Fisheries displacement effects related to closed areas: a literature review of relevant aspects

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Summary

The implementation of the Marine Strategy Framework Directive (MSDF) is rapidly progressing. In 2015 a programme of measures needs to be defined and reported to DG Environment. In this programme, the Frisian Front (FF) and Central Oystergrounds (CO) are designated as search areas for fisheries management, targeting the conservation and possibly recovery of biodiversity of the local seafloor fauna.

A likely effect of installing protected areas is displacement of fisheries: fisheries are (partially) banned, and fishers will have to fish elsewhere. Fisheries displacement, or “fishing effort displacement” refers to the redistribution of the fishing effort formerly in closed areas to remaining fished areas (Grüss, 2014). This displacement of fishing effort may have economic effects, because steaming to and from the fishing grounds may take longer, new fishing grounds have to be explored, and competition for resources may increase.

Fisheries displacement is therefore an important aspect within the context of protecting the FF and CO. However, little is known about displacement of fisheries and the ecological and economic consequences in general, let alone for the fisheries operating in the FF and CO.

In the process of developing measures within the context of the MSFD, the ministry of Economic Affairs assigned a study to IMARES to explore displacement of fishing effort in the Dutch North Sea. The aim of this study was to gain knowledge on fisheries displacement and to put this knowledge in perspective of future measures under MSFD. It is a first attempt to obtain more information, and this study provides a broad and general overview of relevant aspects regarding displacement. This overview was obtained by a literature quick scan. Furthermore, a workshop with fishers was held for a first estimate of displacement related to the MSFD measures.

Displacement - where and why

Displacement in time and space depends highly on the importance of the closed fishing grounds (size and place), the expertise and character of the skipper, distance to the fishing harbours, and the quota for the different fish. These factors all result in a certain level of specialisation of the fisherman/fisheries. The more specialized, the harder it is to displace or to predict where displaced effort will be allocated.

The extent of displacement in terms of location and effort is hard to forecast because of uncertainties in this phase of the process of implementing the closed areas. Moreover, factors which may be relevant in 5 years will determine the extent, spatial and temporal dimensions of displacement in future as well. These are however unknown, in definition and extent.

In general, a few rough estimates on displacement were drafted during the workshop by a small selection of fishers and representatives. We emphasize that these conclusions are not widely discussed and confirmed within the fisheries sector, and reflect only a first attempt to qualify displacement.

- Twinrig nephrops fishers might first explore near/at the borders of the closed area, in case this is nearby their original grounds. Displacement will probably be explorative and heterogeneous in the remaining open areas when fishing grounds are all closed. After exploring, fisheries will concentrate in areas when proper fishing grounds are found.
- Flyshoot fishers may follow the fish on their route and displaced fisheries depend on these routes. As a result, the Frisian Front is an important area for these fisheries in the period May - July. Displacement probably focusses on the open areas, nearby the optimum concentration of fish stocks. Displacement also depends on the amount of quotas. In case of enough plaice quota fishers can displace to the Dogger Bank, with sufficient cod quota they will be able to displace to areas like Skagerrak.
- Pulse fisheries may displace to the remaining open areas of 30 m depth. This depth line goes right through the Frisian front and is the border between harder and softer grounds. Specialists probably have no idea were to displace to in case the largest variants for closure (Flounder) is implemented.

The above scenarios show that displacement cannot be generalized for near future, as well as on the longer term, nor it can be predicted for the whole fleet. Factors such as growth of a certain fleet has not been taken into account.

Displacement - ecological consequences

Understanding the spatial-temporal patterns of fishing-effort allocation around closed areas is essential for assessing their effectiveness (Forcada et al., 2010). As described in this review there are many factors influencing fisheries distribution after area closure. Also the effect of fisheries displacement depends on many different factors. Increased effort in lightly- or unfished areas would cause substantial additional mortality (Greenstreet et al., 2009), whereas increased effort to an already heavily fished area causes relatively little additional mortality of benthic invertebrates. This would also be the case for the North Sea (Dinmore et al., 2003). It has been concluded in literature that closed areas alone appear inefficient at reducing fishing impact on the overall North Sea benthic invertebrate community (Greenstreet et al., 2009). Measures concerning the closure of areas should therefore be combined with additional management measures, such as TAC in order to compensate for the additional fishing pressure in the remaining areas. In addition, fisheries on larger fish within the best fishing grounds could shift to catch of smaller fish in less fishing grounds. This effect of displacement on the (by) catch of smaller fish could also affect fish stocks.

The literature study in general, and the discussions during the workshop, emphasize the need for gear specific high resolution VMS data for use in spatial planning when managing both fisheries (this study) and seabed habitats for e.g. biodiversity conservation (Campbell et al., 2014). The lack of gear type specific (and flag specific) spatial and temporal maps was put forward as essential input for proper discussions. The effort to produce these high resolution maps was not available in this first attempt to outline displacement. Hence, it is hard to make high resolution estimates on consequences as well.

The consequences of displacement (after closing areas), both in ecological as in economic terms, depend largely on the level of specialisation of the fisheries. The level of specialisation results in choices on where and when to fish elsewhere. On the North Sea level, it is yet uncertain where which fisheries will exactly displace to and with what effort. Ecological impact of displaced fisheries depends on the type of habitat, the historic fishing pressure, the additional fishing pressure, and the gear type of displaced fisheries.

In the context of the MSFD potential closures local additional effects on ecology are possible on the borders of some of variants **IF** all fisheries would concentrate along the border of the MPA. Although a (long term and structural) concertation of fisheries along the borders is unlikely to happen, this might temporally be possible for MSFD measure variants Abelone, Capelin, Eel and Flounder- related to flyshoot and twinrig fisheries. For pulse fisheries, additional effects are expected along the 30 m line- along the or in the region of the Frisian Front. The extent of the additional impact is however hard to quantify due to limited information in this phase of the study. Flyshoot fisheries exploring the e.g. Skagerrak will most probably display a heterogeneous distribution, resulting in a low or negligibly additional ecological impact on the benthic community.

Economically, the consequences are drafted in Van Oostenbrugge et al., (2015). Yet, we can state, that fishers without experience in the open remaining areas will be affected more compared to fishers with experience and more generalised way of fishing (exploring and adapting).

