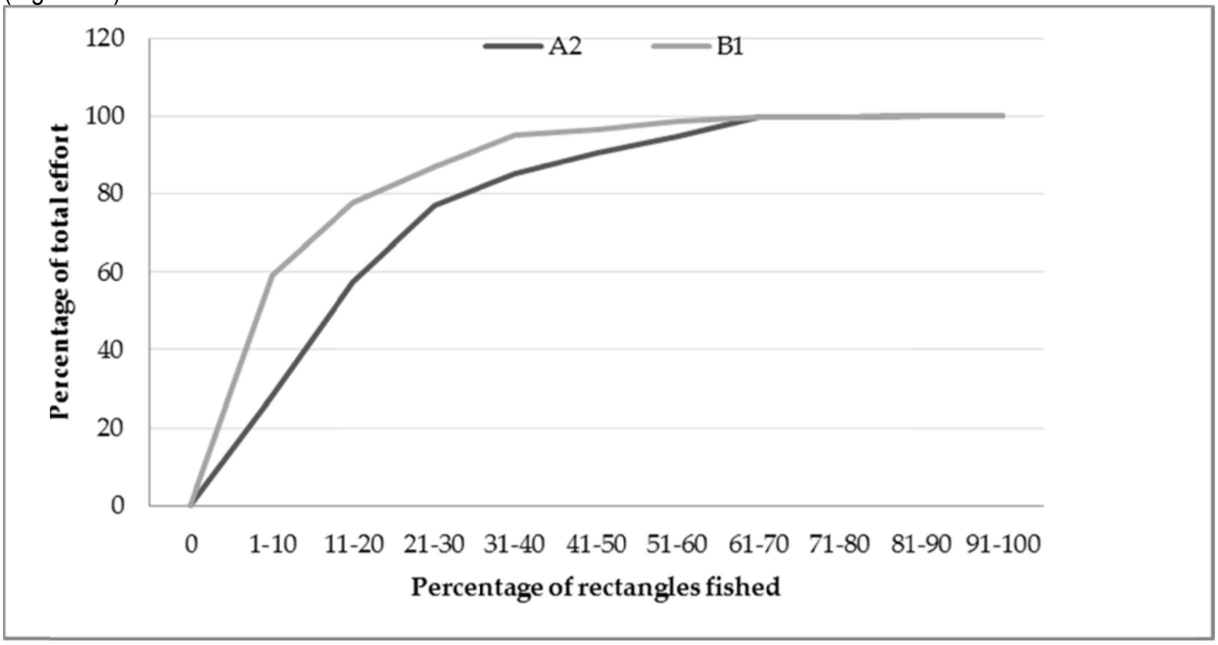


Figure 64. Cumulative effort versus cumulative area fished (both expressed as a percentage of the respective annual totals) for the modelled fleet segments during the modelling period, after ordering the ICES rectangles fished by decreasing effort.

The conditions of A2 and B1 resulted in shifting patterns of fishing effort through the year (Figure 64-Figure 67). Although for both scenarios effort tended to concentrate where fish abundance was high, distance from port became more important with increasing fuel costs. This was a particular evident for A2 (Figure 65 and Figure 66), reflecting highest fuel costs (Table 24). When comparing the three zones, steaming costs were highest for zone 1. Thus, for A2 the concentration of effort was limited in zone 1 in the first quarter of the year, although the CPUE was considerably higher, due to the spawning aggregation, than in zone 2 or 3 (Figure 65 and Figure 66).

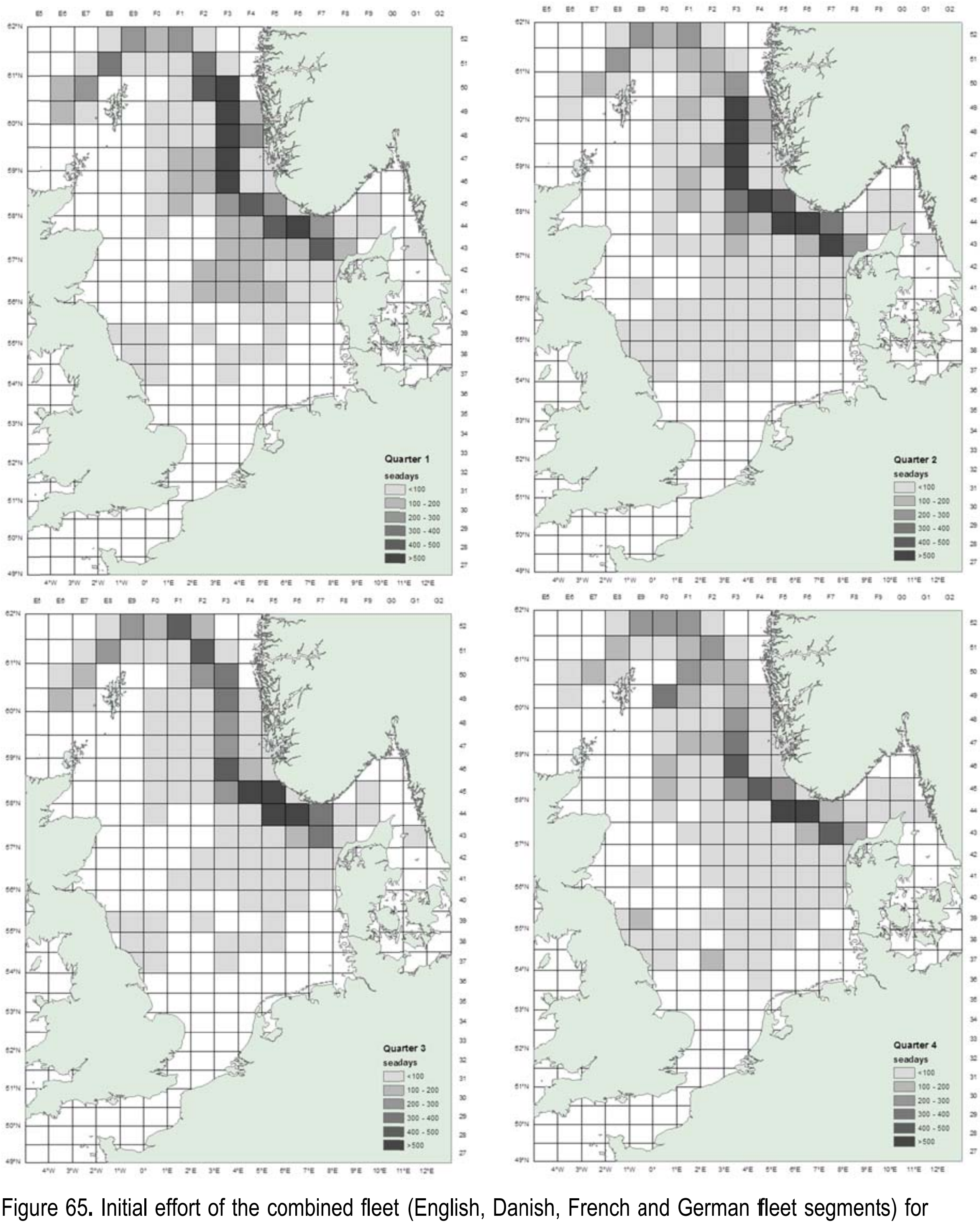


Figure 65. Initial effort of the combined fleet (English, Danish, French and German fleet segments) for each quarter.

For A2, the general pattern of fleet segments concentrating, but not fishing exclusively, in areas where fish were more concentrated was also observed during the rest of the year (Figure 65 and Figure 66).

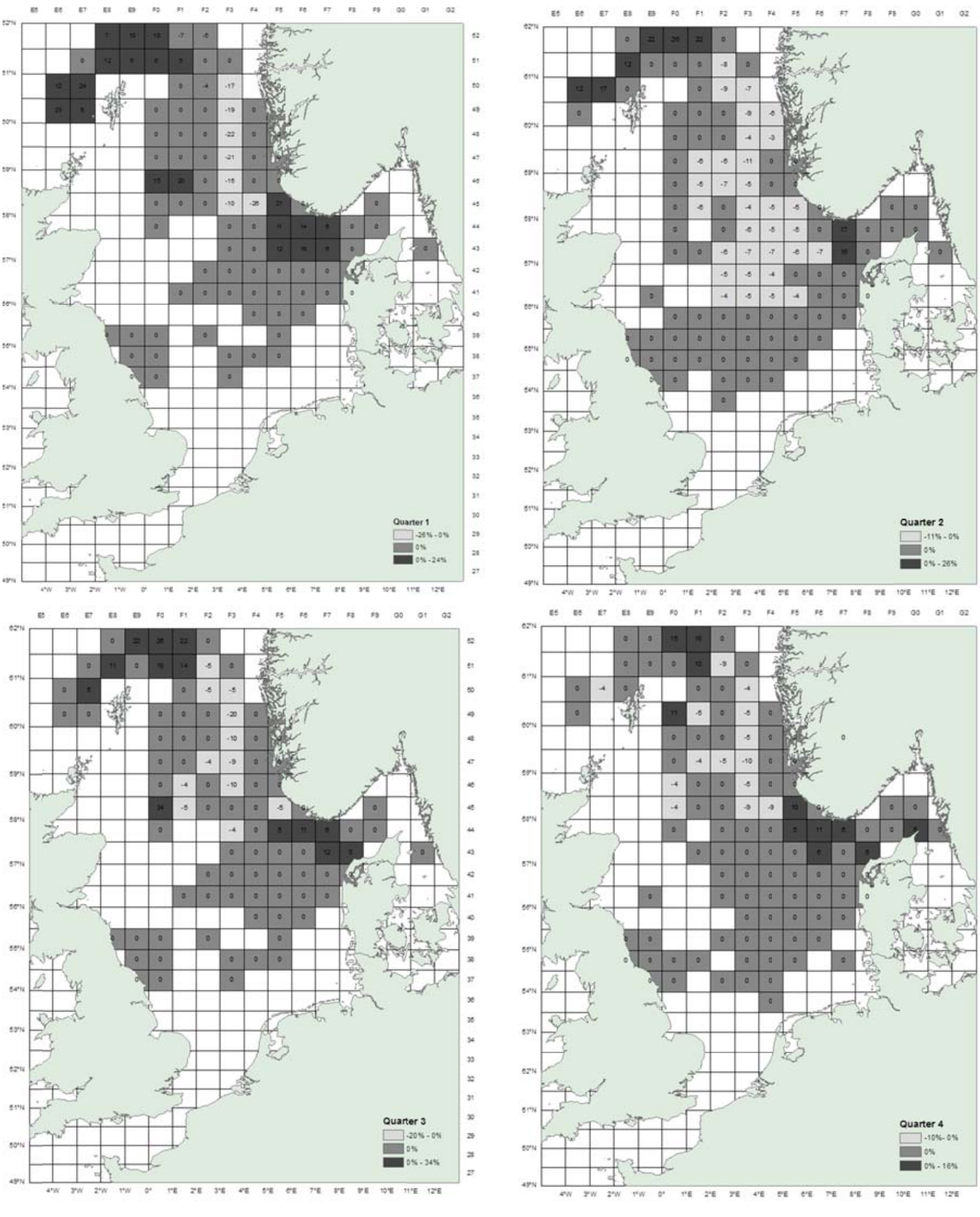


Figure 66**.** Percent change of effort distribution of the combined fleet under A2 in each quarter of the year compared to the basecase values.

For B1, a closure was imposed on the spawning ground of North Sea saithe. The average efficiency of a unit of fishing effort decreased immediately because all fleet segments that continued to fish close to that area were precluded from fishing in high-CPUE areas where fish aggregated to spawn. However, the total effort of the combined fleet segments remained quite constant in the first quarter. In quarter 2 when the closed area was re-opened, the fishing effort became concentrated in zone 1 as CPUE in this zone was higher than in the other zones (Figure 67). In the third quarter effort followed the seasonal migrations to zone 2 and 3, which represented parts of the feeding grounds (Figure 67).

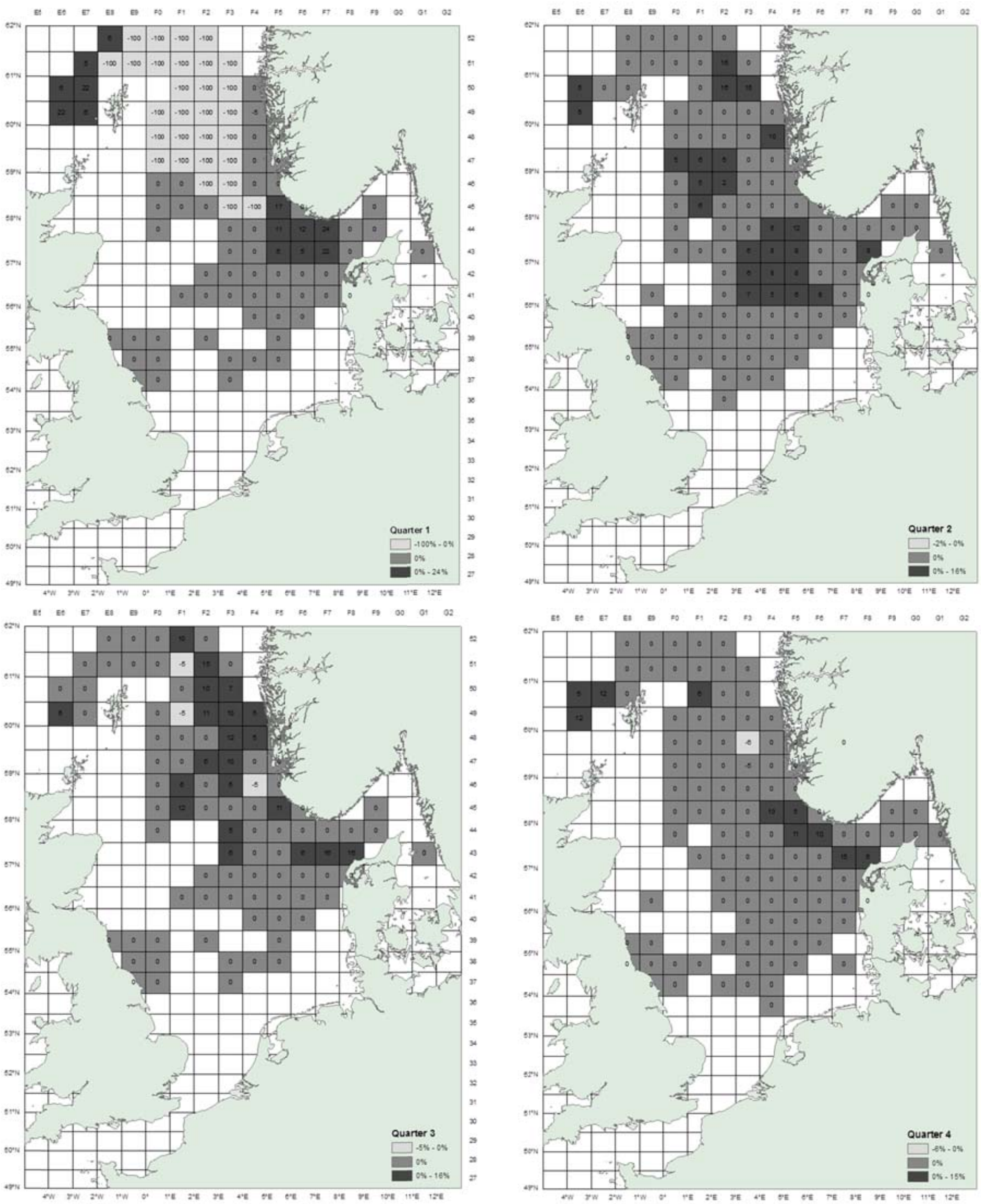


Figure 67. Percent change of effort distribution of the combined fleet under B1 in each quarter of the year compared to the basecase values.

Net profits

Only in the simulations of B1, net profits increased significantly for the overall fleet (Figure 68). With the reference point set at B_{pa} in B1, the imposed area closure increased the overall net profit by 6% in long-term (2050) (Figure 68). The A2 scenario with higher fuel costs resulted in net present value losses to the overall fleet (Figure 68). However, the impacts of A2 and B1 conditions differed considerably between fleet segments. The English fleet segment had the smallest distance from port to the spawning aggregation (zone 1). While other fleet segments of A2 shifted their effort away from zone 1 (high CPUEs) in quarter 1 to zone 3 (lower CPUEs) in quarter 2 and 3 due to the increased fuel costs, the English fleet segment continued to fish in zone 1. Thus, this fleet segment tended to even benefit from

A2 conditions, often taking advantage from high fuel costs that reduced net profits for the overall fleet due to higher steaming costs for the other segments (Figure 66, Figure 67, Figure 68). Moreover, for A2 net profit for the English fleet segment increased even with effort at a lower level than the ones of the other fleet segments as the CPUE was higher in zone 1 than in zone 3. In contrast, the fleet segments from Denmark, France and Germany tended to suffer from the high fuel cost of A2.