Acknowledgements

This study is a quick scan and broad and first study in the Netherlands to reflect on displacement. During the project, many people provided advise, helped to organise the workshop, attended the workshop, and reflected on parts of the results. We thank:

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Glossary of terms

Fisheries displacement	The redistribution of the fishing effort formerly in closed areas to remaining fished areas (Grüss, 2014).
Fishing the line	A frequent harvesting tactic in communities where no-take zones are designated (Kellner et al., 2007)
Marine Strategy Framework Directive (MSDF)	
Marine Protected Area (MPA)	Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment (Kelleher, 1999)
Marine reserve (MR)	A no-take zone
No-take zone (NTZ)	A marine protected area (MPA) from which the removal of any resources, living or dead (eg marine aggregate) is prohibited (Anon, 2001). Also referred to as MR
Searching area	
Spillover	The net movement of fish across the boundary of a reserve into the fished ground, which would be expected to occur on the basis of fundamental physical principles of random movement (Buxton et al., 2014).

1 Introduction

1.1 Background

The implementation of the Marine Strategy Framework Directive (MSDF) is rapidly progressing. In 2015 a programme of measures needs to be defined and reported to DG Environment. In this programme, the Frisian Front (FF) and Central Oystergrounds (CO) are designated as searching areas for spatially explicit fisheries management, targeting the conservation and possibly recovery of biodiversity of the local seafloor fauna. The position of FF and CO are included in *Figure 1*.

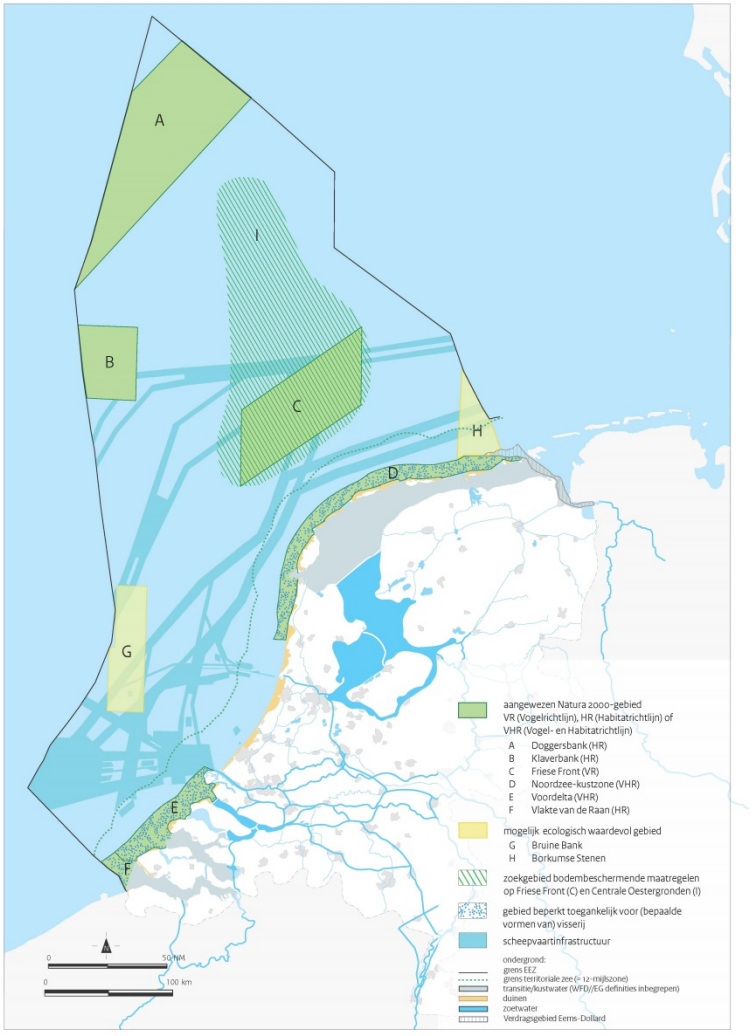


Figure 1 North sea with locations of Frisian Front (c) and Central Oystergrounds (i).

A likely effect of installing protected areas is displacement of fisheries: fisheries are (partially) banned from fishing in the areas, and fishers will have to fish elsewhere. Fisheries displacement, or “fishing effort displacement” refers to the redistribution of the fishing effort formerly in closed areas to remaining fished areas (Grüss, 2014). This displacement of fishing effort may have economic effects, because steaming to and from the fishing grounds may take longer, new fishing grounds have to be explored, and competition for resources may increase.

Fisheries displacement is therefore an important aspect within the context of closing the FF and CO to certain fisheries. However, little is known about the displacement of fisheries and the ecological and economic consequences in general, let alone the FF and CO.

In the process of defining measures, six variants for closure are drafted by the Ministry of Infrastructure and Environment and stakeholders. These six variants are evaluated in a subsequent study on their costs and benefits (Van Oostenbrugge et al., 2015).

1.2 Assignment

In the process of developing measures within the context of the MSFD, the Ministry of Economic Affairs assigned a study to IMARES to explore displacement of fishing effort in the Dutch North Sea. The aim of the study is to gain knowledge on fisheries displacement and to put this knowledge in perspective of future measures under MSFD.

The main research questions to answer were:

1. What is known about displacement of fishing effort after previously implemented habitat protection areas within the North Sea and Wadden Sea.
2. Can this knowledge be used to draft scenarios on the possible effects of closing parts of the FF and CO on the ecology of the region, and the socio-economics of the impacted fisheries?

For question 1, two approaches were followed. First, literature is reviewed to generate an overview of knowledge on displacement, focussing on factors within fisheries practice determining the displacement in time and potential consequences (for ecology and socio-economy). Second, the displacement of fishing effort resulting from a previous closure in the North Sea is analysed is studied using VMS and logbook data.
For question 2, the results of this literature quick scan were discussed with fishers in a workshop. The aim of the workshop was to determine the consequences of closure of parts of the FF and CO (for 6 different scenarios for closure), in terms of fisheries displacement, based on the knowledge and experience of fishers.

This assignment results in three partial studies:

- a literature quick scan on relevant ecological and socio- economic factors related to displacement of fishing effort (report A, being this report),
- a case study on previous closure and displacement in which the actual economic effect is calculated (report B, being De Vries et al., 2015) and
- workshop with fishers to evaluate our findings from literature and translate these to the FF and CO situation (report A, being this report).

The results from the workshop are applied in Van Oostenbrugge et al. (2015), a follow-up study by LEI and IMARES on the cost benefit analysis of measures on the North Sea.

1.3 Methodology

1.3.1 Literature quick scan

The aim of the literature quick scan was to provide a broad overview of displacement aspects. As many studies as possible on North Sea and Wadden Sea were included, but given the limited amount of studies on displacement in these areas, the literature study was broadened to include other regions as well.

The review focussed on articles and reports found by a commonly used online literature searching tool, Scopus (www.scopus.com). The search query used 'displacement AND fishing OR fishery OR fisheries' as keywords. The search was further refined to include only marine studies. Additional studies were found by using the references of relevant studies and by searching for studies from authors known to be working on displacement of fishing effort.
Displacement was reviewed in terms of its effects on the ecology in areas were fisheries were displaced to, and the consequences on socio-economic aspects of fisheries. Important factors are described to understand displacement of fishing effort and underlying mechanisms.
The study results on a broad overview of aspects, rather than a detailed description per aspect.

1.3.2 Workshop with fishers on FF and CO

The aim of the workshop was to determine the consequences of closure of parts of the FF and CO, in terms of fisheries displacement, based on the knowledge and experience of fishers. Fishers were asked to identify where they intend to fish after closure and why, and what that would mean for their fishery. The results from the literature quick scan were used to open the discussion, to reflect on this using their experiences and expectations.

Participants of the workshop were four fishers (representing the fisheries of the FF and CO) and scientists from LEI and IMARES.

The following aspects were discussed during the workshop:

- General experience with displacement and its consequences.
- Expected displacement behaviour and consequences per closure variant (see *Figure 10* in chapter 6 for the variants discussed). Extended descriptions of all variants are provided in Van Oostenbrugge et al. (2015).
- Scenario drafting and assumptions on economic consequences per closure variant: This report drafts the generic workshop findings. See Van Oosterbrugge et al. (2015) for final assumptions and calculations.

1.4 Report structure

This report consists of 8 Chapters. The first chapter contains the introduction to the report. Chapters two to five describe the results of the literature quick scan. Chapter 2 describes the causes of redistribution of fishing effort and examples of fisheries displacement. The chapter also includes a summary of factors determining fisheries displacement. Chapter 3 focussed on effects on ecology and commercial fish stocks, whereas chapter 4 describes the socio economic effects of displacement. A syntheses on general knowledge gaps as identified in literature is presented in chapter 5.

Chapter 6 describes the result from the workshop, in which the experiences of the fishers are described, and their main expectations on displacement following the six closure variants in the context of the MSFD are drafted. In chapter 7, the ecological consequences from these scenarios are discussed. Chapter 8 concludes with a summary on displacement and its ecological effects.

2 Fisheries displacement

2.1 Causes of redistribution of fishing effort

Results from the literature quick scan suggests that reasons for fishers to move from their usual fishing grounds include:

- The implementation of Marine Protected Areas (MPAs) as a conservation management measure, where (certain) fisheries are permanently or temporally not allowed;
- Changes in fuel prizes, causing fishing grounds further away from harbours to be less/more profitable;
- Implementation of, or changes in, fisheries management measures, such as: Total Allowable Catches (TACs); discard bans; real time closures.

This report focusses on the redistribution of fishing effort caused by area closure, also referred to as 'fisheries displacement' (Grüss, 2014). An area can be closed, either for protection of sensitive habitats and species (conservation management) or for protection of commercial fishing stocks (fisheries management). First, examples of observed and predicted fisheries displacement will be described (section 2.2), after which the factors determining fisheries distribution after area closure will be discussed.

2.2 Observed and predicted fisheries displacement

This section describes known cases of fisheries displacement or predictions of fisheries displacement as described in literature. The information on North Sea cases is limited and additional examples of other regions are added in this section. In annex I an overview of the areas studied is presented. The most relevant studies are described in this section.

2.2.1 North Sea

Plaice - and Cod Box

The EU instigated the Plaice Box in 1989 to reduce the discarding of undersized plaice (*Pleuronectes platessa*) in its main nursery areas, and thereby to enhance recruitment to the fishery (Pastoors et al., 2000). The Plaice Box encompasses an area of circa 42,000 km^2 (*Figure 2*). Initially the Plaice Box was closed seasonally, but in 1995 it was closed year round. The closure applied for demersal trawlers exceeding 221 kW main engine power. Fishing by other vessels, such as beam trawlers and shrimpers with engine powers smaller than 221 kW, was permitted. The reason for this exemption was that these vessels were considered to have no alternative to fish further away from their ports (Beare et al., 2013). Between 1995 and 2008, during permanent closure of the Plaice Box, fishing effort by all fisheries has decreased inside and outside the Plaice Box, except for the shrimp trawlers (*Figure 3*). A decrease in overall fishing effort and a change in relative effort between different fleets has thus been observed (Beare et al., 2013).

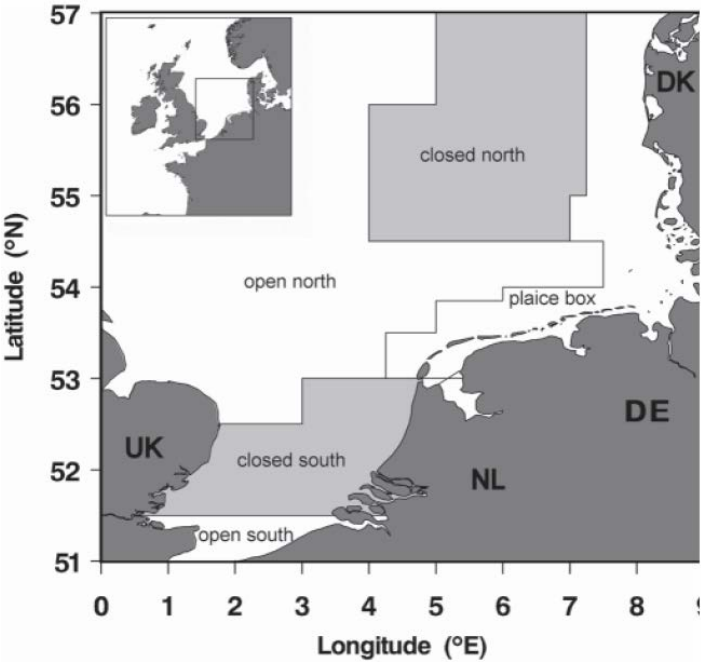


Figure 2 Overview of the open and closed areas in the North Sea. The closed areas, indicated by shading, were closed between 15 February and 30 April 2001 to protect spawning Atlantic cod (Cod Box). The Plaice Box is permanently closed for demersal fisheries such as beam trawling for vessels with engine power exceeding 221 kW (Poos & Rijnsdorp, 2007).