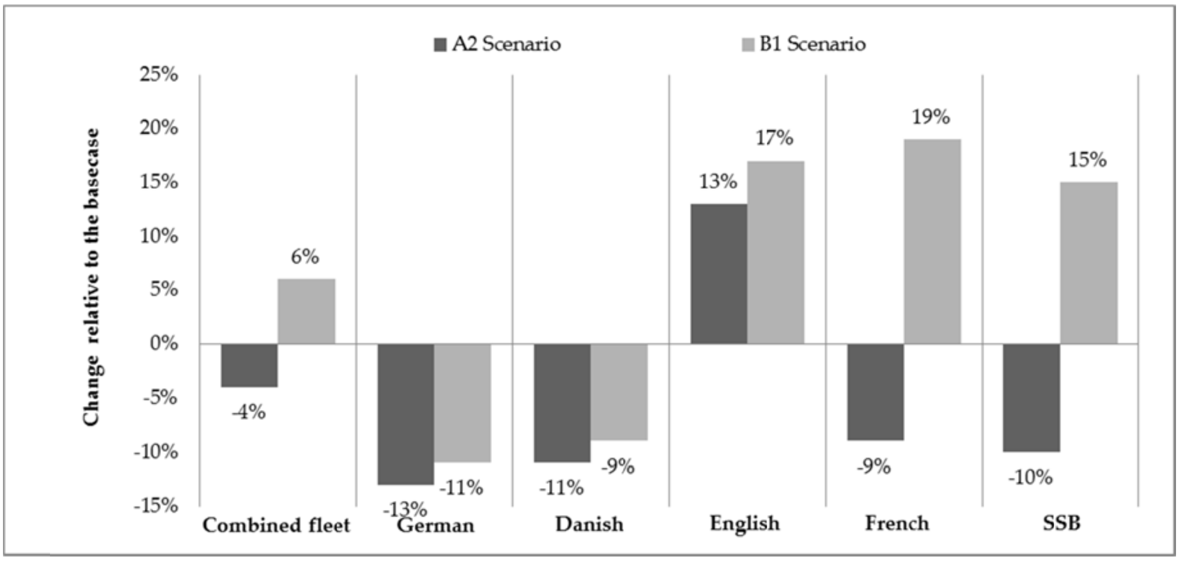


Figure 68. Changes (%) in net profits for the combined fleet, the German, Danish, English and French fleet segments and median SSB values relative to the basecase values. Diagrams show long-term (2050) changes for simulations of A2 (black) and B1 (grey).

For B1, net profits of the French and English fleet segments increased, while net profits of the other fleet segments decreased (Figure 68). Total effort of B1 was initially displaced from zone 1 to zone 3, with total effort in zone 1 falling by 26% and effort in zone 3 rising by 37%. As stock conditions improved, some of that effort returned in quarter 2, but the share of total effort in zone 1 returned to only 93% of the initial level, and effort zone 3 stabilized at 114% of the initial level. However, there were differences between the fleet segments. For instance, for the English and French fleet segments that were fishing in zone 1 in quarter 2, revenues per unit of effort and hence net profits began to rise immediately and reached a level that was 17% to 19%, higher than the basecase values in 2050 (Figure 68). However, in the first quarter of the year when the closure was imposed they were switching from zone 1 to zone 3. In turn, net profits of those segments in this quarter of the year dropped, because they were moving to what was already a less profitable area before the area closure was implemented. On the other hand, fishing effort of the Danish and German fleet segments was already concentrated initially in zone 3, and after the closure, even more of their effort was concentrated there (Figure 65, Figure 67). As a consequence of increased fishing pressure and thus decreasing CPUE, long-term net profits for Danish and German fleet segments fishing in zone 3 declined by 11% and 13%, respectively (Figure 67, Figure 68).

A2 and B1 had heterogeneous effects on the net profits of the different fleet segments, due to different patterns of reallocation of effort. Both A2 and B1 tended to result in considerably high displacement of the fleet segments to zone 3. The combination of a strict HCR with a temporal area closure in B1, increased the long-term net profit for the overall fleet (Figure 68). When compared to the basecase values long-term net profits were 16% higher for B1 and significantly lower for A2 (Figure 68).

Discussion

The simulation results present the possible impacts of A2 and B1 conditions. However, they should be taken with caution, as the results are based on several assumptions. Nevertheless they provide insights into the consequences of A2 and B1 under varying recruitment success and are useful in identifying critical parameters. Identifying key parameters provides a focus point for future empirical work. The results also illustrate how fishermen's behaviour in response to A2 and B1 conditions can impact the results of management measures.

A temporal area closure when fish tend to aggregate may reduce fishing mortality quickly even if the total effort remains constant. Such an area closure was imposed in the simulations of B1. Fishing efficiency was reduced considerably when effort was reallocated to areas where CPUE was lower. The simulations indicate that the conditions of B1 (a strict HCR combined with a temporal area closure) may lead to increasing long-term net profits and SSB. However, area closures are known to also impact other species. This might be of importance when analysing the impacts of A2 and B1 for a mixed fishery. In particular, increases in catches and net profits from stocks that receive protection from the area closure may be offset by a reduction in catches and net profits from stocks that absorb displaced effort. Thus, the effect of temporal area closures are likely to vary across species.

Simulation results demonstrate that B1 and A2 conditions will have heterogeneous impacts on different fleet segments. Based on simulation results effort tends to concentrate where fish abundance is high, but economic costs also play an important role in effort allocation. As costs (i.e. fuel costs due to long distances from port) associated with each area differed between fleet segments, profit rates varied also considerably between fleet segments and areas, resulting in the spatial heterogeneity in the fishery.

2.2.2 Southern North Sea application

The following study is due to be published as a paper with the following reference:
Hamon, K., and Bartelings, H. Spatial FishRent Analysis.

General background

In this study we will simulate how closures on the NorthSea due to various reasons and changes in fuel costs and fish prices will impact the profits of the Dutch fishing fleets. We will also simulate how the fishing fleets will develop due to changes in fishing space and prices, thus being able to estimate the economic viability of the fishing fleets in the North Sea between 2010 and 2030.

For these simulations we have applied the spatial version of FishRent. FishRent is a bio-economic model which simulates fishermen behaviour based on optimal effort allocation. It can take into account the environmental drivers through changes in the stock, the economic drivers like changes in the fuel prices and proposed management measures like the implementation of Natura 2000 sites and simulates the catches and profits for the next 25 years. The model generates basic economic indicators such as gross value added and net profits. The model also generates a variety of other outputs, e.g. size of stocks and fleets, production costs, catches and landings. More information about FishRent and the methodology used in FishRent can be found at: http://www3.lei.wur.nl/fishrent/.

Aims and objectives

To test the outcome of future management two scenarios were investigated. Those scenarios were drawn from the Vectors wide scenarios A2 and B1 (see section B.1 this deliverable) with the following assumptions for the development of wind farms, nature conservation areas and maritime traffic.

Table 25. Description of the closure scenarios.

	A2	B1
Wind farms	50% wind farms DE+NL+DK → coexist scenarios UK → phase 1 and 2 of current plans	100% wind farms DE+NL+DK → coexist scenarios UK → phase 1, 2 and 3 of current plans
Nature conservation	Some MPA closed DE+NL → areas for mobile gears closed (coexist) DK → all closed UK → close offshore planned MPAs	All MPA closed DE+NL → all closed (coexist) DK → all closed UK → close offshore + inshore planned MPAs
Transport	No extra closure	Closure of area exclusively for maritime traffic
Fuelprice	Increase of 114% by 250	Increase of 76% by 2050
Fishprice	Increase of 35% by 2050	Increase of 16% by 2050

Please note that these scenarios are not political authorized but based on previous EU project (COEXIST), IPCC scenarios A2 and B1 and expert knowledge on the long term future of those activities.

Material and methods

Data

FishRent is developed based on the available economic data in the DCF. The economic parameters are calibrated using DCF data[15]. DCF economic data refers to annual economic data for the main fleet segments as defined by the DCF. Landing and effort data was based on logbook information. Biological data used is taken from ICES

Model description

Fishrent (Salz et al., 2010) is a multi-species multi-fleet bioeconomic model that has been developed from best practice knowledge gained from similar models used in Europe over the past decade (E.g. Frost et al., 2009). Fishrent is both a simulation model and optimisation model that can enable consideration of a diverse array of policy aims. Developed initially in Excel, the main outputs describe the likely trajectories and status of the modelled fisheries and fleets under the policy aims considered. The model has been modified and this version of the model is written in GAMS (General Algebraic Modeling System)[16], with input and output interfaces in R[17]. The new version of the model includes all the features of the Excel model and the spatial description of species and effort.

The model optimizes the catch and landings of Species *i*, Segment *j*, area *n*, period *p* within year *t* given that the overall net profits are maximized. Depending on the choice of the user the model can function with monthly, quarterly or yearly time periods. Although the model as of yet only optimizes within a year, the model can simulates the catches and landings over a set time period. This means that the model will run for each year as defined by the user. Data input for consecutive years will be taken from model calculations of previous years.

[15] http://datacollection.jrc.ec.europa.eu/dcf-legislation

[16] www.gams.com

[17] R core Team, 2012

Objective function
Total profit is maximized subject to production and balance constraints. The total profit is calculated as a sum of the profit of all fishing segments *j*.

Objective: $Maximize\ \sum_j PrF_j$

Profit of a fishing segment *j* is calculated as the revenue minus variable and fixed costs. Three types of variable costs are distinguished: fuel cost (FuC), crewcost (CrC), and other variable costs (VaC). Two types of fixed costs are distinguished: fixed cost (FxC) and capital costs (CaC).

$$PrF_j = Rev_j - FuC_j - CrC_j - VaC_j - FxC_j - CaC_j$$

Yearly revenue of a fishing segment *j* is calculated as the sum over the period of the value of the landings of the target species (*Land*) times a percentage of the value of other catches (OtSpR). It is assumed that the catch of other species is linearly related to the value of landings of the target species. Thus if the value of landings of the target species increases with 10% the value of landings of other species increases with a similar percentage.

$$Rev_j = \sum_{i,p} \left[Land_{i,j,p} * price_{i,j,p}^{fish} * (1 + OtSpR_j) \right]$$

As an alternative the model can also maximize the gross cash flow (GCF) instead of the net profits. The gross cash flow is defined as the revenue minus the variable cost.

$$GCF_j = Rev_j - FuC_j - CrC_j - VaC_j$$

Economic costs
The five economic cost variables are calculated on a yearly basis per fishing segment. Although it would be possible to calculate the economic cost per period it is not considered practical as most European countries collect economic data on a yearly basis and not on monthly or quarterly basis.
The fuel costs are calculated based on the effort in days (Eff) spend fishing and steaming. In the model the effort spent fishing determines the catch. However to catch fish the vessels need to steam to the fishing area. These steaming costs also need to be included in the fuel costs. To calculate the total effort spend on fishing and steaming, the fishing effort is multiplied by a factor $(1 + \beta_{j.n}^{s})$*. The* β *differs on the distance between the home port and the fishing area n. As the homeport(s) can differ between segments the β's can also differ between segments. By calculating the steaming effort in such a way it is implicitly assumed that within a trip a vessel will steam to an area, fish there and steam back. Thus a vessel cannot go to several areas within a trip. More information about the calculation of the β's will be given in …..*
The fuel cost are calculated as the effort spend steaming and fishing times a parameter representing the average fuel consumption per unit of effort $(FuC_{i,j,n}^{0})$ times the indexed fuel price ($price_j^{fuel}$)

$$FuC_j = \sum_{n,p} \left[FuC_{i,j,n}^{0} * \left(1 + \beta_{j,n}^{s}\right) * Eff_{j,n,p} * price_j^{fuel} \right]$$

The crew costs are calculated as a share in the revenue minus the fuel costs. This structure is chosen as it closely resembles how the crew wages are determined in the Netherlands. In the Netherlands the crew get a small fixed wage and a larger variable wage depended on the profit of fishing trips.

$$CrC_j = CrC_j^{0} * (Rev_j - FuC_j)$$

The variable cost, being e.g. costs of landings, auction and harbour fees, are determined as a fixed share of the gross revenue.

$$VaC_j = VaC_j^0 * Rev_j$$

The fixed costs, also named vessel costs or semi-fixed costs are administration, insurance, maintenance, etc. It is assumed that these costs depend implicitly on the value of the vessel and are constant per vessel. The value of the segment is calculated as a fixed amount per vessel time the size of the segment j ($\mathrm{Fle_j}$) times an indexed price per vessel ($\mathrm{price_j^{inv}}$). If the indexed price is set at a different value than 1, then changes in construction costs per segment can be accounted for.

$$FxC_j = FxC_j^0 * Fle_j * price_j^{inv}$$

The capital costs include both depreciation and interest costs. The capital costs are calculated in a similar way as the fixed costs.

$$CaC_j = CaC_j^0 * Fle_j * price_j^{inv}$$

Production function

The revenue in the model is determined by the landings of the targets species *i*. The landings in turn are determined by the catch of the species. Landings and catches are not per definition the same as the model takes into account the possibility of over quota discards.

$$Land_{i,j,p} = \sum_{n} \left[Catch_{i,j,n,p} - Disc_{i,j,n,p} \right]$$

The catch of a species is calculated by a Cobb-Douglas function. Catch of species *i* of segment *j* in area *n* in period *p* depends on the fishing effort and the available biomass (*CB*). $C_{i,j,n,p}^0$ is a measure of the catchability of the biomass in area *n* and t_j is a measure of technological creep.

$$Catch_{i,j,n,p} \leq C_{i,j,n,p}^0 * \left(1 + t_j\right) * {Eff_{j,n,p}}^{\alpha_{j,n}} * {CB_{i,n,p}}^{\beta_{j,n}}$$

Balance equations: Effort

The use of fishing effort is limited in two balance equations. First of all the minimum effort used per segment has to be bigger than a certain percentage of the total available effort for that segment.

$$\sum_{n,p} \left[(1 + \beta_{j,n}^s) * Eff_{j,n,p} \right] \geq Eff^{min} * MIN[maxEff_j, dasM_j * Fle_j]$$

Second the maximum effort used per segment within a year has to be smaller than the maximum effort available to each segment.

$$\sum_{n,p} \left[(1 + \beta_{j,n}^s) * Eff_{j,n,p} \right] \leq MIN[maxEff_j, dasM_j * Fle_j]$$

The maximum available effort per fleet segment is determined based on two parameters. First of all in the long term management plans a maximum amount of effort can be defined ($maxEff_j$). Second the max effort is defined as the maximum number of sea days available to a vessel ($dasM_j$) times the number of vessels in a segment (Fle).

The size of a fleet segment is determined by the size of the fleet segment in the previous year plus the (dis)investments.

$$Fle_j = Fle_j^{year-1} + Inv_j$$

Investment in a fleet segment is dependent on the profits made in that fleet segment in the previous year. Theoretically the investments should be determined by expectations of future profit, but there is no empirical data, which could be used to support such theorem in the model. Instead, perceived profitability in the preceding year, expressed as ratio between break-even revenues minus realised revenues divided by realised revenues is used to determine the (dis)investments in each year. The break revenue is calculated as

$$BeR_j = \frac{CrC_j - FxC_j - CaC_j}{(1 - \frac{FuC_j}{Rev_j} - \frac{VaC_j}{Rev_j})}$$

This leads in some years to quite substantial changes in the number of vessels in a fleet segment, which could occur as vessels from other segments may enter the given fishery. At the same time, it was recognised that the inertia of the system (licensing, knowledge of skippers, etc.) does not allow such full flexibility. Consequently, parameters have been introduced to limit the maximum annual (dis)investments. Furthermore, it has been assumed that the active fleet will first achieve a certain minimum number of days-at-sea per vessel before the number of vessels will be expanded $(\mathrm{DasM_j} * \mathrm{io_j})$ to avoid continuous growth of the fleet, while at same time the number of days-at-sea per vessel could be proportionately falling, as long as break-even revenues exceed realised revenues.
This leads to the following investment function:

If $BeR_j > Rev_j$ or $DasOp_j < DasM_j * io_j$

$$Inv_j = MAX\left[psh_j * Inv_j^{min} * Fle_j, psh_j * \frac{Rev_j - BeR_j}{Rev_j} * Fle_j\right]$$

If $BeR_j \leq Rev_j$

$$Inv_j = MIN\left[psh_j * Inv_j^{max} * Fle_j, psh_j * \frac{Rev_j - BeR_j}{Rev_j} * Fle_j\right]$$

Where $Inv_j^{min}$is the maximum percentage of disinvestments and $Inv_j^{max}$is the maximum percentage of investments in a year. psh_j is a share of the percentage of the profit that can be invested.

Balance equations: Catch and Biomass

Catch is limited by the available biomass. For each species, area and period the catch cannot exceed the available biomass.

$$\sum_j Catch_{i,j,n,p} \leq CB_{i,n,p}$$

The biomass of species i area n and period p is calculated as the biomass of the previous period plus the growth of the biomass minus the total catch. The total catch includes undersized discard calculated as a fixed share of the catch $(dsh_{i.j})$ and catches of other fishing segments not taken into account in the model $(csh_{i,j})$.
Two types of species are distinguished: mobile and stationary species. The biomass is calculated differently depending on the mobility of the species. For mobile species it is assumed that after a period the biomass will be redistributed over all areas according to a predefined distribution factor $dist_{i,n}$. This means that within a period the biomass can be completely depleted but after the end of the period the biomass will be restored according to the overall growth of the stock.

$$CB_{i,n,p} \leq dist_{i,n} * \left\{\sum_n [CB_{i,n,p-1} + Growth_{i,n,p-1}] - \frac{\sum_{j,n}[Catch_{i,j,n,p-1} * (1 + dsh_{i.j})]}{\sum_j csh_{i,j}}\right\}$$

For stationary species the biomass within an area only depends on the stock, growth and the catches within the area. Biomass within an area can therefore be completely depleted.

$$CB_{i,n,p} \leq CB_{i,n,p-1} + Growth_{i,n,p-1} - \frac{\sum_j [Catch_{i,j,n,p-1} * (1 + dsh_{i.j})]}{\sum_j csh_{i,j}}$$

The growth of the stock is calculated once a year based on the biomass in the last period of the previous year.

$CB_{i,n}^{year} = CB_{i,n,p}$ for p is last period

Depending on the type of species, two types of growth functions can be used: a 3rd degree polynomial growth function or a logistic growth function.
3rd degree polynomial growth function:

$$Growth_{i,n,p} = dist_{i,n,p} * \left\{ r_i^0 + r_i^1 * \left[\sum_n CB_{i,n}^{year}\right]^1 - r_i^2 * \left[\sum_n CB_{i,n}^{year}\right]^2 + r_i^3 * \left[\sum_n CB_{i,n}^{year}\right]^3 \right\}$$

Logistic growth function:

$$Growth_{i,n,p} = dist_{i,n,p} * \left\{ Growth_{i,}^0 * \frac{1 - CB_{i,n}^{year}}{cap_{i,n}} \right\}$$

<u>Balance equations: TAC</u>
In case a species is managed by quotas, an extra balance equation is added to the model which states that the total catch of the segment minus over quota discards has to be lower than the available quota. Depending on the selected policy scenario over quota discards will either be allowed to be positive or will be kept at zero level.

$$\sum_{n,p} (Catch_{i,j,n,p} - Disc_{i,j,n,p}) \leq TAC_i * tsh_{i,j}$$

In long term management plans a target fishing mortality is defined to reach a sustainable catch. This target mortality is used to calculate the sustainable TAC. First of all the model calculates the current fishing mortality as the total catch divided by the total biomass.

$$F_i = \frac{\sum_{j,n,p} Catch_{i,j,n,p} * \frac{1}{\sum_j csh_{i,j}}}{\sum_n CB_{i,n}^{year}}$$

If the fishing mortality is above the target mortality the quota need to be reduced. However in most long term management plans an optimal path towards the target fishing mortality is defined. For example in the flatfish management plan in the North Sea, the fishing mortality should be reduced by 10% every year until the target mortality is reached.
In the model this is taken into account in the following equation:

If $F_i \geq F_i^{tar}$ $\quad F_i^{tar} = F_i * fsh_i$

Where fsh_i is a fixed percentage depending on value mentioned in the management plan.