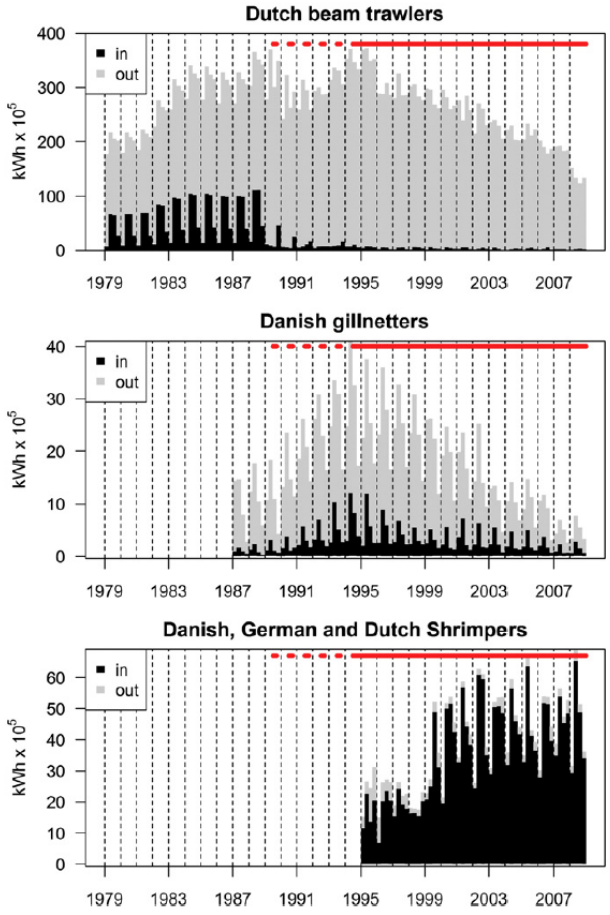


Figure 3 Quarterly fishing effort (kWh) of Dutch beam trawlers (top), Danish gillnetters (middle) and combined Danish, German and Dutch shrimpers (bottom) inside and outside the Plaice Box area between 1979 and 2008 (Beare et al., 2013).

In 2001 two areas in the North Sea were temporally closed to demersal trawling to protect spawning Atlantic cod: the Cod Boxes (*Figure 2*). Dinmore et al. (2003) assessed the effect of the closure of the Cod Box. The fishing effort moved during closure towards open grounds west of the Northern closed area. During the closure an additional part of the open areas were newly trawled as a result of effort displacement.
The closure of the Cod Boxes (Figure 2) also allowed studying the response of the Dutch beam trawl fleet exploiting common sole and plaice (Poos & Rijnsdorp, 2007). The closure caused redistribution of the Dutch beam trawl effort towards open areas within the North Sea and areas outside the North Sea. In the first few weeks there was an increase in competition on the fishing grounds. The response of individual vessels was affected by the area specialisation of the fisherman. Vessels without prior experience in the open areas showed a larger decline in catch rate compared with vessels that previously fished in these open areas and were more likely to stop fishing during the closed period (Poos & Rijnsdorp, 2007). The area specialization may be caused by differences in (i) (personal) knowledge of skippers on the resource distribution and the optimal rigging of the gear for the fishing ground (sea bed characteristics, currents), (ii) vessel and gear design, or (iii) possession of individual transferable quota (ITQ) for the various target species. The data in the study by Poos and Rijnsdorp (2007) did not allow disentangling these effects on the observed area specialization.

2.2.2 Scotland

The Clyde Sea Sill MPA is designated (at time of the study not closed yet) with the aim to conserve certain features (i.e. the presence of black guillemots (*Cepphus grille*), circalittoral and offshore sand and course sediment communities, fronts). The amount of fishing activity that may be affected by the Clyde Sea Sill MPA (*Figure 4*) was analysed (Marine Scotland, 2014a). Actual displacement in terms of where and when which vessels are displaced to is however not yet analysed. An average reduction of effort for vessels over 15 m for demersal trawl and scallop dredge is estimated to be approximately 5% and 2%, respectively. For vessels under 15 m displacement effect would be very low. This assessment is done based on the actual activity within the Clyde Sea Sill MPA that would be displaced. Where to and why is not described.

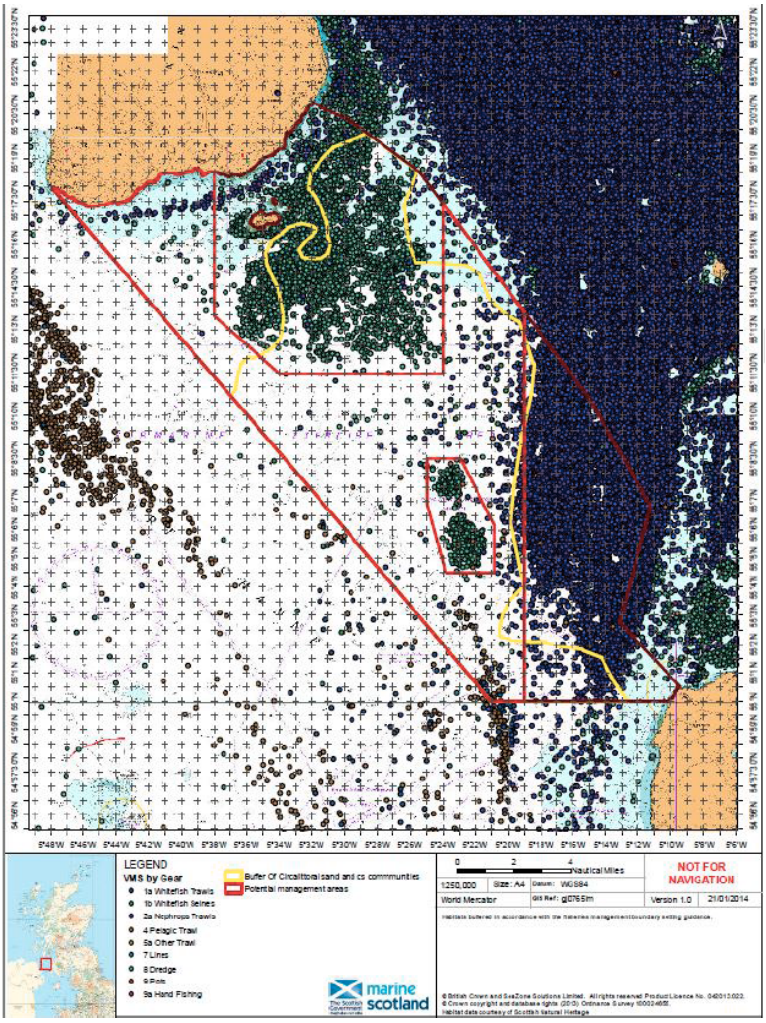


Figure 4 Proposed management area and existing fishing areas within the Clyde Sea Sill MPA. Green and blue dots indicate fishing are for different gears. Red line represents the proposed management area. Yellow line represent the area where circalittoral and offshore sand and course sediment communities found (Marine Scotland, 2014a).

2.2.3 Baltic sea

In the Baltic Sea MPAs were established to protect valuable habitats. Suuronen et al. (2010) studied the response of fishers on area closure in those MPAs. In 1995 seasonal closure for cod fishing was enforced, which was extended to seasonal closure for all fishing activities from 1997-2003. In 2004 and in 2005 the area was enlarged. In 2005 it was closed year-round and two additional permanent closed areas were enforced. The number of vessels, the total fishing effort and the average landed catch per trip in the active Swedish cod fishing fleet in 2005 were halved compared to 1996. Demersal fishing increased by almost 100% (based on the average number of fishing trips per year by demersal trawlers). The enlargement of the MPA in 2005 caused effort displacement of demersal- and pelagic cod fishery towards the boundaries of the MPA (Suuronen et al., 2010). Prior to 2005, many demersal cod trawlers switched their gear in February, harvesting pre-spawning adult cod that rose up from the seabed with pelagic trawls. However, this fishery was partly displaced in 2005 by the northward enlargement of the Bornholm MPA (Suuronen et al., 2010).

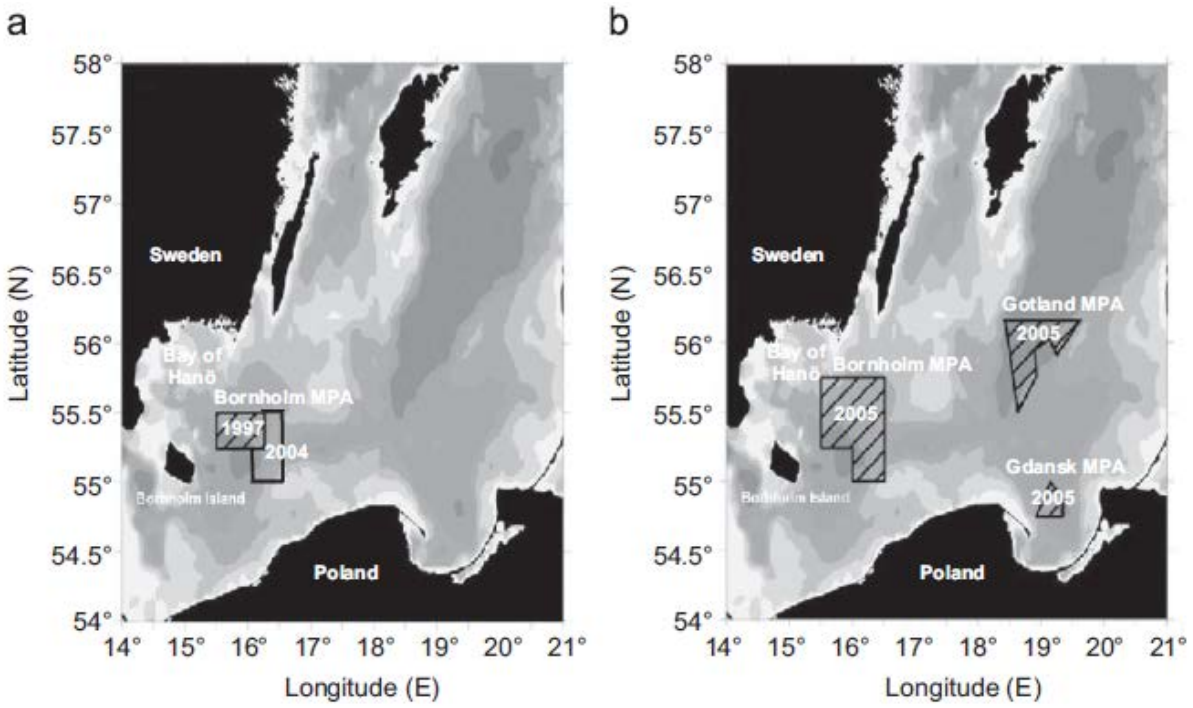


Figure 5 MPAs and their introduction years in the Baltic Sea Main Basin: (a) the Bornholm MPA was enforced temporally during the spring–summer seasons in 1997–2003 with yearly varying duration. In 2004 the MPA was extended east and south-east and (b) in 2005 the Bornholm MPA was expanded northwards and was enforced year-round. Additional year-round MPAs were introduced in 2005 in the Gdansk Deep and in the southern GotlandDeep (Suuronen et al., 2010).

2.2.4 USA and Canada

Large areas off the northeast coast of the USA that were closed for groundfish protection for more than ten years. These closures affected fishing effort distribution (Murawski et al., 2005). Prior to closure 31% of trawl effort (1991-1993) occurred within the 22 000 km^2 of area that would eventually be closed year-round. In 2001-2003 about 10% of effort targeting groundfish was deployed within 1 km of the marine protected area (MPA) boundaries, and about 25% within 5 km (Murawski et al., 2005). Average revenue per hour trawled was about twice as high within 4 km of the boundary, than for more distant catches, but the catch variability was greater nearer closed area boundaries (Murawski et al., 2005).

Van der Lee et al. (2013) examined the distributional response of vessels of the otter trawl groundfish fishery to the seasonal closure on the Scotian Shelf (*Figure 6*). First closure of the area was in 1970 to protect the spawning haddock (*Melanogrammus aeglefinus*). Currently, the area is closed from 1 February to 15 June each year to protect spawning haddock. Overall, the effect of the closure was to displace effort directed towards Browns Bank to the surrounding areas, concentrating effort near the boundaries of the closure, consistent with a fishing the line strategy. There was also an apparent increase in effort on the bank following the reopening of the closure in some of the years examined, likely in an effort to capitalize on residual fish remaining on the bank (van der Lee et al., 2013).