Based on the target fishing mortality the model calculates the sustainable TAC, using the Baranov function (Lassen, 2000).

$$TAC_i = \sum_{n,p} \left[CB_{i,n}^{year} * (1 - e^{-F_i^{tar}}) \right]$$

Although not included in this equation, the model allows for a limit on yearly changes in the TAC if this is defined in the long term management plan. For example in the flat fish management plan North Sea the yearly changes of the TAC cannot exceed 15%. If the sustainable TAC exceeds the 15% change the change will be cut of at 15% of last years TAC.

Price elasticity

Fish prices of species i in period p are based on the prices of those species in the same period the previous year adapted by price elasticity. However, this is only relevant if the fishery lands a significant share of the total supply of a species. Setting price elasticity at zero leads to constant prices. By linking the price of a species in a certain period with the price of the species in that period a year before, the model includes seasonal effects in the prices. However it is implicitly assumed that these seasonal effects will not change apart from changes due to the price elasticity.

The price per species is calculated as follows:

$$price_{i,j,p}^{fish} = price_{i,j,p}^{fish} * \frac{\sum_j Land_{i,j,p}}{\sum_j Land_{i,j,p}^{year-1}}$$

Results

Case study description

The case study includes 3 Dutch fleet segments (NL_TBB_1224, NL_TBB_2440 and NL_TBB_40XX). These fleet segments can target either flatfish (sole and plaice) or shrimps. We have divided the North Sea into 152 areas. The spatial repartition of the Dutch fishing fleets targeting flatfish and shrimp in the North Sea over the different areas is shown in Figure 69. The smaller beamtrawlers (NL_TBB_1224) are more concentrated along the coast while larger beamtrawlers (NL_TBB_2440 and NL_TBB_40XX) spread their effort over the all North Sea. The distribution of the fishing effort of the fleets is explained by the distribution of their target species (Figure 70).

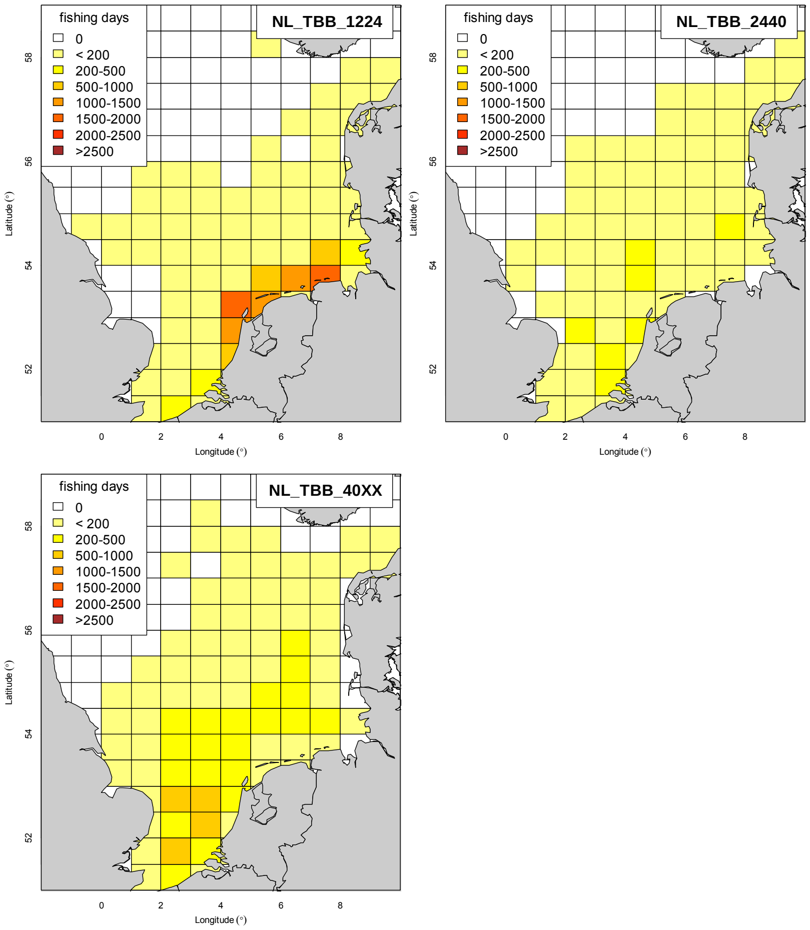


Figure 69. Initial fishing effort distribution in fishing days for the 3 fleets in the case study.

The three target species investigated show also different degrees of aggregation. While legal size sole and plaice are distributed over the all North Sea with some areas with larger concentration of plaice in the middle North Sea (source IMARES growth model, WP2.2), shrimp is concentrated along the coast (source: German and Dutch CPUEs). The importance of the three studied species for the three fleets can be seen on figure 3. Three profiles can be identified based on the value of the landings per species: the Dutch small beamtrawlers rely mainly on shrimp although sole and other species are also contributing to the revenue the large Dutch beamtrawlers target virtually no shrimp and sole and plaice represent the majority of their revenue. Area closures will likely have different impacts on the fleets depending on the location of the areas closed.

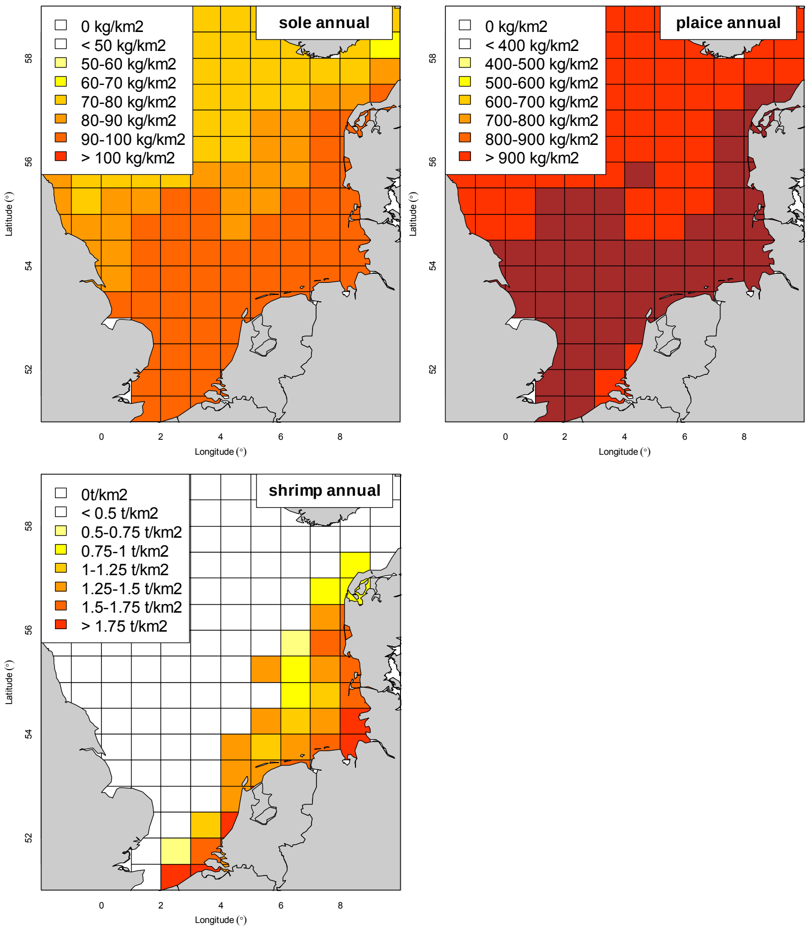


Figure 70. Initial annual species distribution for sole, plaice and shrimps.

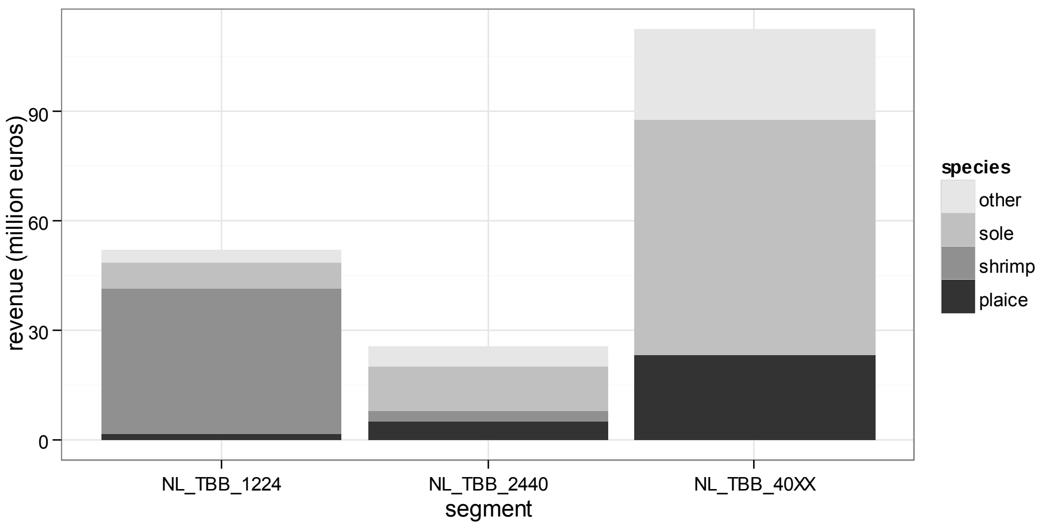


Figure 71. Initial source of revenue per species for the six fishing fleets based on the observation of the activities of the different fleets included in the study.

The closures described in table 1 and in section B.1 of this deliverable are translated into partial closures of fishing grounds. Here ICES rectangles are used as potential fishing choices that are closed proportionally to the surface at sea covered by the area closed (Figure 72). In the scenarios, closures are implemented from 2013 on and have an access restriction to a proportion of the biomass being equal to the proportion of the area closed. No spill-over effect is assumed within a year but the biomass of the species is re-distributed over all areas at the beginning of the year.

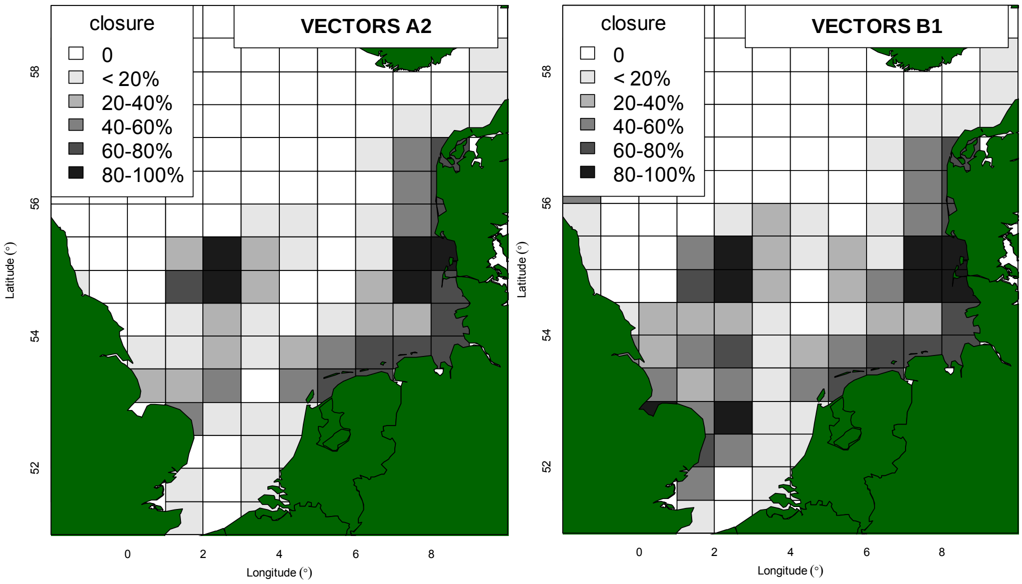


Figure 72. Closure scenarios as proportion of the areas at sea

Results

The results of the scenarios will be compared to a base-case scenario, a sort of "business as usually" where the trends noticeable in the base data (years 2008 to 2010) are projected towards the future. Thus we will be able to show how the scenarios with regard to limitation in fishing space and changes in fish prices and fuel prices impact the results specifically.

The future performances of the fleets in a status quo situation are compared to the predicted performances in case of closures implemented in 2013. Profitability of the shrimpers fleet is hardly impacted by fishing closures (Figure 73). The flatfish fleets are impacted with different responses. For Dutch beamtrawlers 24 to 40m, the closures of the A2 scenario lead to an increase in profit. This is due to the increase in plaice biomass, protected with the closures (Figure 74). For the beamtrawlers larger than 40m that have high fuel consumption, the increase in plaice does not compensate the increase in fuel price. The B1 closures lead to a drop in profit for the large beamtrawlers that must go fishing further. They partly switch to areas with a larger plaice stock, thus catching more plaice. This slightly decreases the biomass of plaice in the first years. The B1 closures also leads to a lower profit than the basecase for the beamtrawlers 24-40m in the later years mainly because this segments also needs to find further fishing grounds thus increasing their fuel cost. However it is important to keep in mind that the economic impact of the measures are limited, less than 1% for the larger beamtrawlers and between 1% and 2% for the other segments.

In addition to the reduction in profit the scenarios lead to an increase of fishing density (Figure 75).

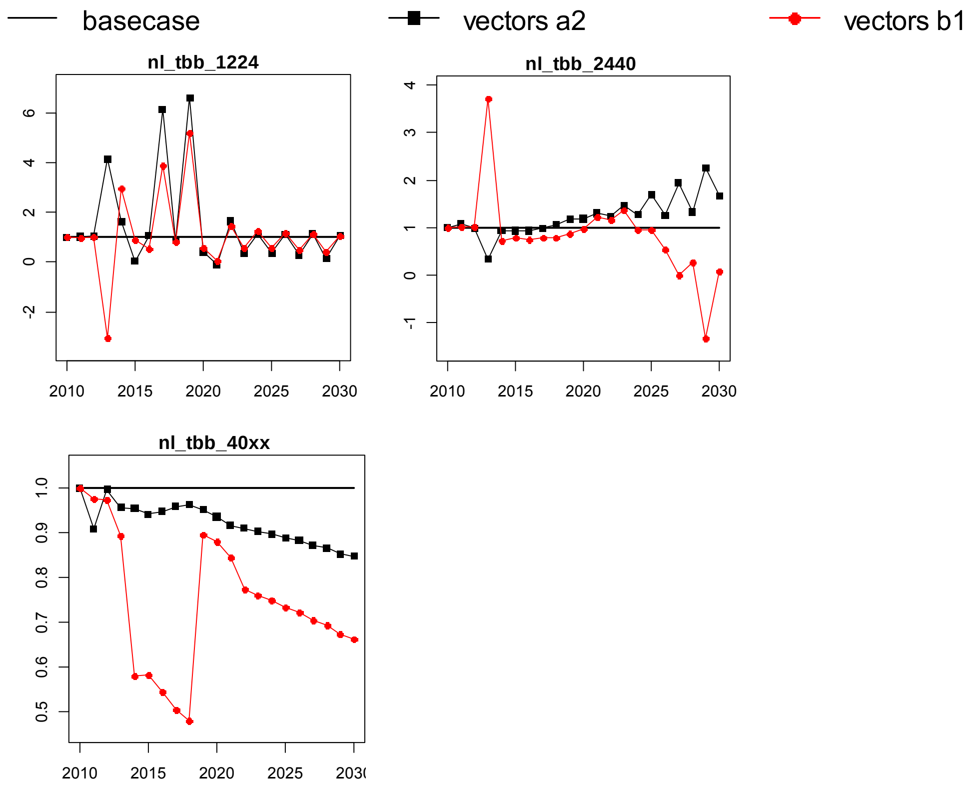


Figure 73. Profit of the three fleets for the two scenarios relative to the basecase same scale all segments?

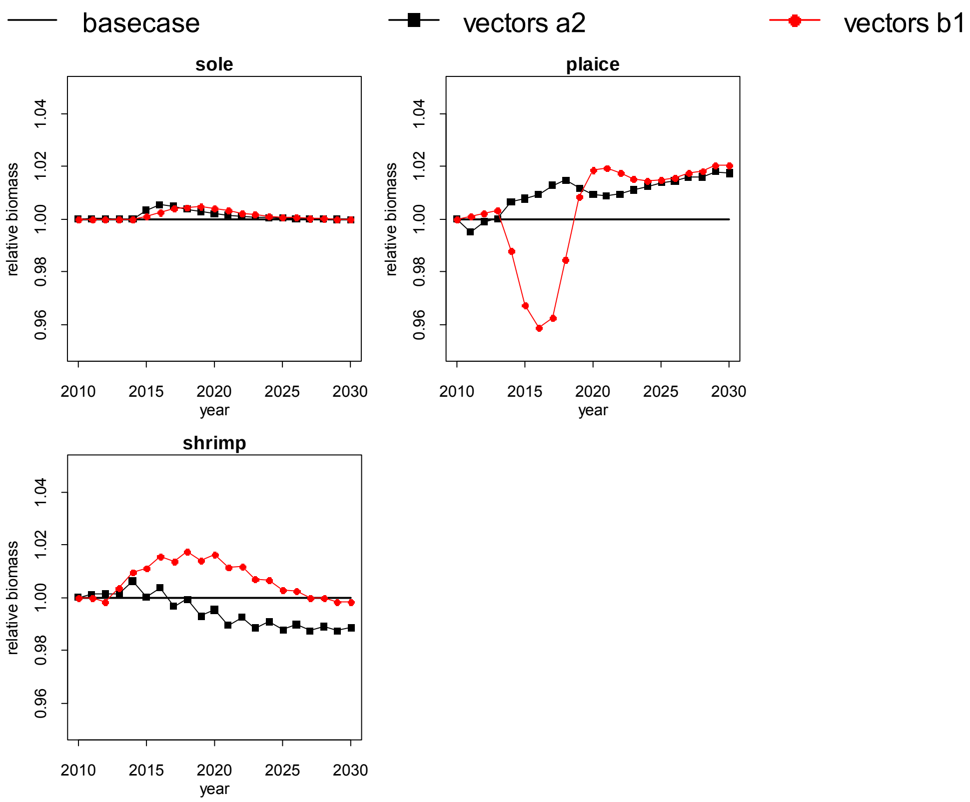


Figure 74. Biomass of sole, plaice and shrimp for the two scenarios relative to the base case

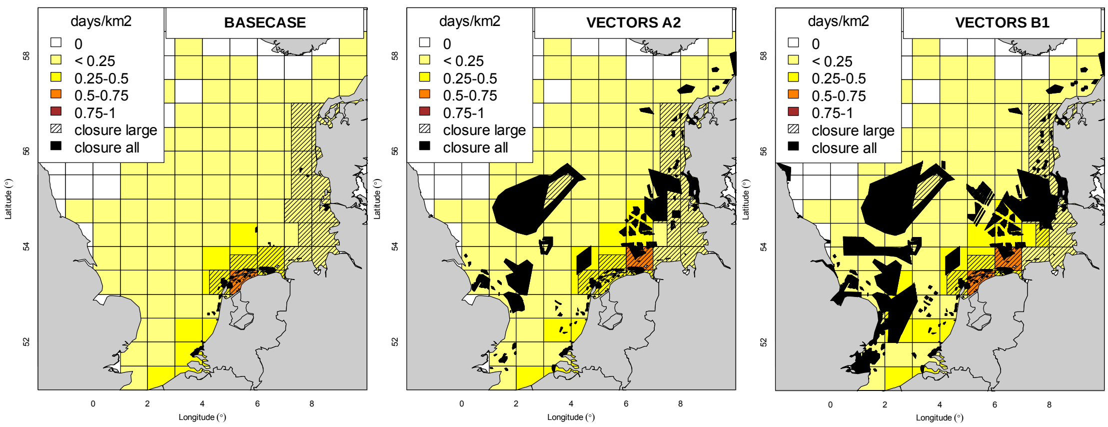


Figure 75. Maps of fishing intensity by ICES rectangle for the basecase and the two scenarios other scale to see some more differences between scenarios?

Discussion

The projections to 2030 of the Dutch beamtrawl fleets show a financial picture that is more positive than what when looking at the static distribution of fishing and the individual stress levels (see section B.1 this deliverable). The projections of FISHRENT show a lower profit for the scenarios compared to the basecase for the large beamtrawlers. However the financial impact is small, less than 1% difference to the results without closures and price changes.

The results show that the fishing fleet will develop similarly as compared to the business as usual scenario. The fishing fleet is not expected to be reduced further due to the extra closures and the expected price increases because the extra financial costs due to the measures is so small. The fleet is mobile enough to adjust to the new fishing limits. Apart from that, the stock of both plaice and sole is recovering fully. Therefore, the increase of the revenue of the fishing fleet due to the increase of catch of sole and plaice is offsetting the higher fuel cost for a large part.

Overall the stock is more protected due to the closures. However the fishing intensity in some areas increases substantially. Therefore since costs of crowding are not included in this analysis, we may slightly underestimate the financial cost of the closures. The financial impact will most probably be somewhere between the results of this analysis and the individual stress level analysis.

2.3 Fishing fleets competing for space with other sectors of activity in the Baltic Sea: application of the DISPLACE spatially-explicit IBM model

The following study is due to be published as a paper with the following reference:
Bastardie, F., Nielsen, J.R., and Miethe, T. 2013. DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement – integrating underlying fish population models. Canadian Journal of Fisheries and Aquatic Sciences, in press; Advance Access DOI: 10.1139/cjfas-2013-0126.

DISPLACE is an individual-based model (IBM) which on a per-vessel basis covers several fisheries and stocks (Bastardie *et al.* 2013; www.displace-project.org). It is a benchmark tool capable of integrating fishermen's decision-making processes when they face changes in fisheries management, economic factors influencing their fishery and economic viability on an individual business basis, as well as changes in the underlying stock dynamics, including spatial and seasonal patterns in resource availability. IBMs are expected to provide a better and more precise prediction of the overall operating costs to operate the vessel and run the business more economically efficiently. This is because the fishing operation costs are modelled explicitly according to individual effort and fishing power. The coupling of the vessel IBM model with resource dynamics and the consequences of fishing scenarios on both fish populations and fishing fleets and fisheries (métiers) avoid a major shortcoming when resources are modelled as instantly renewable between harvesting seasons, as it minimizes the risks for local depletion, serious overexploitation, and potential collapse of the resource.

The combination of the evolution of the resources and their distribution with the spatial allocation of the fishing effort and fishing power by different vessels related to individual fishermen habits, forced re-locations or opportunistic behaviours, e.g. based on the individual experienced catch rate, create system dynamics which are very complex and difficult to handle analytically. Hence, the purpose of the DISPLACE model is to combine the fishing activity and resource dynamics with very high resolution in time, space and fishing units, which is rarely done although in literature it is recognized as necessary. That is, to take into account fish population responses to fishing and fishermen behaviour, impacting on local scale and on a single fishing operation level, in the assessment of various management actions. The DISPLACE model has the primary goal of identifying suboptimal and inefficient regulations by scenario evaluation including, e.g., the effects of fishing closures, both in economic and biological terms as well as in relation to energy efficiency in terms of fuel use.

The DISPLACE model combines a spatially explicit size-structured population model of the harvested stocks with an individual-based model of fishing vessels moving over a fishing arena or resting at ports at an hourly time step. The fishing arena is discrete and is defined as a graph (a set of vertices and edges;Figure 76) to facilitate the modelling of individual vessel movements and directed individual decisions. For the conditioning of the vessel-operating model in DISPLACE, the vessel-specific lists of visited harbours and fishing grounds and the frequency of the number of visits to each of them are obtained by linking the observed continuous displacements (from satellite VMS data) to the discrete graph nodes.

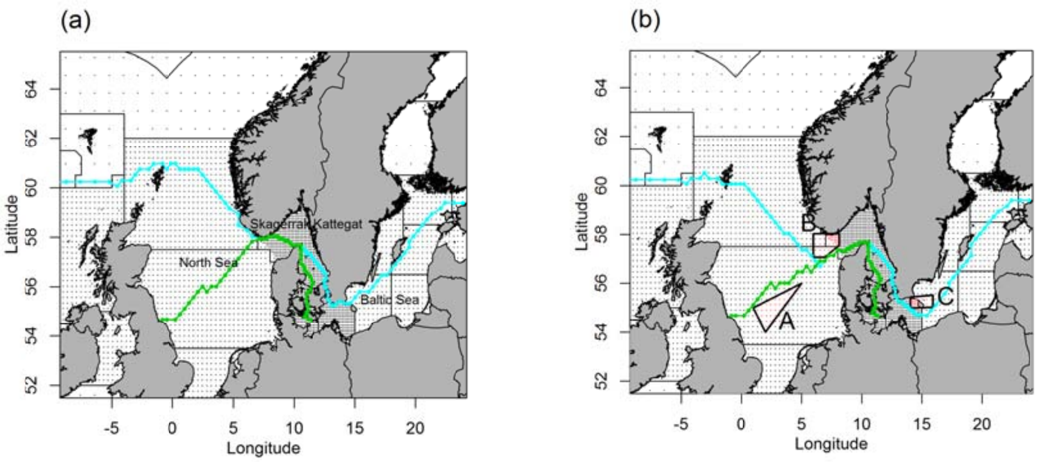


Figure 76. Overview of the fishing arena around Denmark and Germany with the set of nodes constituting the underlying graph and network on which the vessels can move in DISPLACE. The two shortest paths between a departure and an arrival node are shown for illustration purposes, a) by default and b) when area-based fisheries management applies (A-Dogger Bank, B- Norwegian deep, C-Bornholm deep) showing area avoidance. Source: Bastardie et al. (2013).

The DISPLACE model documents and implements the dynamics of 16 commercially important fish stocks for the North Sea and the Baltic Sea (Figure 77). Because these stocks have a spatial and seasonal structure the abundance of these stocks is modelled explicitly to obtain higher resolution spatially as well as disaggregated quarter-based abundance surfaces. This is based on a) the availability of detailed stock structure information from the yearly stock assessments (e.g., stock numbers by age) performed by ICES (www.ices.dk) for each of those stocks in their full stock distribution area, and then b) spatially distributed by length group according to relative catch rates from the ICES IBTS and BITS research vessel surveys (www.ices.dk). In addition, 22 stocks that are not routinely assessed and for which the total stock numbers are mostly unknown (or with too high uncertainty) are accounted for in the catch process (total yield and revenue from those species), while the dynamics for those stocks are not explicitly modelled.

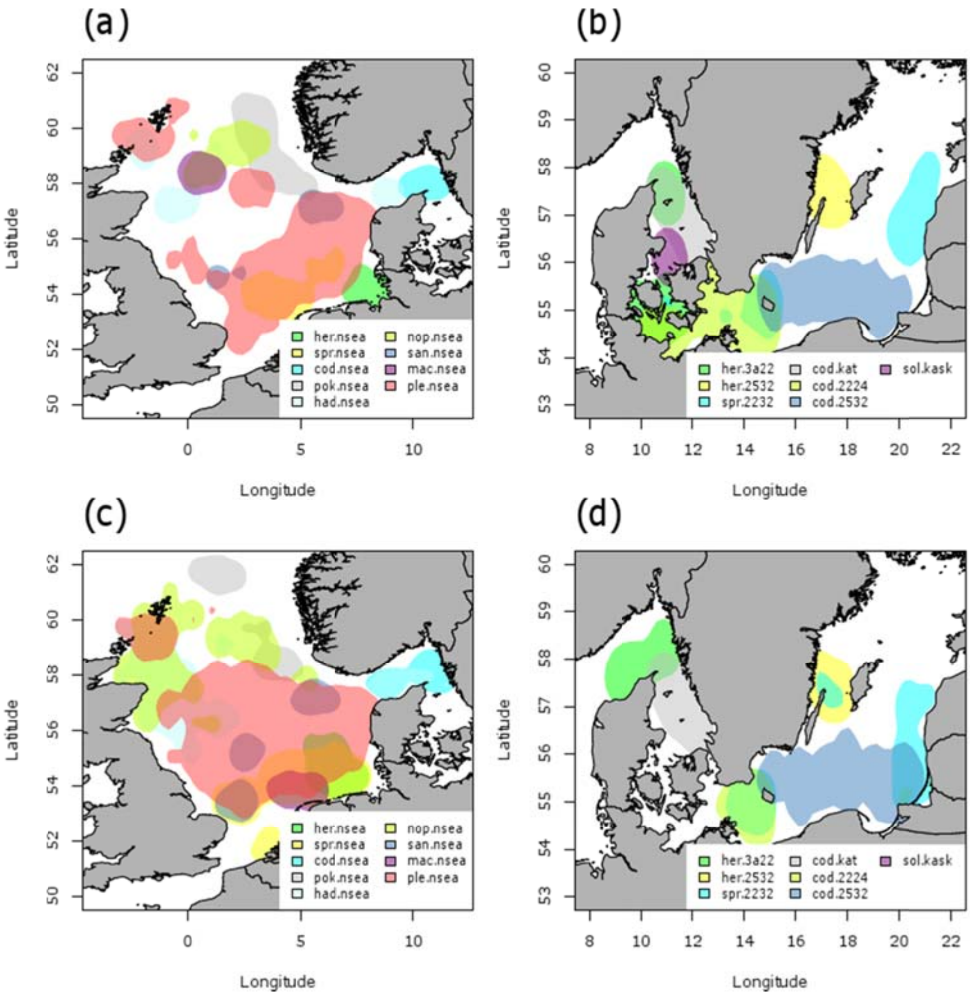


Figure 77. Main bulk of the distribution area of the explicit stocks: (a) and (c) in the North Sea, (b) and (d) in the Baltic Sea, (a) and (b) in the first semester, and (c) and (d) in the second semester of the year. For each stock, the main bulk of the spatial distribution is obtained after applying a kernel density (with sigma=0.5) on the spatial pattern of the stock-specific nodes weighted by the proportion of the stock available on each node (the presence and the availability on each node are obtained from research survey data, see above). Colours are overlapping. Source: Bastardie et al. (2013b).

In the DISPLACE model, each vessel depletes the stocks (on hourly time steps) at certain locations by taking catches as specified by a catch equation. The vessel-specific catch equation is obtained by merging the stock distribution information (spatially explicit availability) with the commercial fishery catch rate from each fishing vessel at a given fishing ground. During the DISPLACE simulation, this regression is used at each hourly time step in a predictive mode to draw the total catches (in weight) from the availability of the resources on each node where a vessel is located and displaying the activity by metier. The local abundances in terms of the number of individuals per stock, node, and size group are then updated removing the catches (in numbers per size group) realized by the active vessel.

In the investigated areas, the stocks are shared resources and the overall fishing pressure is the result of several nations, fleets and métiers active exploitation of the same stocks. For the sake of completeness (i.e., a full feedback loop and coupling on the abundance dynamics of stocks), the simulations also account for the depletion of the stocks which result from the catches of "other" vessels (i.e., "other" vessels are the vessels which are not individually simulated because, e.g., they are not VMS-equipped vessels, are < 15 m in length, or are from other countries) by using spatial landings EU STECF data (http://stecf.jrc.ec.europa.eu/data-reports).

Alternative scenarios affecting the population dynamics can also be evaluated such as management scenarios, different fishing options and/or fishing behaviour options. Multi-year runs from a given year onwards are conducted in the DISPLACE scenario simulation, evaluation and testing. Time series of the abundance per size group are generated for all explicit stocks and start from the initial population numbers provided from ICES stock assessments. The scenarios of alternative hypotheses on fishermen behaviour, implementation of management, vessel optimization behaviour, and alternative population states can be compared relative to the baseline scenario after the five years projections. Indicators of trip planning, landings, gross value added (GAV), and energy efficiency are generated for each simulated vessel. These variables are examined per vessel or on an aggregated basis by fleet or métier.

The DISPLACE model generates VMS-like data (i.e., the recorded geographical vessel positions at every time step of the simulation) and vessel logbook-sales-slips-like data (i.e., the landings in weight and value per species per vessel for every trip as well as the consumed fuel and the operating costs per trip) which are merged at the trip level afterwards according to specific scenario analyses. The stock abundances are also available on each node of the model at given time step. Consequently, the model outcomes allow for the mapping of stock-specific spatial impact surfaces defined as the ratio of the simulated biomass removed by the catching process over the underlying available biomass (Figure 78).
For DISPLACE, extensive efforts have been used to parameterise and dynamical couple both the vessel activities and the biological stock dynamics aspects. For the vessel activities, obtained from the now widely available high resolution VMS-logbook coupled data (Bastardie *et al.* 2010b) for vessel movements, the individual parameterisation is attainable and informs the specific effort allocation and potential movement of each vessel.

There is a need to better encompass the connection between the micro-scale fishermen decisions and their economic causes and consequences at the macro-scale level (e.g. via the stocks and fish market dynamics) when evaluating the economic viability of the fishing sector and the sustainability of the marine ecosystems (stocks). In the DISPLACE model, vessels are simulated individually to visit their own specific grounds and ports at their own frequency which regenerates the individual fishing variability otherwise usually encapsulated into a regional aggregation. If the model complexity is increased, the model constitutes a support tool for incorporating the best available data on biological and fisheries dynamics in a unified framework. Besides this, further dynamics and investigations of the socio-economic drivers of the individual vessel activities and their consequences are expected to emerge. This is among other from the outcomes of questionnaire surveys made on Danish fishermen who were recently asked in detail (Bastardie *et al.* 2013a) on how and on what basis they make their decisions when planning and conducting a fishing trip. The questionnaire outcomes can guide and improve the assessment of the potential non-linear effects of fisherman choices, e.g. when they respond to fluctuations in target stock abundances and densities and/or regulations and/or signals from the fish markets and the fuel prices.