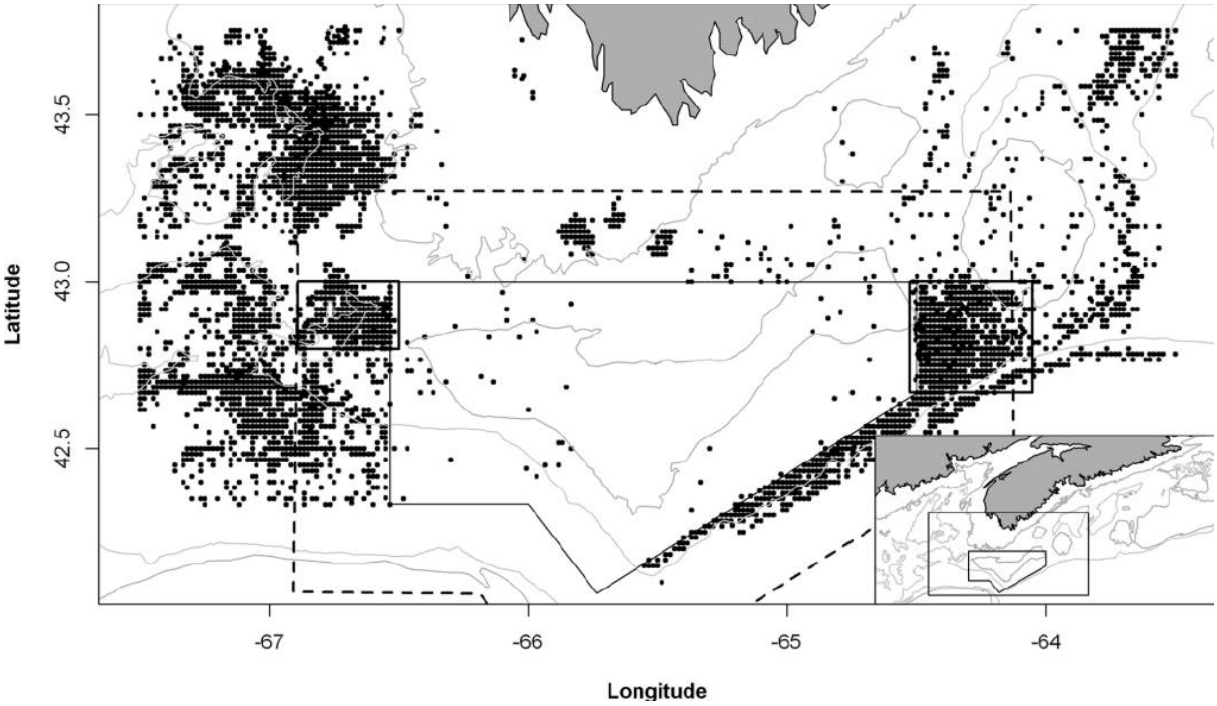


Figure 6 Area studied by van der Lee et al. (2013). Individual trawls are plotted for the closure period from 2005 to 2008. East and west "fishing the line" (FTL) regions are in the thick lined boxes. The dashed line represents the boundary line used for modelling (van der Lee et al., 2013).

2.3 Factors determining fisheries distribution before and after area closure

The fisheries distribution after area disclosure depends on many different aspects. Several factors determining fisheries distribution after area closure have been identified (Murawski et al., 2005; Forcada et al., 2010; Poos & Rijnsdorp, 2007; van der Lee et al., 2013; Horta e Costa et al., 2013; Suuronen et al., 2010; Bastardie et al. 2015; Ramírez et al., 2015):

- Spillover of fish / distance to borders of closed areas;
- Experience, area specialisation and tradition;
- Preferred habitat of target species / water depth;
- Distance to the landing port (costs, including fuel price);
- Space limitation;
- Fishing rights;
- Temporality of area closure.

In the sub-sections below, these factors are described.

2.3.1 Spillover of fish / distance to borders of closed areas

For some species there could be "spillover", defined as the net movement of fish across the boundary of a reserve into the fished ground. Such spillover is expected on the basis of fundamental physical principles of random movement (Buxton et al., 2014). Spillover attracts fisheries to the borders of closed areas (Murawski et al., 2005), a phenomenon called "fishing the line" (Kellner et al., 2007; Grüss, 2014). Fishing the line is a frequent harvesting tactic in fisheries where no-take zones are designated (Kellner et al., 2007). The distance to borders of no-take zones is an important factor explaining fisheries aggregations around MPAs, associated with increased fishery yield (Horta e Costa et al., 2013). However, although Sanchez Lizaso et al. (2000) concluded that although there is potential biomass export from MPA's, little empirical evidence of this export has been reported. Meanwhile, fishing the line has been observed around the 1400 ha Tabarca Marine Reserve in the Mediterranean off south-east Spain (Forcada et al., 2010). The reserve was established to protect breeding stocks, to improve recruitment to neighbouring areas, and to restock marine species of commercial interest for artisanal fisheries (i.e. traditional, small scale fisheries). Although the concentration of fishing effort around this MPA could be

caused by the expectation of fishers for better catches along the boundaries, the fact that the Tabarca Marine Reserve was established more than 20 years ago makes it likely that “fishing the line” here is caused by real fishery benefits (Forcada et al., 2010 and references therein).
The spill over effect and, consequently, fishing the line, was also studied in a closed area on the Scotian Shelf by van der Lee et al. (2013), see *Figure 6*. The area is closed from February to June each year to protect spawning haddock. Depending on the area, displacement and its relation to catch rates or effort could or could not be observed. In one area catch rates were greater, corresponding with larger effort, but in another area, no trends in catch rates were often observed, potentially indicating vessel distributions that correspond to the ideal free distribution. Implementation of a seasonal area closure on Browns Bank resulted in concentrations of vessels near the closure boundary, suggestive of a fishing the line strategy, with specific catch rate trends depending on vessel spatial distributions and target species. Space limitation, patchy distribution of fish aggregations and uneven bottom topography are possible factors explaining this observation (van der Lee et al., 2013).

2.3.2 Experience, tradition, and area specialisation

It is assumed that habits and traditions for fishers’ choices are predominant, which is supported by several studies (Bastardie et al., 2015 and reference within). Based on studies by e.g. Tidd et al., 2012; Marchal et al., 2013; Van Putten et al., 2013, it can be assumed that fishers’ choices are predominant when, e.g. the same fishers visit the same areas from time to time and only change their well-defined patterns when they are actually forced to do so. Dynamic patterns result from their experiences in catch rates on fishing grounds and fishing costs. This assumption is supported by several studies where there are observed strong effects of tradition in fisher effort allocation behaviour. Such experience-based behaviour of fishers is likely to be the outcome of factors that are more or less stable. Factors include stable regulations, weather conditions (wind speed, wind direction and waves), fishing seasons, and market demands. In addition strong local traditions and knowledge exchange among fishers steer the behaviour of fishers (Andersen et al., 2012).

Area specialisation among vessels means that vessels are doing well in one area but not in the other. Area specialisation may be caused by differences in (Poos & Rijnsdorp, 2007):

- Personal knowledge of the skipper;
- Vessel and gear design;
- Possession of individual transferable quota (ITQ) for different target species.