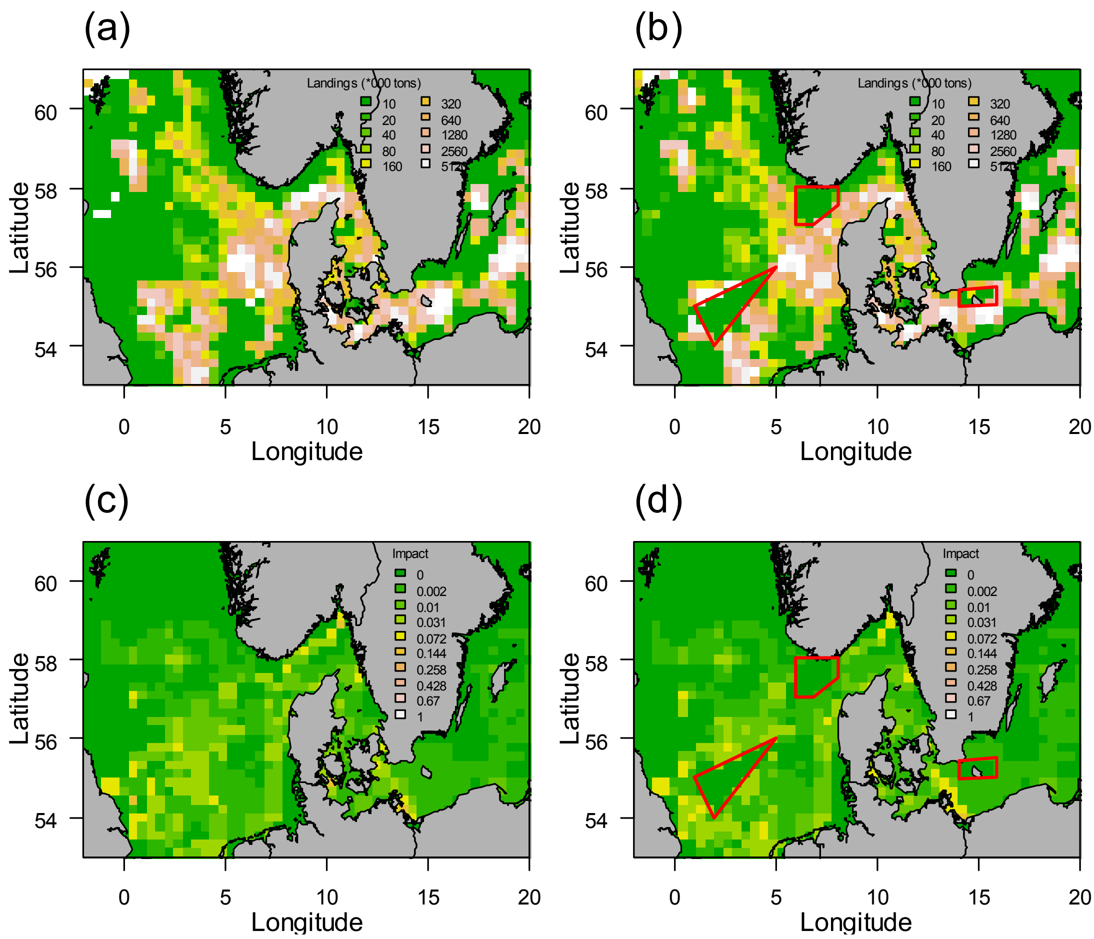


Figure 78. Simulated origin of (all species confounded) landings from active Danish and German vessels across the region per block (cell) of 29 x 25 km (0.45 by 0.225 degrees) obtained after merging per trip the simulated individual tracks with the simulated landings. (a) the baseline scenario; (b) the closure scenario, which implement a set of three closed areas and assumes the individual displacement of effort toward areas with high catch rates specifically to each vessel; (c) impact on cod stocks per cell (i.e., ratio of the removed biomass during January of the final year over the underlying available biomass at the beginning of the final year) for the baseline scenario; (d) impact on cod stocks per cell for the closure scenario. Source: Bastardie et al. (2013b).

Modelling the interactions between fishery and stock dynamics as well as the economic fishery importance on a highly spatial disaggregated scale, is useful in a context of broader spatial planning, marine management, and stakeholder involvement. It is important to develop supporting tools for impact evaluations that can inform all parties (scientists, stakeholders, and managers) on the overall fishing sector dynamics on a highly disaggregated scale to develop a collective understanding and common discussion platform based on quantitative predictions of impacts and beneficial/detrimental effects of any new spatial marine planning project.

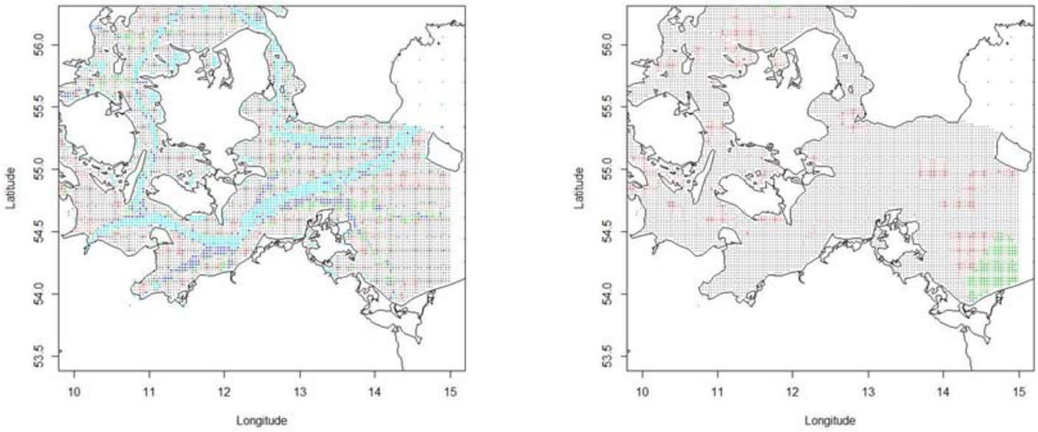


Figure 79. Spatial occupation per node in DISPLACE e.g. (left) commercial shipping traffic (from AIS signal, source: HELCOM) or (right) military areas, NATURA 2000, wind farms, etc. (source: DTU-Aqua).

While some activities are by nature spatially limited (e.g. by suitable bottom types, management, etc.), it is likely that other uses of the sea will further constrain the possibilities of displacing each vessel's fishing activities. The impact assessment and scenario evaluation of wider marine cross-sector use, exploitation of the marine environment, and competition for space can be considered and integrated in the DISPLACE spatial explicit evaluation tool using economic performance and impact as a potential common denominator.

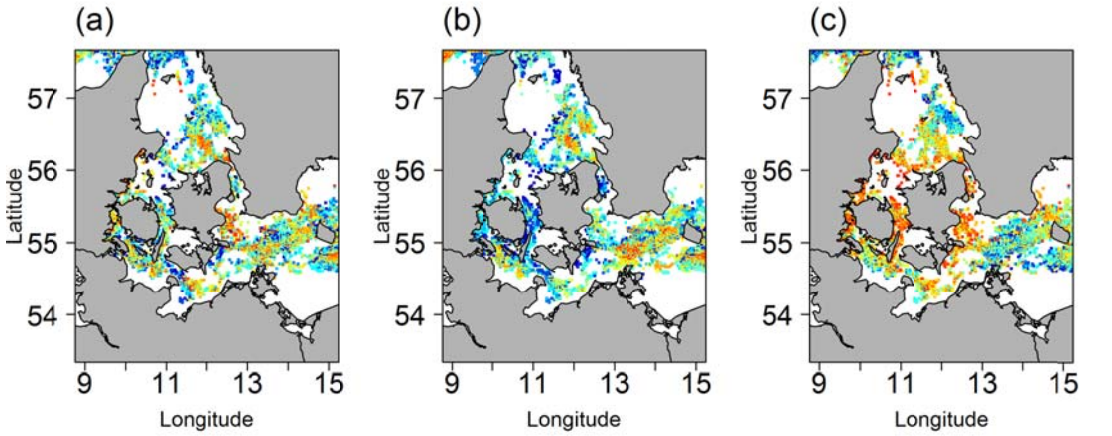


Figure 80. Three indices of spatial use by the Danish vessels (>12m) visiting the Kattegat and the Baltic Sea in 2012, (a) contribution of each cell to the total landing revenue, (b) revenue of the vessel visiting the cells over the total revenue, and (c) revenue realized on the cells by the visiting vessels over the total revenue of the same vessels. Note that the index 'a' decomposes into indices 'b' and 'c'. The gradient colour shows low (blue) up to high (red) index values. After Bastardie et al 2010b.

Work is on-going is to apply and downscale the DISPLACE model to the commercially important and busy Western Baltic marine area where several utilisations of the sea currently coexist (Figure 79). In line with this it is evaluated to which extent the international plans for offshore wind farms in the Baltic area are affecting the fishing opportunities per activity and fishing community in the vicinity of the planned wind farm sites (Figure 80 and Figure 81).

Hence, preliminary data mining shows that the planned offshore wind farms in the area do not really interfere with important fishing grounds for the Danish fisheries (Figure 81). A notable exception is the large 'Kriegers Flak' site (where turbines that will be shared between Denmark, Germany and Sweden). A wind farm here will impact important existing fishing grounds.

Indices on Figure 81 reveal that this area is not really an important area in terms of total revenue at the scale of the entire Danish fisheries because it is not visited by "big players". By contrast the area is important for a large portion of vessels (likely conducting small scale fisheries) which realise a significant portion of their total 2012 revenue in the designated area. Accordingly, it will impact many fishing businesses and the local societies. If this impact leads to major disruption of the fishing activities, major consequences on the population dynamics should be further investigated by applying the DISPLACE model.

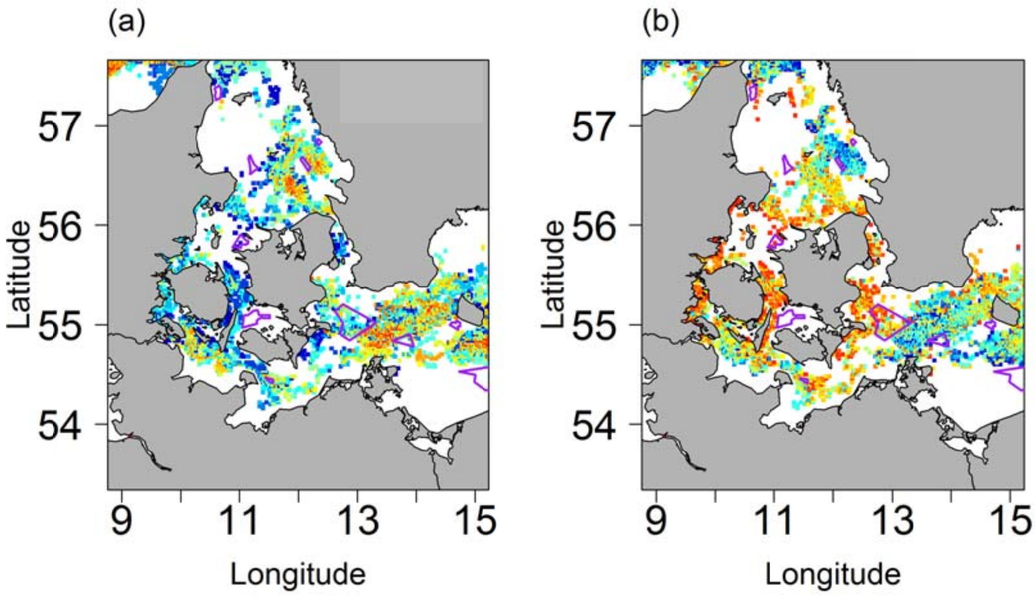


Figure 81. Indices 'b' and 'c' (same as defined in Figure 80 caption) with the planned (from 2013) wind farms given in purple polygons (source: compiled by DTU-Aqua).

The DISPLACE model is currently parameterized to evaluate whether the impacted vessels are able to cope with such spatial marine planning in form of possible displacement and whether vessels will likely reallocate their fishing effort on the surrounding grounds. The evaluation will cover the implications in terms of individual profitability, and also in terms of the sustainability of the exploitation of the main commercial stocks in the area (i.e. sprat, herring, cod and flatfish) and possibly the likely effect on the benthic communities from redirected bottom-disturbing activities. Integration of the Swedish and German vessels (also operating in the area) on top of the Danish ones is also planned to expand the impact evaluation.

3 Conclusions

The main objectives of the research carried out in the WP2.3 work package were, (1) to identify and quantify the key drivers of fishers' behaviour interacting with other fleets and other sectors of activity operating in the same maritime domain and also, (2) to forecast fishing effort allocation in response to additional spatial or resource-based constraints due to the implementation of a new sector of activity, closed areas, or other management measures. The WP2.3 team has contributed to these objectives by, (1) collating an innovative combination of cross-sectoral data, (2) stimulating methodological advances, either in terms of mathematical developments, or innovative applications of existing methods and, (3) producing a large amount of innovative research results of interest to research scientists, advice-givers and decision-makers.

Considerable efforts were first dedicated by the WP2.3 team to collate data reflecting human offshore activities, using a consistent exchange format across all countries where possible. The reason for adopting a common exchange format was to allow the application of a quantitative method initially developed for one case study to others with little adjustments and without breaching data confidentiality agreements. This approach enabled application of the discrete-choice models developed in A.1.2 and the other spatial approaches developed in Section A.1.3 to a variety of French, English and Dutch fleets in the Eastern Channel and the North Sea. Likewise, adopting a common exchange format facilitated the parameterization of the forecast models used to evaluate the short-term (ISLA, Section B.1) and the medium-term (FISHRENT, Section B.2.2) economic effects of closed areas and/or the implementation of new windfarm plants in the North Sea. These modelling approaches could then be applied to several North Sea countries' fleets without exchanging datasets: ISLA was applied to both Dutch and German fleets, and FISHRENT to the Dutch, German, English, French and Danish fleets. Importantly also, an effort of standardization was made in designing the questionnaires intended to the different semi-structured interviews conducted with French, English and Dutch fishers in the Eastern Channel and the German Bight (Section A.2) and, more generally, with various French, English and Polish stakeholders belonging to different sectors of activity in the Eastern Channel, the Dogger Bank and the Gdansk Bay (Section A.3).

The data exchange formats used to collect fisheries information at various spatial resolutions were slightly adjusted from the EFLALO and TACSAT formats that were developed in previous EU-funded projects (e.g., FP5 TECTAC, FP6 CAFÉ, FP6 AFRAME) and are nowadays widely used in relation to the EU Data Collection Framework (Hintzen et al. 2012). In addition to the existing EFLALO and TACSAT (and of EFLALO++ resulting from the combination of these two), two new data exchange formats were created to collate information on the pressure exerted on fishing activities by other human uses or closed areas, either dynamically using the ARBRE-DYN format (the pressure is then measured by a time-dependent metric, e.g., aggregate extraction intensity, maritime traffic density), or statically using the ARBRE-STAT format (the pressure is then measured by the time-invariant spatial overlap exerted by a windfarm plant or by closed areas). We suggest that the new ARBRE-DYN and ARBRE-STAT formats should be further tested and subsequently considered as plausible standards for collating information on other sectors of activity impacting fishing fleets, within the Common Fisheries Policy (e.g., through the Data Collection Framework) but also the Marine Strategy Framework Directive.

Quantitative and qualitative methodological approaches have been conducted to improve the understanding of the processes underpinning the behaviour of human agents operating and interacting in a common maritime domain, with a particular focus on fishing activities.

Innovative methodological approaches, building on the concept of hidden Markov chains (HMC), have first been developed to model vessel trajectories. HMC were used for the first time by Vermard et al. (2010) to discriminate between steaming and fishing. Substantial mathematical developments have been brought about by the VECTORS WP2.3 team to improve that approach. In Section 1.1.1, vessels movements are modelled by a discrete time solution of a (continuous time) stochastic differential equation on vectorial speeds. In Section 1.1.2, HMC were used in an original way, to not only discriminate between fishing and steaming, but also for the first time to discriminate between métiers and /or gears operated, with some success.

Discrete-choice models building in a random utility function (RUMs) have now been widely used in fleet dynamics and effort allocation studies (Holland and Sutinen 1999; Hutton et al. 2004; Vermard et al. 2008; Marchal et al. 2009). In these studies, the main drivers of fishing behaviour considered were economic opportunities and traditions, and these appeared indeed to determine spatial effort allocation. Similar RUMs were applied in Sections A.1.2.1, A.1.2.2, A.1.2.3 and A.1.2.4 to a variety of French, English and Dutch fleets operating in the Eastern Channel or the North Sea, but with additional explanatory variables reflecting spatial interactions/competitions with other fishing fleets, maritime traffic, aggregate extractions, wind farms and closed areas. To the best of our knowledge, it is the first time the impact of competition with other fishing and non-fishing sectors on fleet dynamics has been investigated using discrete-choice models. The results of these investigations indicated that traditions (reflected by past effort allocation) and economic opportunism are driving factors for effort allocation in both the Eastern Channel and the North Sea for the French, English and Dutch fleets under investigation. However, discrete-choice models have also been applied in an innovative way to evaluate the impact of spatial interactions (effects of other human uses and closed areas) on fleet dynamics. Alternative spatial approaches have been complementarily conducted in the Eastern Channel to investigate more specifically, at a finer spatial scale resolution than that considered in the RUMs, the spatial interactions between, (1) fishing activities and aggregate extractions (Section A.1.3.1), (2) fishing activities and maritime traffic (Section A.1.3.2). The results of the quantitative approaches pursued to analyse (indirectly) the key drivers of fishers' behaviour (Sections A.1.2 and A.1.3) were then contrasted with the outcomes of semi-structured interviews carried out in the Eastern Channel and the North Sea (Sections A.2 and A.3). We comment below on the different fishers' decision-making drivers, based on the outcomes of both quantitative and qualitative approaches.

The impact of traditions and expected profit could be demonstrated in almost all cases (French, English and Dutch fleets operating in the Eastern Channel, Dutch fleets operating in the German Bight), bearing out the outcomes of previous studies applied to other fisheries worldwide (Holland and Sutinen 1999; Hutton et al. 2004; Vermard et al. 2008; Marchal et al. 2009). These results were also largely confirmed by the French and Dutch stakeholders interviewed in the English Channel and German Bight respectively.

The effects of closed areas on fishing activities were investigated in the Eastern Channel. In the Eastern Channel access to the 6-mile and 12-mile coastal areas is restricted. As expected, these restricted areas had a negative impact on English dredgers and Dutch fly-shooters. The effect on the French vessels existed but was clearly fleet-dependent. This could reflect either that fishing fleets are not uniformly affected by the restricted areas, or the spatial data resolution was too coarse, or both. It was not possible to investigate in a similar quantitative way the impact of closed areas on fishing activities outside the Eastern Channel. Still, the impact of conservation and closed areas on fishing activities was confirmed directly by fishers operating in all the case study areas: Eastern Channel, German Bight, Dogger Bank and Gdansk Bay.

Considering the spatial interactions between fishing activities and other sectors of activity, it should first be noted that fishers may interact with other fishers. In the Eastern Channel, the outcomes from discrete-choice models suggested that French dredgers interacted positively with English beamers and dredgers, revealing they're fishing on the same grounds when targeting (and competing for) scallops. English dredgers and Dutch fly-shooters were also shown to interact with other fleets when operating in the Eastern Channel. In the North Sea, the presence of other fleets impacted Dutch fleets differently. The interaction was positive when the fleets shared the same fishing ground (e.g., Dutch and German fleets in the German Bight), and negative when they fished on separate grounds and possibly target different species (e.g., Dutch and Danish fleets in the German Bight). Spatial competition between fishers was confirmed by interviewing French and Dutch fishers operating in the Eastern Channel and the German Bight respectively.

The impact of maritime traffic on fishers' behaviour was investigated in the Eastern Channel using a variety of approaches. The outcomes of discrete-choice models indicated that maritime traffic adversely influenced the English dredgers. The spatial distribution of Dutch fly-shooters did not appear to be substantially affected by maritime traffic. Many, but not all, of the French fleets under investigation tended to avoid shipping lanes. The relationship between fishing activities and maritime traffic was more complex to interpret for the French fleets than for the English fleets, likely due to the coarser spatial resolution of the data used in the French case. An effort was then made to better understand, at a finer spatial scale, the specific impact of shipping on French vessels. For example, in the red mullet fishery, fishing vessels would avoid shipping lanes when traffic intensity was high and stock density low or medium. However, when stock density was high, their spatial allocation did not appear to be influenced by the intensity of maritime traffic. In that case the risk of being caught in an accident within the shipping lanes was offset by the expected profit. The interviews conducted in the Eastern Channel confirmed that maritime traffic has been a constraint for fishing activities, but less so nowadays due to the decrease in the number of trawlers. The impact of maritime traffic on fishing activities could not be evaluated quantitatively in the German Bight. The Dutch fishers interviewed in the German Bight area indicated, however, that shipping and transport adversely affected their activities. In other regions (Dogger Bank, Gdansk Bay), maritime traffic did not appear as a big issue to the fishers being interviewed. Overall, it may be concluded that the impact of traffic intensity has generally a repelling effect on the distribution of fishing fleets in the Eastern Channel, likely due to the particularly high traffic intensity in this region. However, this effect is probably not linear, and also depends on the spatial and temporal scale of the analysis, on the fleet, and on the targeted species. Also, it is not possible to extrapolate the impact of maritime traffic as analysed in the Eastern Channel to other case studies.

As suggested from the discrete-choice modelling analyses, over the whole Eastern Channel, aggregate extraction has a repelling effect on English scallop dredgers. However, the spatial and time series analyses carried out at a more localized level (i.e., for each aggregate extraction site independently), and for a wider range of English and French fleets, suggest that the interactions between aggregate extraction and fishing activities are of a more complex nature. Some fleets (e.g., potters targeting whelks and large crustaceans, netters targeting sole, and even scallop dredgers), were attracted to the vicinity of aggregate extraction sites. This could happen either because their target species may temporarily benefit from organic matter in suspension following an extraction (e.g., suspension-feeders or scavengers), or possibly because the aggregate extraction sites have been positioned on the habitats utilized by these species (e.g., scallops). However, this does not suggest that the spatial extent or the dredging intensity of minerals exploitationshould be increased, as these species are believed to be sensitive to aggregate extraction. In the Eastern Channel, the impact of aggregate extraction on fishing activities was confirmed by French and English fishers operating in this area. Overall, while the results of the discrete-choice models indicated a generally straightforward (and generally repelling) effect of aggregate extraction intensity on the distribution of fishing effort, the results from the in-depth study were indicative of a more complex relationship. Aggregate extractions were not perceived as an issue in the North Sea and the Gdansk Bay.

The impact of other sectors of activity (e.g., wind farms, oil/gas platforms) on fishing activities could not be investigated quantitatively. Wind farms were not operated yet in the regions being investigated at the time of writing. Still, the fishers' interviews conducted in all regions indicated that wind farms were seen as a concern to them in the Eastern Channel, the German Bight and the Gdansk Bay, but less so in the Dogger Bank. Oil and gas platforms are already operating in the North Sea, and these are considered as an issue by some fishers operating in this region.

The semi-structured interviews also indicated how the different stakeholder groups interacted together. In some areas, competing stakeholders have found ways to work together for integrated spatial management, such as in the English Channel and the Dogger Bank, in others such as the Gulf of Gdansk, they are just learning to work together. In the UK, especially, a great deal of effort has been put into stakeholder involvement such as with their Balanced Seas project. The primary complaint with this was that timelines were too short; once stakeholders had learned to communicate and work together, then the project ended before progress could be made. Additionally some stakeholders, in this case conservationists and the aggregate extraction industry, came together to push for similar aims, showing that some alliances can take place even between traditional “competitors.” In the Dogger Bank groups have also come together to manage the area, in this case with the special area of conservation (SAC) management plan, with negotiations taking place between relevant stakeholders in a Dogger Bank Steering Group and with management scenarios proposed to the North Sea RAC. The primary difference with the Dogger Bank is some groups, in this case conservationists, became disillusioned with the processand they have refused to participate further in the process given the expense they incurred, and what they view as too many compromises in favour of industry. In the English Channel, groups in general seem to compromise and come together, despite differences. The conservationist mandate has been strengthened in recent years, but is being tempered by the UK government’s vision for “clean, healthy, safe, productive, and biologically diverse oceans and seas;” consequently pragmatism and compromise is automatically built-in to the system. The UK has also formed statutory bodies whose role is to liaise with industry to help minimize impacts on the environment. In contrast, on the Dogger Bank and in the Gulf of Gdansk, conservationists and other groups appear less willing to compromise, making integrated management much more challenging. In the Dutch situation most consultations are with other federal agencies, major marine industry sectors, and public review of plan documents. The Dutch respondents however don’t think they have any influence on these developments.

A range of forecast models with different structures was then applied to predict the bioeconomic impact on fishing fleets of (quota-induced) resource competition combined with discard restrictions (DSVM, Section B.2.1) and of area-based restrictions (inferred by other fleets, other sectors of activity, and/or closed areas) in the short-term (ISLA, Section B.1) and the medium-term (FISHRENT, Section B.2.2; DISPLACE, Section B.2.3). The discrete-choice models used to estimate fleet dynamics drivers based on historical time series were also applied to provide forecast of effort allocation one year ahead for the French fleets (Section A.1.2.1) and the English scallop dredgers (Section A.1.2.2) operating in the Eastern Channel. Scenarios A2 (“National enterprise” scenario) and B1 (“Global community scenario”), as defined under VECTORS WP1, have been tested using the ISLA and the FISHRENT models in the North Sea, and RUM in the Eastern Channel.

These forecast models can be ranked by increased complexity, which also provides indications on how these should be understood and/or used by marine managers. ISLA is the most simple of those models, providing short-term forecast based on historical data only. ISLA could be used by managers to quickly anticipate the stress fishers may experience in the short term as a result of the installation of a new plant overlapping with their fishing ground (e.g., oil rig, wind farm) or the enforcement of a new closed area. ISLA, however, cannot be used by mangers to predict the effects on fishing effort spatial displacement or the knock-on pressure exerted on marine ecosystem (and on commercial species in particular). The RUM (when applied in predictive mode) and DSVM models are more complex as they explicitly build in fleet dynamics in the form of effort allocation. However, these models do not build in the dynamics of fish populations. These models could be used by managers to evaluate the impact of catch quotas combined with a discard ban (DSVM) or area-based restrictions (RUM) on fishing effort allocation one year ahead. However, in the absence of a biological model, long-term projections cannot be carried out with these models. FISHRENT and DISPLACE are the most complex of the models investigated here. Both account for the dynamics of fishing fleets, fish population, and economics. However, these models are conceptually different: DISPLACE is an IBM working at a fine spatial resolution; FISHRENT is primarily an economic optimization model working at a coarser spatial resolution. Both models could be applied to evaluate the impact of area-based restrictions, in combination with conservation management measures (e.g., catch or effort quotas), on the conservation and economic utilization of fisheries resources. DISPLACE could be considered more particularly by marine managers in charge of organizing spatial planning at a fine resolution. In return, FISHRENT would probably be better suited to evaluate the impact of economic incentives and right-based management (e.g., Individual Transferable Quotas).

The outcomes of VECTORS WP2.3, as presented in this report, will feed in VECTORS WP5.1 dedicated to holistic ecosystem modelling. In the Eastern Channel, the fleet dynamics model developed under Section A.1.2.1 is being integrated into the comprehensive ATLANTIS model. The combined effects of aggregate extraction and fishing activities, as well as their spatial interactions, have also been implemented in the ISIS-Fish model used in WP5.1. In the North Sea, the FISHRENT models are further developed in VECTORS WP3.3 dedicated to economic modelling. Finally, the outcomes of the semi-structured interviews conducted under Sections A.2 and A.3 will contribute to the objectives of VECTORS WP6, particularly with respect to the participation of stakeholders to the science developed within the VECTORS project.

4 References

Abernethy, K.E., Trebilcock, P., Kebede, B., Allison, E.H., and Dulvy, N.K., 2010. Fuelling the decline in UK fishing communities? *ICES Journal of Marine Science*, 67, 1076–1085.

Allison, G.W., Lubchenco, J., and Carr, M.H. 1998. Marine reserves are necessary but not sufficient for marine conservation. *Ecological Applications*, 8, 79–92.

Alverson, D..L, Freeberg, M.H., Murawski, S.A., Pope, G.J. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper 339.

Andersen, B.S., and Christensen, A.-S. 2006. Modelling short-term choice behaviour of Danish fishermen in a mixed fishery. In: Proceedings of the 2005 North American Association of Fisheries Economists Forum (Ed. by U.R. Sumaila, and A. Madsen). *Fisheries Centre Research Reports*, 14, 13−26.

Andersen, B.S., Vermard, Y., Ulrich, C., Hutton, T., and Poos, J.-J. 2010. Challenges in integrating short-term behaviour in a mixed-fishery Management Strategies Evaluation frame: a case study of the North Sea flatfish fishery. *Fisheries Research*, 102, 26−40.

Andersen, B.S., Ulrich, C., Eigaard, O.R., and Christensen, A.-S. 2012. Short-term choice behaviour in a mixed fishery: investigating métier selection in the Danish gillnet fishery. *ICES Journal of Marine Science*, 69, 131–143.

Anderson, J., and Guillen, J. 2009. Annual Economic Report on the EU Fishing Fleet. Office for Official Publications of the European Communities, Luxembourg.

Anon. 2011. High level meeting on banning discards. Brussels 1 March 2011Non paper Brussels: Commission of the European Communities:4 pp.

Barry, J., Boyd, S., and Fryer, R. 2010. Modelling the effects of marine aggregate extraction on benthic assemblages. *Journal of the Marine Biological Association of the United Kingdom*, 90, 105-114.

Bastardie, F., Vinther, M., Nielsen, J.R., Ulrich, C., and Storr-Paulsen, M. 2010a. Stock-based vs. fleet-based evaluation of the multi-annual management plan for the cod stocks in the Baltic Sea. *Fisheries Research*, 101, 188−202.

Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J., and Degel, H. 2010b. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. *Fisheries Research*, 106, 41-53.

Bastardie, F., Nielsen, J.R., Andersen, B.S., and Eigaard, O.R. 2013a. Integrating individual trip planning in energy efficiency - Building decision tree models for Danish fisheries. *Fisheries Research*, 143, 119-130.

Bastardie, F., Nielsen, J.R., and Miethe, T. 2013b. DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement - integrating underlying fish population models. 2013. *Canadian Journal of Fisheries and Aquatic Sciences*, *in press;* Advance Access DOI: 10.1139/cjfas-2013-0126.

Batschelet, E. 1981. Circular Statistics in Biology. London, Academic Press.

Begossi, A. 2001. Mapping spots: fishing areas or territories among islanders of the Atlantic Forest (Brazil). *Regional Environmental Change*, 2, 1–12.

Ben-Akiva, M., and Lerman, S.R. 1985. Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press Series in Transportation Studies. 390.

Bertrand, S., Diaz, E., and Niquen, M. 2004. Interactions between fish and fisher's spatial distribution and behaviour : an empirical study of the anchovy (*Engraulis ringens*) fishery of Peru. *ICES Journal of Marine Science*, 61, 1127–1136.

Bertrand, S., Burgos, J.M., Gerlotto, F., and Atiquipa, J. 2005. Lévy trajectories of Peruvian purse-seiners as an indicator of the spatial distribution of anchovy (*Engraulis ringens*). *ICES Journal of Marine Science*, 62, 477–482.

Bertrand, S., Bertrand, A., Guevara-Carrasco, R., and Gerlotto, F. 2007. Scale-invariant movements of fishermen : The same foraging strategy as natural predators. *Ecological Applications*, 17, 331–337.

Beukers-Stewart, B.D., and Beukers-Stewart, J.S. 2009. Principles for the management of inshore scallop fisheries around the United Kingdom. Report to Natural England, Countryside Council for Wales and Scottish Natural Heritage. University of York.

Biseau, A. 1998. Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. *Aquatic Living Resources*, 11, 119–136.

Bose, S., and Crees-Morris, A. 2009. Stakeholder's views on fisheries compliance: An Australian case study. *Marine Policy*, 33, 248-253.

Botsford, L.W., Micheli, F., and Parma, A.M. 2007. Biological and ecological considerations in the design, implementation and success of MPAs. In Report and Documentation of the Expert Workshop on Marine Protected Areas and Fisheries Management: a Review of Issues and Considerations, Rome, 12–14 June 2006, pp. 109–148. *FAO Fisheries Report*, 825, 332 pp.

Bovet, P., Benhamou, S. 1988. Spatial-analysis of animals movements using a correlated random-walk model. *Journal of Theoretical Biology*, 131, 419–433.

Box, G.E.P., and Jenkins, G.M. 1976. *Time Series Analysis: Forecasting and Control,* San Francisco: Holden-Day.

Boyd, S.E., Rees, H.L. 2003. An examination of the spatial scale of impact on the marine benthos arising from marine aggregate extraction in the central English Channel. *Estuarine, Coastal and Shelf Science*, 57, 1-16.

Boyd, S.E., Limpenny, D.S., Rees, H.L., Cooper, K.M., and Campbell, S. 2003. Preliminary observations of the effects of dredging intensity on the re-colonisation of dredged sediments off the southeast coast of England (Area 222). *Estuarine Coastal and Shelf Science*, 57, 1-16.

Branch, T.A. 2009. How do individual transferable quotas affect marine ecosystems? *Fish and Fisheries*, 10, 39-57

Brand, A.R. 2006. The European scallop fisheries for *Pecten maximus, Aequipecten opercularis* and *Mimachlamys varia*. In: Shumway S, Parsons GJ (eds) Scallops: Biology, Ecology and Aquaculture. Elsevier, Amsterdam, p 1460.

Brillinger, D. 2010. *Handbook of Spatial Statistics*, chapter 26. Chapman and Hall/CRC Handbooks of Modern Statistical Methods. CRC Press.

Browman, H.I., and Stergiou, K.I. 2004. Perspectives on ecosystem-based approaches to the management of marine resources. *Marine Ecology Progress Series,* 274, 269–303.

Buchen, L. 2009. Battling scientists reach consensus on health of global fish stocks. *Nature News*.

Buisman, F.C., Bakker, T., Bos, E., Kuhlman, T., and Poos, J.-J. 2011. Effecten van een verbod op discards in de Nederlandse platvisvisserij. LEi-rapport 2011-014.

Buléon, P., and Shurmer-Smith, L. 2007. Espace Manche, un monde en Europe / Channel Spaces, a world within Europe. Espace Manche Development Initiative (EMDI), INTERREGIIIB ENO, 195 pp.

Campbell, H., Nicholl, R., and Meyer, G. 1993. Search behavior in the purse seine tuna fishery. *Natural Resource Modeling*, 7, 15-35.

Cappell, R. 2001. Economic aspects of discarding - UK case study: Discarding by North Sea Whitefish Trawlers. In: Final report for DG Fish, European Communities, and MAFF. UK: Nautilus Consultants, Edinburgh.

Carpentier, A., Coppin, F., Curet, L., Dauvin, J.-C., Delavenne, J., Dewarumez, J.-M., Dupuis, L., Foveau, A., Garcia, C., Gardel, L., et al. 2009. Channel Habitat Atlas for marine Ressource Management, final report / Atlas des Habitats des Ressources Marines de la Manche Orientale, rapport final (Charm phase II). INTERREG 3a Programme, IFREMER, Boulogne-sur-mer France. 626 pp.

Catchpole, T.L., Frid, C.L.J., and Gray, T.S. 2005. Discarding in the English north-east coast Nephrops norvegicus fishery: the role of social and environmental factors. *Fisheries Research*, 72, 45-54.

Catchpole, T.L., and Gray, T.S. 2010. Reducing discards of fish at sea: a review of European pilot projects. *Journal of Environmental Management*, 91, 717-723.

Cattell, R.B. 1966. The Scree test for the number of factors. *Multivariate Behavioral Research*, 1, 245–276.

Christensen, V., and Pauly, D. 1992. ECOPATH II — a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, 61, 169–185.

Christensen, A.-S., and Raakjær, J., 2006. Fishermen's tactical and strategic decisions: A case study of Danish demersal fisheries. *Fisheries Research*, 81, 258–267.

Clark, C.W., and Butler, R.W. 1999. Fitness components of avian migration: A dynamic model of Western Sandpiper migration. *Evolutionary Ecology Research*, 1, 443-457.

Clark, C.W., and Mangel, M. 2000. Dynamic state variable models in ecology: Methods and applications, Vol. Oxford University Press.

Coglan, L., Pascoe, S., Mardle, S., and Hutton, T. 2004. An analysis of the characteristics of fishers and their behaviour strategies following area closures. *In* Proceedings of the 12th International Conference of the International Institute of Fisheries Economics and Trade (IIFET), 26−29 July 2004. Ed. by Y. Matsuda *et al*. (CD-Rom).

Cooper, K.M. 2005. Cumulative effects of marine aggregate extraction in an area east of the Isle of Wight. A fishing industry perspective. Science Series Technical Report, CEFAS Lowestoft, 126: 28pp. (http://www.cefas.co.uk/publications/techrep/tech126.pdf).

Croissant, Y. 2011. mlogit: multinomial logit model. R package version 0.2-2. http://CRAN.R-project.org/package=mlogit.