As a result of area specialization, area closure may affect vessels differently, depending on their experience in the remaining open areas. The closing of the cod boxes in 2001 revealed that vessels with little experience in the open areas showed a lower level of fishing activity or even stopped fishing during the closure (see *Figure 2*). The ‘resident’ vessels meanwhile continued fishing on the grounds on which they fished in previous years (Poos & Rijnsdorp, 2007). In addition, the reduction in catch rate in the open area during closure of the protected area is stronger for the vessels with little experience in the open areas compared to the ‘resident’ vessels. These observations suggest area specialisation in the fishery (Poos & Rijnsdorp, 2007). In case of permanent MPAs, it is expected that the effect of area specialisation will decrease in time. Immigrant vessels will adapt to the new areas and in time they will be undistinguishable from the resident vessels. Therefore, the economic effect of area specialisation will probably be temporally.

2.3.3 Preferred habitat of target species / water depth

Water depth affects fisheries distribution (Horta e Costa et al., 2013; Keller et al., 2014). Hence, water depth is an important factor explaining fisheries aggregations around MPAs, associated with target species distribution (Horta e Costa et al., 2013).
Artisanal fisheries (traps, trammel and gill nets), and jigs showed fisher- and fisheries-specific adaptions to multiple protection measures in a MPA on the west coast of Portugal (Horta e Costa et al., 2013). Preferred habitat of target species were driving much of the fishers' choices. Options in displacement will be steered by these factors. Because the border of an MPA in the Baltic Sea was close to a steep slope Swedish trawlers had difficulties to operate in the area which was traditional fishing ground (Suuronen et al., 2010). Polish gill netters took over the profitable fishing areas. Thus overall fishing effort in this area was redistributed from Swedish trawlers to Polish gill netters. Fleets (and therewith countries) can thus be unevenly affected by MPAs.

2.3.4 Distance to the landing port

Distance to the landing port is an important factor explaining fisheries aggregations around MPAs, which is associated with costs (Horta e Costa et al., 2013). Fuel prices influence this factor, see also the socio-economic effects (chapter 4.1.3).

2.3.5 Space limitation

The amount of space that is available after closure is smaller for the same number of fishers. This creates competition for space, which is amplified by patchy distributions of fish aggregations and uneven bottom topography. Both can limit the number of desirable fishing locations. The number of desirable fishing locations was one of the factors thought to explain the effort distribution after the temporally Browns Bank closure on the Scotian Shelf (van der Lee et al., 2013).

2.3.6 Fishing rights

The availability of fishing rights (quota) in open areas could also influence the fisheries distribution after area closure. This was observed in the North Sea, where two large areas were temporally closed in 2001 to protect spawning Atlantic cod (Poos & Rijnsdorp, 2007). Because of shortage of fishing rights (quota) in areas other than the North Sea, the number of vessel re-allocating their activities to fishing grounds outside the North Sea was relatively small compared with the total size of the fleet (Poos & Rijnsdorp, 2007).

2.3.7 Duration of area closure

There are several studies indicating that seasonally closed areas are known to attract more fishing effort after opening than prior to closure (Murawski et al., 2000 & 2005; Poos & Rijnsdorp, 2007; van der Lee et al., 2013). This was observed in the North Sea as well as in other areas.

After the closure of two areas in the North Sea in 2001 to protect spawning Atlantic cod was lifted, the fishing effort peaked in the previously closed areas, coinciding with a VPUE (value per unit effort) that was well above the seasonal value in the reference years. This could be caused by the high survival during closure resulting in high abundance of the species (Poos & Rijnsdorp, 2007). However, the attraction of more fishing effort after opening a seasonal closed area than prior to closure was also observed even while average CPUE (catch per unit effort) was the same or lower (Murawski et al., 2005).

Between 1990 and 1993, when the Plaice Box was seasonally closed to large trawlers of the North Sea flatfish fisheries, the large beam trawlers clearly reacted with spikes in fishing effort when the area was temporarily opened (Beare et al., 2013).

3 Ecological effects of fisheries displacement

3.1 Potential ecological effects

The literature quick scan results in the following list of potential effects of displacement of fishing effort.

- Effects on habitats and/or species, depending on:
    - fishing effort prior and after closure
    - amount of effort displaced, as well as the gear type
    - homogeneity of trawling effort after closure
    - protected species within the closed area, i.e. fish- or benthic species
    - additional management measures
- Effects on commercial fish stocks, depending on:
    - spatial distribution and quantity of displaced fishing effort
    - the degree of fish movement across closed-area boundaries
    - the relative catchability of the target stock(s) outside the closures
    - the level of protection afforded to undersized animals taken by the fishery
    - temporality of the closure
- Effects on discards/bycatch

In the following sections these aspects are discussed in more detail.

3.2 Effects on habitats and/or species

Greenstreet et al. (2009) describes two situations in fisheries displacement. Both positive and negative effects of MPAs on benthic invertebrates have been demonstrated. These are shown to be a trade-off between recovery in closed areas and declines in areas to which trawling activity was displaced:

1. Displacing fishing effort to an already heavily fished area causing relatively little additional mortality of benthic invertebrates;
2. Displacing fishing effort to lightly fished areas causes substantial additional mortality of benthic invertebrates. This is because the initial effects of fishing on biomass, production, diversity and trophic structure are the most important ones (Hiddink et al., 2006, Jennings and Kaiser, 1998 in Dinmore et al., 2003).

Greenstreet et al., (2009) point out that the first situation is more desirable and is more likely when relatively lightly fished areas are selected for MPA designation. This corresponds to the study of Dinmore et al. (2003). Dinmore et al. (2003) also emphasise that displacement of fishing effort to previously unfished areas can have a disproportionate impact on benthic communities . In *Table 1* the recovery time for three groups of benthic organisms is presented based on Dinmore et al. (2003). Modelling the effect of the closure of the Cod Box in 2001 in the central North Sea (*Figure 2*) showed that larger hard bodied macrofauna would require 10 years to recover from the impacts of effort displaced to previously unfished areas Dinmore et al., 2003), but that is depends also on the traits of the organism.