Cooper, K.M., Boyd, S.E., Eggleton, J.D., Limpenny, D. S., Rees, H. L., and Vanstaen, K. 2007. Recovery of the seabed following marine aggregate dredging on the Hastings Shingle Bank, SE England. *Estuarine, Coastal and Shelf Science*, 75, 547-558.

Curtis, H., Graham, K. & Rossiter, T. 2006. Options for improving fuel efficiency in the UK fishing fleet. Sea Fish Industry Authority, Edinburgh.

Daan, N. 1997. TAC management in North Sea flatfish fisheries. *Journal of Sea Research*, 37, 321-341.

Dare, P.J., Darby, C.D., Durance, J.A., and Palmer, D.W. 1993. The distribution of scallops, Pecten maximus, in the English Channel and Celtic Sea in relation to hydrographic and substrate features affecting larval dispersal and settlement. In *Proceedings of the 9th International Pectinid Workshop, Nanaimo, BC, Canada*, Vol. 1, pp. 20-27.

Daw, T.M. 2008. Spatial distribution of effort by artisanal fishers: exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. *Fisheries Research*, 90, 17–25.

Defra 2011. Consultation on a new evidence based for a proposed new English scallop order. London:Defra.

Degnbol, P., and Wilson, D.C. 2008. Spatial planning on the North Sea: a case of cross-scale linkages. *Marine Policy*, 32, 189–200.

Depestele, J., Vandemaele, S., Vanhee, W., Polet, H., Torreele, E., Leirs, H., and Vincx, M. 2011. Quantifying causes of discard variability: an indispensable assistance to discard estimation and a paramount need for policy measures. *Ices Journal of Marine Science*, 68, 1719-1725.

Deporte, N., Ulrich, C., Mahévas, S., Demanèche, S., and Bastardie, F., 2012. Regional Métier Definition: a Comparative Investigation of Statistical Methods Using a Workflow Applied to International Otter Trawl Fisheries in the North Sea. *ICES Journal of Marine Science*, 69, 331-342.

Desprez, M. 2000. Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: short and long-term post-dredging restoration. *ICES Journal of Marine Science*, 57, 1428-1438.

Desprez, M., Pearce, B., Le Bot, S. 2010. The biological impact of overflowing sands around a marine aggregate extraction site: Dieppe (eastern English Channel). *ICES Journal of Marine Science*, 67, 270-277.

Desprez, M., Le Bot, S., Duclos, P.-A., de Roton, G., Villanueva, M., Ernande, B., and Lafite, R. 2013. Monitoring the impacts of marine aggregate extraction. Knowledge Synthesis 2012 (GIS SIEGMA). Presses universitaires de Rouen et du Havre, 43 pp.

Diamond, B., and Beukers-Stewart, B.D. 2011. Fisheries Discards in the North Sea: Waste of Resources or a Necessary Evil? *Reviews in Fisheries Science*, 19, 231-245.

Dodge, S., Robert W., and Ehsan F. 2009. Revealing the physics of movement: Comparing the similarity of movement characteristics of different types of moving objects. *Computers, Environment and Urban Systems*, 33, 419-434.

Domenech and Mcfadden 1975. Urban travel demand: A behavioral analysis, with T. Domencich, North Holland: Amsterdam, 1975. Reprinted by The Blackstone Company: Mount Pleasant, MI, 1996.

Dorn, M.W. 2001. Fishing behavior of factory trawlers: a hierarchical model of information processing and decision-making. ICES Journal of Marine Science, 58, 238–252.

Douvere, F. 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine Policy*, 32, 762– 771.

Dowling, N.A., Wilcox, C., Mangel, M., and Pascoe, S. 2012. Assessing opportunity and relocation costs of marine protected areas using a behavioural model of longline fleet dynamics. *Fish and Fisheries*, 13, 139-157.

Drabble, R. 2012. Monitoring of East Channel dredge areas benthic fish population and its implications. *Marine Pollution Bulletin*, 64, 363-372.

Drud, A. 1991. CONOPT—a large scale GRG codeARKI Consulting Development A. S, Bagsvaerd, Denmark.

Dugan, J.E., and Davis, G.E. 1993. Applications of marine refugia to coastal fisheries management. Canadian Journal of Fisheries and Aquatic Sciences, 50, 2029–2042.

Dupont, D.P. 1993. Price Uncertainty, Expectations Formation and Fishers' Location Choices. *Marine Resource Economics* 08.

Earnhart, D. 2002. Combining Revealed and Stated Data to Examine Housing Decisions Using Discrete Choice Analysis. Journal of Urban Economics, 51, 143–169.

Eastwood, P. 2007. Human activities in UK offshore waters: an assessment of direct, physical pressure on the seabed. ICES Journal of Marine Science, 64, 453-463.

EC 1992. Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. Official Journal L 206.

EC 2000. Data Collection Regulation (EC 1543/2000). Official Journal L 176 , 15/07/2000 P. 0001 – 0016.

EC 2003. Directive No. 2244/2003 Laying down detailed provisions regarding satellite-based vessel monitoring systems. Official Journal of the European Union 2003, L333: 17−27.

EC 2004. Council Regulation (EC) No. 423/2004 of 26 February 2004 Establishing measures for the recovery of cod stocks. In: Official Journal of the European Union, L70/8.

EC 2006. Commission Staff Working Paper. Report of the ad-hoc meeting of independent experts on fleet-fishery segmentation. Nantes, France, 12–16 June 2006. 98 pp.

EC 2007. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions", An Integrated Maritime Policy for the European Union, COM (2007) 575 final, Brussels, 10.10.2007.

EC 2008a. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

EC 2008b. Commission regulation (EC) No 665/2008 of 14 July 2008 laying down detailed rules for the application of Council Regulation (EC) No 199/2008 concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. *Official Journal of the European Union* 3.

EC 2008c. Communication from the Commission: Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU. Brussels, 25.11.2008, COM(2008) 791 final.

EC 2008d. Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008 establishing a Framework for Community Action in the Field of Marine Environmental Policy. Official Journal L 164, 25/06/2008 P. 0019 – 0040.

EC 2008e. Council Regulation No. 949/2008 of 6 November 2008 adopting a multiannual Community programme pursuant to Council Regulation (EC) No. 199/2008 establishing a

Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. 52 pp.

EC 2009a. Green Paper: Reform of the Common Fisheries Policy. COM (2009) 163.

EC 2009b. No. 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy, amending Regulations (EC) No. 847/96, (EC) No 2371/2002, (EC) No. 811/2004, (EC) No. 768/2005, (EC) No. 2115/2005, (EC) No. 2166/2005, (EC) No. 388/2006, (EC) No. 509/2007, (EC) No. 676/2007, (EC) No. 1098/2007, (EC) No. 1300/2008, (EC) No. 1342/2008 and repealing Regulations (EEC) No. 2847/93, (EC) No. 1627/94 and (EC) No. 1966/2006. Official Journal of the European Union 2009, L343: 1−50.

EC 2010. Commission decision of 18 December 2009 adopting a multiannual Community programme for the collection, management and use of data in the fisheries sector for the period 2011-2013 (2010/93/EU). *Official Journal of the European Union* 64.

Efron, B., and Tibshirani, R. 1993. *An Introduction to the Bootstrap*. Monographs on Statistics & Applied Probability. Chapman & Hall.

ESRI 2010. ArcGIS Desktop 10, Service Pack 3: Redlands, CA: Environmental Systems Research Institute, Inc.

FAO 2003. Fisheries management. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries, 4, Suppl. 2, 112 pp.

FAO 2008. The state of world fisheries 2008. *State of World Fisheries and Aquaculture SOFIA 2008* 196

FAO 2010. The State of World Fisheries and Aquaculture 2010. Rome, FAO. 197.

FAO 2012. The State of World Fisheries and Aquaculture 2012. Rome, FAO. 209.

Foden, J., Rogers, S.I., and Jones, A.P. 2009. Recovery rates of UK seabed habitats after cessation of aggregate extraction. *Marine Ecology Progress Series*, 390; 15-26.

Forewind 2013. Community Consultation Summary, Dogger Bank Teesside A & B, November to December 2013.

Fulton, E.A., Smith, A.D.M., and Smith, D.C. 2007. Alternative Management Strategies for Southeast Australian Commonwealth Fisheries: Stage 2: Quantitative Management Strategy Evaluation. Australian Fisheries Management Authority Report.

Fulton, E.A., Smith, A.D.M., Smith, D.C., and van Putten, I.E. 2011. Human behaviour: the key source of uncertainty in fisheries management. *Fish and Fisheries*, 12, 2–17.

Gillis, D.M., Peterman, R.M., Tyler, A.V. 1993. Movement dynamics in a fishery: application of the ideal free distribution to spatial allocation of effort. *Canadian Journal of Fisheries and Aquatic Sciences*, 50, 323–333.

Gillis, D., and Peterman, R. 1998. Implications of interference among fishing vessels and the ideal free distribution to the interpretation of CPUE. *Canadian Journal of Fisheries and Aquatic Sciences*, 55, 37-46.

Gillis, D.M. 2003. Ideal free distributions in fleet dynamics: a behavioral perspective on vessel movement in fisheries analysis. *Canadian Journal of Zoology*, 81, 177–187.

Gillis, D.M., Peterman, R.M., and Pikitch, E.K. 1995a. Implications of Trip Regulations for High Grading - a Model of the Behavior of Fishermen. *Canadian Journal of Fisheries and Aquatic Sciences*, 52, 402-415.

Gillis, D.M., Pikitch, E.K., and Peterman, R.M. 1995b. Dynamic discarding decisions - foraging theory for high-grading in a trawl fishery. Behavioral Ecology, 6, 146-154.

Gloaguen, P., Mahevas, S., Rivot, R., Woillez, M., Guitton, J., Vermard, Y., and Etienne, M.P., submitted. An autoregressive model to describe fishing vessel movement and activity. Submitted to *Environmetrics*.

Gordon, H.S. 1953. An economic approach to the optimum utilization of fishery resources. *Journal of Fisheries Research Board of Canada*, 10, 442 – 457.

Graham, N., and Fryer, R.J. 2006. Separation of fish from Nephrops norvegicus into a two-tier cod-end using a selection grid. *Fisheries Research*, 82, 111-118.

Gurarie, E., Andrews, R.D., and Laidre, K.L. 2009. A novel method for identifying behavioural changes in animal movement data. *Ecology Letters*, 12, 395–408.

Haiganoush, K., Preisler, A.A., Ager, B., Johnson, K., and Kie, J.G. 2004. Modeling animal movements using stochastic differential equations. *Environmetrics*, 15, 643–657.

Hardin, G. 1968. The Tragedy of the Commons. Science, 162: 1243−1248.

Hausman, J., and McFadden, D. 1984. Specification Tests for the Multinomial Logit Model. *Econometrica*, 52, 1219–1240.

Hensher, D.A., and Greene, W.H. 2003. The mixed logit model: the state of practice. *Transportation*, 30, 133–176.

Hilborn, R., and Ledbetter, M. 1979. Analysis of the British Columbia salmon purse-seine fleet: dynamics of movement. *Journal of the Fisheries Research Board of Canada*, 36, 384–391.

Hilborn, R. 1985. Fleet Dynamics and Individual Variation: Why Some People Catch More Fish than Others. *Canadian Journal of Fisheries and Aquatic Sciences*, 42, 2–13.

Hilborn, R., and Walters, C.J. 1987. A general-model for simulation of stock and fleet dynamics in spatially heterogeneous fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 44, 1366-1369.

Hilborn, R., and Kennedy, R.B. 1992. Spatial pattern in catch rates - a test of economic-theory. *Bulletin of Mathematical Biology*, 54, 263-273.

Hilborn, R. 2004. Ecosystem-based fisheries management: the carrot or the stick? *Marine Ecology Progress Series*, 274, 275–278.

Hintzen, N.T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., Deporte, N., Egekvist, J. ***et al.*** **2012**. VMStools: open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. *Fisheries Research*, 115/116, 31–43.

Hintzen, N.T., Coers, A., and Hamon, K. 2013. A collaborative approach to mapping value of fisheries resources in the North Sea (Part 1: Methodology) IJmuiden: IMARES, (Report C001/13) – 24pp.

Holland, D.S., and Sutinen, J.G. 1999. An empirical model of fleet dynamics in New England trawl fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 56, 253–264.

Holland, D.S., and Sutinen, J.G. 2000. Location Choice in New England Trawl Fisheries: Old Habits Die Hard. *Land Economics*, 76, 133–149.

Houston, A.I., and McNamara, J.M. 1999. Models of Adaptive Behaviour, Vol. Cambridge University press.

Hutton, T., Mardle, S., Pascoe, S., and Clark, R.A. 2004. Modelling fishing location choice within mixed fisheries : English North Sea beam trawlers in 2000 and 2001. *ICES Journal of Marine Science*, 61, 1443–1452.

Howell, T.R.W., Davis, S.E.B., Donald, J., Dobby, H., Tuck, I., and Bailey, N. 2006. Report of Marine Laboratory Scallop Stock Assessments. Report No. 08/06, Fisheries Research Services.

ICES 2009. Effects of Extraction of Marine sediments on the Marine Ecosystem. Cooperative Research 1998-2004. Report n° 297, 182 pp.

ICES 2010. Report of the ICES Advisory Committee 2010. In: ICES Advice, 2010, Book 6.

ICES 2011. Report on the ICES Advisory Committee 2011. In: ICES Advice, 2011, Book 6.

ICES 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Document, CM 2012/ACOM: 13.

ICES 2013. ICES Advice 2013. Book 6. ICES Document, CM 2013/ACOM: 1-12.

Jabeur, C., Gobert, B., and Missaoui, H. 2001. Typologie de la flottille de pêche côtière dans le golfe de Gabès (Tunisie). *Aquatic Living Resources*, 13, 421–428.

Jagers, S.C., Berlin, D., and Jentoft, S. 2012. Why comply? Attitudes towards harvest regulations among Swedish fishers. *Marine Policy*, 36, 969-976.

Johnson, D.S., London, J.M., Lea, M.-A., and Durban, J.W. 2008. Continuous-time correlated random walk model for animal telemetry data. *Ecology*, 89, 1208–1215.

Jonsen, I.D., Flemming, J.M., and Myers, R.A. 2005. Robust state-space modeling of animal movement data. *Ecology*, 86, 2874–2880.

Jonsen, I.D., Myers, R.A., and James, M.C. 2006. Robust hierarchical state–space models reveal diel variation in travel rates of migrating leatherback turtles. *Journal of Animal Ecology*, 75, 1046–1057.

Jonsen, I.D., Myers, R.A., and James, M.C. 2007. Identifying leatherback turtle foraging behaviour from satellite telemetry using a switching state-space model. *Marine Ecology-Progress Series*, 337, 255– 264.

Joo, R., Bertrand, S., Tam, J., and Fablet, R. 2013. Hidden Markov Models: The Best Models for Forager Movements? *PLoS ONE*, 8, e71246.

Kelleher, K. 2005. Discards in the world's marine fisheries. An update. *FAO Fisheries Technical Paper* T470:131.

Kourti, N., Shepherd, I., Greidanus, H., Alvarez, M., Aresu, E., Bauna, T., Chesworth, J., Lemoine, G., and Schwartz, G. 2005. Integrating remote sensing in fisheries control. *Fisheries Management and Ecology*, 12, 295–307.

Kraus, G., Pelletier, D., Dubreuil, J., Möllmann, C., Hinrichsen, H-H., Bastardie, F., Vermard, Y., *et al.* 2009. A model-based evaluation of Marine Protected Areas: the example of eastern Baltic cod (*Gadus morhua callarias L.). ICES Journal of Marine Science*, 66, 109–121.

Lassen, H., and Medley, P. 2001. Virtual population analysis: a practical manual for stock assessment, FAO.

Lebart, L., Morineau, A., and Warwick, K.M., 1984. Multivariate Descriptive Statistical Analysis. Correspondence Analysis Related Techniques for Large Matrices. John Wiley & Sons, New York.

Leblond, E., Lazure, P., Laurans, M., Rioual, C., Woerther, P., Quemener, L., and Berthou, P. 2010. The RECOPESCA project : a new example of participative approach to collect fisheries and in situ environmental data. *CORIOLIS Quarterly Newsletter*, 37, 40–48.

Le Floc'h, P., Daurès, F., Nourry, M., Thébaud, O., Travers, M., and Van Iseghem, S. 2011. The influence of fiscal regulations on investment in marine fisheries: A French case study. *Fisheries Research*, 109, 257–264.

Lee, J., South, A.B. & Jennings, S. 2010. Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data. *ICES Journal of Marine Science*, 67, 1260–1271.

Lehuta, S., Petitgas, P., Mahévas, S., Huret, M., Vermard, Y., Uriarte, A., and Record, N.R. 2013. Selection and validation of a complex fishery model using an uncertainty hierarchy. *Fisheries Research*, 143, 57 – 66.

Leslie, H.M., and McLeod, K.L. 2007. Confronting the challenges of implementing marine ecosystem-based management. *Frontiers in Ecology and the Environment*, 5, 540-548.

Lewy, P., and Vinther, M. 1994. Identification of Danish North Sea trawl fisheries. *ICES Journal of Marine Science*, 51, 263–272.

Little, L.R., Kuikka, S., Punt, A.E., Pantus, F., Davies, C.R., and Mapstone, B.D. 2004. Information flow among fishing vessels modelled using a Bayesian network. *Environmental Modelling & Software*, 19, 27-34.

Little, L.R., Punt, A.E., Mapstone, B.D., Begg, G.A., Goldman, B., and Williams, A.J. 2009. An agent-based model for simulating trading of multi-species fisheries quota. *Ecological Modelling*, 220, 3404-3412.

Loannides, C., and Whitmarsh, D. 1987. Price formation in fisheries. *Marine Policy*, 11, 143–145.

Maddala, G.S. 1983. Limited Dependent and Qualitative Variables in Econometrics. Econometric Society Monograph, 3. Cambridge University Press, Cambridge, UK.

Mahévas, S., and Pelletier, D. 2004. Isis-fish, a generic and spatially explicit simulation tool for evaluating the impact of management measures on fisheries dynamics. *Ecological Modelling*, 171, 65–84.

Mahévas, S., Vermard, Y., Hutton, T., Iriondo, A., Jadaud, A.A., Maravelias, C.D., et al. 2011. An investigation of human vs. technology-induced variation in catchability for a selection of European fishing fleets. ICES Journal of Marine Science, 68, 2252–2263.

Mangel, M. 1987. Oviposition site selection and clutch size in insects. *Journal of Mathematical Biology*, 25, 1-22.

Mangi, S.C., Rodwell, R.D., and Hattam, C. 2011. Assessing the impacts of establishing MPAs on fishermen and fish merchants: the case of Lyme Bay, UK. AMBIO, 40: 457.

Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., Santurtún, M., Tien, N., and Ulrich, C. 2006. Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. *Canadian Journal of Fisheries and Aquatic Sciences*, 63, 510–533.

Marchal, P., Poos, J-J., and Quirijns, F. 2007. Linkage between fishers' foraging, market and fish stocks density: examples from some North Sea fisheries. *Fisheries Research*, 83, 33−43.

Marchal, P. 2008. A comparative analysis of métiers and catch profiles for some French demersal and pelagic fleets. *ICES Journal of Marine Science*, 65, 674–686.

Marchal, P., Lallemand, P., and Stokes, K. 2009. The relative weight of traditions, economics, and catch plans in New Zealand fleet dynamics. *Canadian Journal of Fisheries and Aquatic Sciences*, 66, 291–311.

Marchal, P., Little, L.R., and Thébaud, O. 2011. Quota allocation in mixed fisheries: a bioeconomic modelling approach applied to the Channel flatfish fisheries. *Ices Journal of Marine Science*, 68, 1580-1591.

McFadden, D. 1974. The measurement of urban travel demand. *Journal of Public Economics*, 3, 303–328.

McFadden, D. 1979. Quantitative methods for analysing travel behaviour of individuals: some recent developments. In: Behavioural Travel Modelling (D. Hensher and P. Stopher, eds.). Croom Helm, London, 279–318.

McFadden, D. 1981. Econometric models of probabilistic choice. In: Structural Analysis of Discrete Data with Econometrics Applications (Manski, C.F. and McFadden, D., eds.). MIT Press, Cambridge, MA., 198–272.

McKelvey, R. 1983. The fishery in a fluctuating environment: coexistence of specialist and generalist fishing vessels in a multipurpose fleet. Journal of Environmental Economics and Management, 10, 287–309.

McLachlan, G.J., and Krishnan, T. 1997. *The EM algorithm and extensions*, volume 274. Wiley, New York.

Messina, G., and Notti, E. 2007. Energy Saving In Trawlers: Practical And Theoretical Approaches. In: ICMRT 2007 Final Report.

Millischer, L., and Gascuel, D. 2006. Information transfer, behavior of vessels and fishing efficiency: an individual-based simulation approach. *Aquatic Living Resources*, 19, 1–13.

Mills Flemming, J.E., Field, C.A., James, M.C., Jonsen, I.D., and Myers, R.A. 2006. How well can animals navigate ? estimating the circle of confusion from tracking data. *Environmetrics*, 17, 351–362.

Mills, C.M., Townsend, S.E., Jennings, S., Eastwood, P.D., and Houghton, C.A. 2007. Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data. *Ices Journal of Marine Science*, 64, 248–255.

Morales, J.M., Haydon, D.T., Frair, J., Holsiner, K.E., and Fryxell, J.M. 2004. Extracting more out of relocation data : Building movement models as mixtures of random walks. *Ecology*, 85, 2436–2445.

Neis, B., Schneider, D.C., Felt, L., Haedrich, R.L., Fischer, J., and Hutchings, J.A., 1999. Fisheries assessment: what can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Sciences*, 56, 1949–1963.

Newell, R.C., Hitchcock, D.R., and Seiderer, L.J. 1999. Organic enrichment associated with outwash from marine aggregates dredging : a probable explanation for surface sheens and enhanced benthic production in the vicinity of dredging operations. *Marine Pollution Bulletin*, 38, 808-818.

Nostbakken, L., Thebaud, O., and Sorensen, L.-C. 2011. Investment Behaviour and Capacity Adjustment in Fisheries: A Survey of the Literature. *Marine Resource Economics* 26.

NSRAC 2005. The Fisheries Secretariat 05/13/2005: North Sea RAC discusses spatial planning. http://www.fishsec.org/2005/05/13/north-sea-rac-discuss-spatial-planning/

Pascoe, S.D., and Robinson, C. 1998. Input Controls, Input Substitution and Profit Maximisation in the English Channel Beam Trawl Fishery. *Journal of Agricultural Economics*, 49, 16–33.

Patterson, T.A., Basson, M., Bravington, M.V., and Gunn, J.S. 2009. Classifying movement behaviour in relation to environmental conditions using hidden markov models. *Journal of Animal Ecology*, 78, 1113–1123.

Pauly, D., Christensen, V., and Walters, C. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. ICES Journal of Marine Science, 57, 697 –706.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., and Zeller, D. 2002. Towards sustainability in world fisheries. Nature, 418, 689–695.

Pawson, M.G. 1995. Biogeographical identifcation of English Channel fish and shellfish stocks. MAFF Fisheries Research Technical Report 99. CEFAS, Lowestoft, 72 pp.

Peel, D., and Good, N.M. 2011. A hidden markov model approach for determining vessel activity from vessel monitoring system data. *Canadian Journal of Fisheries and Aquatic Sciences*, 68, 1252–1264.

Pelletier, D., and Ferraris, J. 2000. A multivariate approach for defining fishing tactics from commercial catch and effort data. *Canadian Journal of Fisheries and Aquatic Sciences*, 57, 51–65.

Pelletier, D., and Mahévas, S. 2005. Spatially explicit fisheries simulation models for policy evaluation. *Fish and Fisheries*, 6, 307–349.

Pelletier, D., Mahévas, S., Drouineau, H., Vermard, Y., Thébaud, O., Guyader, O., and Poussin, B. 2009. Evaluation of the bioeconomic sustainability of multi-species multifleet fisheries under a wide range of policy options using ISIS-Fish. *Ecological Modelling*, 220, 1013–1033.

Peterman, R.M. 2004. Possible solutions to some challenges facing fisheries scientists and managers. ICES Journal of Marine Science, 61, 1331–1343.

Pet-Soede, C., van Densen, W.L.T., Hiddink, J.G., Kuyl, S., and Machiels, M.A.M. 2001. Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia. *Fisheries Management and Ecology*, 8, 15–36.

Poos, J.-J., and Rijnsdorp, A.D. 2007a. The dynamics of small-scale patchiness of plaice and sole as reflected in the catch rates of the Dutch beam trawl fleet and its implications for the fleet dynamics. *Journal of Sea Research*, 58, 100–112.

Poos, J.-J., and Rijnsdorp, A.D. 2007b. An "experiment" on effort allocation of fishing vessels: the role of interference competition and area specialization. *Canadian Journal of Fisheries and Aquatic Sciences*, 64, 304-313.

Poos, J.-J., Bogaards, J.A., Quirijns, F.J., Gillis, D.M., and Rijnsdorp, A.D. 2010. Individual quotas, fishing effort allocation, and over-quota discarding in mixed fisheries. *Ices Journal of Marine Science*, 67, 323-333.

Pradhan, N.C., and Leung, P. 2004a. Modeling trip choice behavior of the longline fishers in Hawaii. *Fisheries Research*, 68, 209–224.

Pradhan, N.C., and Leung, P. 2004b. Modeling entry, stay, and exit decisions of the longline fishers in Hawaii. *Marine Policy*, 28, 311–324.

Protter, P. 2004. *Stochastic Integration and Differential Equations : Version 2.1*. Applications of mathematics. Springer.

R Core Team 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

R development team, 2012. R: A Language and Environment for Statistical Computing.

R Core Team 2013. *R : A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rabiner, L.R. 1989. A tutorial on hidden markov models and selected applications in speech recognition. In *Proceedings of the IEEE*, pages 257–286.

Ran, T., Keithly, W.R., and Kazmierczak, R.F. 2011. Location choice behavior of Gulf of Mexico shrimpers under dynamic economic conditions. *Journal of Agricultural and Applied Economics*, 43, 29–42.

Revuz, D., and Yor, M. 1999. *Continuous Martingales and Brownian Motion*. Grundlehren der mathematischen Wissenchaften A series of comprehensive studies in mathematics. Springer.

Rijnsdorp, A.D., and Millner, R.S. 1996. Trends in population dynamics and exploitation of North Sea plaice (Pleuronectes platessa L) since the late 1800s. *Ices Journal of Marine Science*, 53, 1170-1184.

Rijnsdorp, A.D., Broekman, P.L. van M., and Visser, E.G. 2000. Competitive interactions among beam trawlers exploiting local patches of flatfish in the North Sea. *ICES Journal of Marine Science*, 57, 894–902.

Rijnsdorp, A.D., Daan, N., and Dekker, W. 2006. Partial fishing mortality per fishing trip: a useful indicator of effective fishing effort in mixed demersal fisheries. *Ices Journal of Marine Science*, 63, 556-566.

Rijnsdorp, A.D., Daan, N., Dekker, W., Poos, J.-J., and Van Densen, W.L.T. 2007. Sustainable use of flatfish resources: Addressing the credibility crisis in mixed fisheries management. *Journal of Sea Research*, 57, 114-125.

Riou, P., Le Pape, O., and Rogers, S.I. 2001. Relative contributions of different sole and plaice nurseries to the adult population in the Eastern Channel: application of a combined method using generalized linear models and a geographic information system. *Aquatic Living Resources*, 14, 125–135.

Robinson, C., and Pascoe, S. 1997. Fisher behaviour: exploring the validity of the profit maximising assumption. CEMARE (Centre for the Economics and Management of Aquatic Resources) Research Paper, 110. University of Portsmouth, UK.

Salas, S., and Gaertner, D. 2004. The behavioural dynamics of fishers: management implications. *Fish and Fisheries*, 5, 153–167.

Salz, P., Buisman, E., Frost, H., Accadia, P., Prellezo, R., and Soma, K. 2010. Study on the remuneration of spawning stock biomass, Final Report, Framian, 298 pp.

Salz, P., Buisman, E., Frost, H., Accadia, P., Prellezo, R., and Soma, K. 2011. Fishrent:bio-economic simulation and optimization model for fisheries. LEI Report, 2011: 024.

Sammer, K., and Wüstenhagen, R. 2006. The influence of eco-labelling on consumer behaviour – results of a discrete choice analysis for washing machines. *Business Strategy and the Environment*, 15, 185–199.

SAS Institute Inc. 1999. SAS/STAT User's Guide, Version 8, Cary, NC.

SAS 2010. SAS Institute Inc., Cary, NC, USA. SAS/ETS package, version 9.3.

Shumway, R.H., and Stoffer, D.S. 2000. *Time Series Analysis and Its Applications*. Springer Texts In Statistics. Springer-Verlag GmbH.

Sinnott, R.W. 1984. Virtues of the Haversine. *Sky and Telescope*, 68, 159.

Skaar, K.L., Jorgensen, T., Ulvestad, B.K.H., and Engas, A. 2011. Accuracy of VMS data from norwegian demersal stern trawlers for estimating trawled areas in the barents sea. *ICES Journal of Marine Science*, 68, 1615–1620.

Smith, C.L., and McKelvey, R. 1986. Specialist and generalist roles for coping with variability. North *American Journal of Fishery Management*, 6, 88–99.

Smith, M.D. 2002. Two econometric approaches for predicting the spatial behavior of renewable resource harvesters. *Land Economics*, 78, 522–538.

Smith, M.D., Wilen, J.E. 2003. Economic impacts of marine reserves : the importance of spatial behavior. *Journal of Environmental Economics and Management*, 46, 183–206.

Soulié, J.-C., and Thébaud, O. 2006. Modeling fleet response in regulated fisheries: An agent-based approach. *Mathematical and Computer Modelling*, 44, 553–564.

Stelzenmüller, V., Ellis, J.R., and Rogers, S.I. 2010. Towards a spatially explicit risk assessment for marine management: Assessing the vulnerability of fish to aggregate extraction. Biological Conservation, 143, 230-238.

Taal, C., Bartelings, H., Beukers, R., Van Duijn, A.J., Klok A.J., Van Oostenbrugge J.A.E., and Smit, J.P.G. 2009. Visserij in cijfers 2009. In, Book Rapport 2009-070. Landbouw Economisch Instituut Den Haag.

The World Bank 2005. Turning the tide - Saving fish and fishers: Building Sustainable and Equitable Fisheries and Governance. Washington, The World Bank 10.

Thébaud, O., Daurès, F., Guyader, O., Travers, M., and Van Iseghem, S. 2006. Modelling the adjustement of fishing fleets to regulatory controls: the case of South-Brittany trawlers (France), 1990-2003. AMURE Publications. Working Papers Series D13-2006, 17.

Tidd, A.N., Hutton, T., Kell, L.T., and Padda, G. 2011. Exit and entry of fishing vessels: an evaluation of factors affecting investment decisions in the North Sea English beam trawl fleet. *ICES Journal of Marine Science*, 68, 961–971.

Tidd, A.N., Hutton, T., Kell, L.T., and Blanchard, J. L. 2012. Dynamic prediction of effort re-allocation in mixed fisheries. *Fisheries Research*, 125/126, 243−253.

Train, K. 1998. Recreation demand models with taste differences over people. *Land Economics*, 74, 230–239.

Train, K. 2003. Discrete Choice Methods With Simulation (Cambridge, UK: Cambridge University Press).

Turbout, F. 2013. Regards sur l'Espace Manche, recueil de cartes. Channel Arc Manche Integrated Strategy (CAMIS project, http://camis.arcmanche.eu).

Uhlenbeck, G.E., Ornstein, L.S. 1930. On the theory of the brownian motion. *Physical Review*, 36, 823–841.

Ulrich, C., Gascuel, D., Dunn, M.R., Le Gallic, B., and Dintheer, C. 2001. Estimation of technical interactions due to the competition for resource in a mixed-species fishery, and the typology of fleets and métiers in the English Channel. *Aquatic Living Resources*, 14, 267–281.

Ulrich, C., and Andersen, B.S. 2004. Dynamics of Fisheries, and the Flexibility of Vessel Activity in Denmark Between 1989 and 2001. *ICES Journal of Marine Science*, 61, 308-322.

Ulrich, C., Reeves, S.A., Vermard, Y., Holmes, S.J., and Vanhee, W. 2011. Reconciling single-species TACs in the North Sea demersal fisheries using the Fcube mixed-fisheries advice framework. *ICES Journal of Marine Science* ,68, 1535-1547.

Van Putten, I.E., Kulmala, S., Thébaud, O., Dowling, N., Hamon, K.G., Hutton, T., and Pascoe, S. 2011. Theories and behavioural drivers underlying fleet dynamics models. *Fish and Fisheries*, 13, 216–235.

Van Putten, I.E., Gorton, R.J., Fulton, E.A., and Thebaud, O. 2013. The role of behavioural flexibility in a whole of ecosystem model. *ICES Journal of Marine Science*, 70, 150–163.

Vanstaen, K., Limpenny, D., Lee, J., Eggleton, J., Brown, A., and Stelzenmüller, V. 2007. The scale and impact of fishing activities in the eastern English Channel: an initial assessment based on existing geophysical survey data. CEFAS, Lowestoft.

Vanstaen, K., Clark, R., Ware, S., Eggleton, J., James, J.C.W., Cotteril, C., Rance, J., Manco, F., and Woolmer, A. 2010. Assessment of the distribution and intensity of fishing activities in the vicinity of aggregate extraction sites. MALSF-MEPF Project 08/P73. Cefas, Lowestoft, 116pp.

Vaz, S., Carpentier, A., and Coppin, F. 2007. Eastern English Channel fish assemblages: measuring the structuring effect of habitats on distinct sub-communities. *Ices Journal of Marine Science*, 64, 271-287.

Vermard, Y., Marchal, P., Mahévas, S., and Thébaud, O. 2008. A dynamic model of the Bay of Biscay pelagic fleet simulating fishing trip choice : the response to the closure of the European anchovy (*Engraulis encrasicolus*) fishery in 2005. *Canadian Journal of Fisheries and Aquatic Sciences*, 65, 2444–2453.

Vermard, Y., Rivot, E., Mahévas, S., Marchal, P., and Gascuel, D. 2010. Identifying fishing trip behaviour and estimating fishing effort from VMS data using bayesian hidden markov models. *Ecological Modelling*, 221, 1757–1769.

Walker, E., and Bez, N. 2010. A pioneer validation of a state-space model of vessel trajectories (VMS) with observers' data. *Ecological Modelling*, 221, 2008–2017.

Wallace, A.P.C. 2012. *Understanding fishers spatial behaviour to estimate social costs in local conservation planning.* Unpublished PhD thesis. Imperial College London.

Wilen, J.E., Smith, M.D., Lockwood, D., and Botsford, L.W. 2002. Avoiding Surprises: Incorporating Fisherman Behavior into Management Models. *Bulletin of Marine Science*, 70, 553–575.

Willmott, C.J., and Matsuura, K. 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research*, 30, 79–82.

Wilson, D.C., and McCay, B.J. 2001. Fishery Management, Human Dimension. In Encyclopedia of Ocean Sciences, John H. Steele, ed. (Oxford: Academic Press), pp. 1023–1028.

Woillez, M., Poulard, J.-C., Rivoirard, J., Petitgas, P., and Bez, N. 2007. Indices for capturing spatial patterns and their evolution in time, with application to European hake (Merluccius merluccius) in the Bay of Biscay. *ICES Journal of Marine Science*, 64, 537–550.

Woillez, M., Rivoirard, J., and Petitgas, P. 2009. Notes on survey-based spatial indicators for monitoring fish populations. *Aquatic Living Resources*, 22, 155–164.

Woillez, M., Gloaguen, P., Mahévas, S., Rivot, E., Guitton, J., and Vermard, Y. Adapting Hidden Markov Models to the diversity of fishing boat movements and activities. In preparation.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., and Smith, G.M. 2009. Mixed effect models and extensions in ecology in R, Vol, New York.