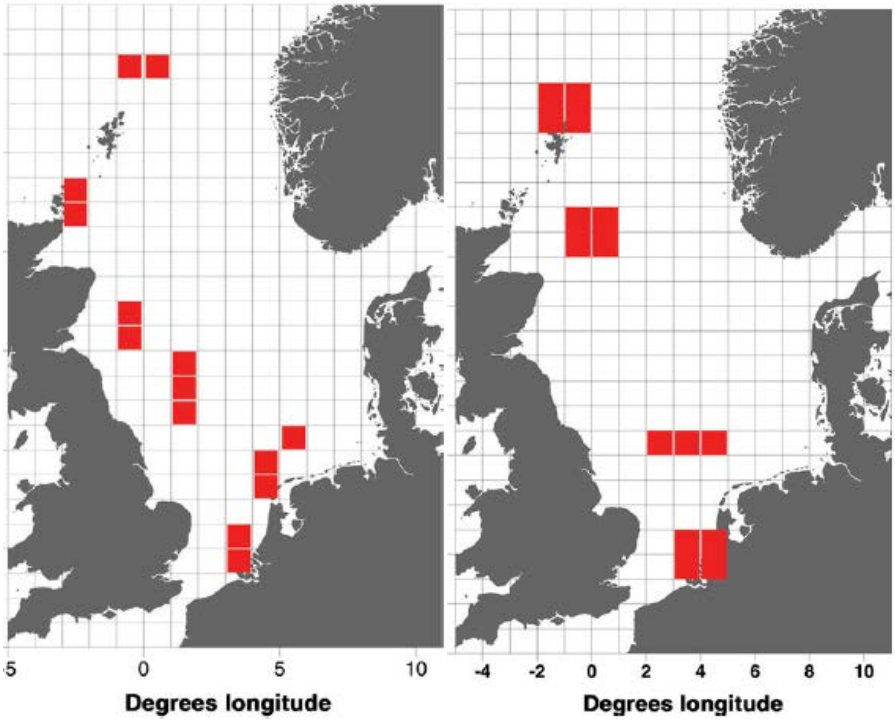
Table 1 Predicted recovery times for different groups of benthic organisms to reach 95% of unimpacted biomass after trawling a previously unfished area 1–4 times during the 12-week cod box closure (after Dinmore et al. (2003).

		Recovery time (months)			
Group	Size range	1	2	3	4
Meiofauna	1–200 µg	2	3	4	4
Soft macrofauna	1.9–500 mg	18	34	40	45
Hard macrofauna	88 mg to 105 g	67	92	108	124

Repeated imposition of such a seasonal area closure would lead to small long-term reductions in the mean production of benthic communities. However, while the homogeneity of trawling effort increased in the year of closure, the distribution of effort was still relatively patchy and had less impact on benthic communities than would be expected if effort distribution were uniform or random (Dinmore et al., 2003). The increased homogeneity, coupled with the displacement of trawling activity to previously unfished areas, is predicted to have slightly greater cumulative impacts on total benthic invertebrate production and lead to localized reductions in benthic biomass for several years.

The importance of heterogeneous fishing effort distribution was also emphasised by Duplisea et al. (2002). The study of Duplisea et al. (2002) simulated the impacts of trawling disturbance on benthos in the central North Sea and showed that macrofauna persisted in many heavily trawled regions, suggesting that trawling is sufficiently heterogeneous to provide spatial refuges less impacted by trawling. The analyses suggests that management measures that do not reduce total effort but do lead to effort displacement and spatial homogenization may have adverse effects on the benthic communities (Duplisea et al. 2002). In combination with the findings of Dinmore (2003) and table 1, the findings of Duplisea should be discussed in more detail regarding the homogeneity of the benthic community as well.

The use of MPAs in the North Sea was studied to examine potential adverse ecological effects of fisheries displacement compared to potential ecological benefits gained from MPAs (Greenstreet et al., 2009). Based on modelled data, closing 7.7% of the North Sea to protect groundfish species diversity (*Figure 7*a) was expected to increase the fishing impact on benthic invertebrates. Local reductions in benthic fishing mortality within the MPAs were outweighed by increased fishing mortality elsewhere in the North Sea, resulting from fishing effort displacement (Greenstreet et al., 2009).
Thus the area closure negatively affected North Sea benthos (in terms of annual mortality). However, closing 7.3% of the North Sea specifically to protect benthic invertebrates (*Figure 7*b) was expected to reduce ground fish fishing mortality by 1.7–3.8%. Even more, when combined with appropriate reductions in total allowable catch (TAC), 16.2–17.4% reductions in fishing mortality of benthic invertebrates were achieved. This implies that additional fisheries management measures will greatly enhance the ecological benefit of MPAs for benthic invertebrates.



a. b.

Figure 7 (a) Selection of 7.7% of the North Sea area as MPAs designed to conserve groundfish species assemblage types and (b) selection of 7.3% of the North Sea area as MPAs designed to reduce benthic invertebrate fishing mortality (adapted from Greenstreet et al., 2009).

The model-based DISPLACE (focusing on the western Baltic Sea, see *Figure 8*) showed that fisheries displacement did not lead to an increase in the spatial fishing footprint on sensitive habitats, for example, ecological “hot spots” of diversity such as hard bottom (Bastardie et al., 2015). The authors reason that if the conservation areas are specifically designated to covering a minimum surface area of each of those habitats, fisheries displacement does not lead to an increase in the spatial fishing footprint on sensitive habitats.

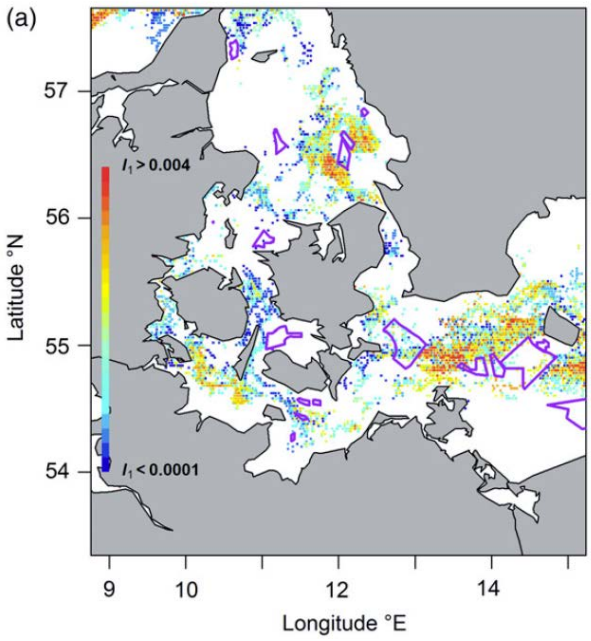


Figure 8 Study of the affected effort within the planned and existing offshore windmill farms sites in the Baltic proper by gridding the 90% coverage of the spatial effort allocation on a 1.5 × 1.5 km spatial resolution. Index I_1 (a) is a measure of the importance (to the total revenue from the fisheries) of the vessel visiting a given cell i, The planned wind farms are given in purple polygons (Bastardie et al., 2015).

The potential for environmental effects from displacement has been assessed for the designated Scottish MPA's (Marine Scotland, 2014b). In July 2014 thirty MPAs were designated by the Scottish government and measures for the management of the MPAs are being developed, see *Figure 9*. A Strategic Environmental Assessment (SEA) of the measures proposed for management of MPAs and SACs is required by the Environmental Assessment (Scotland) Act 2005.

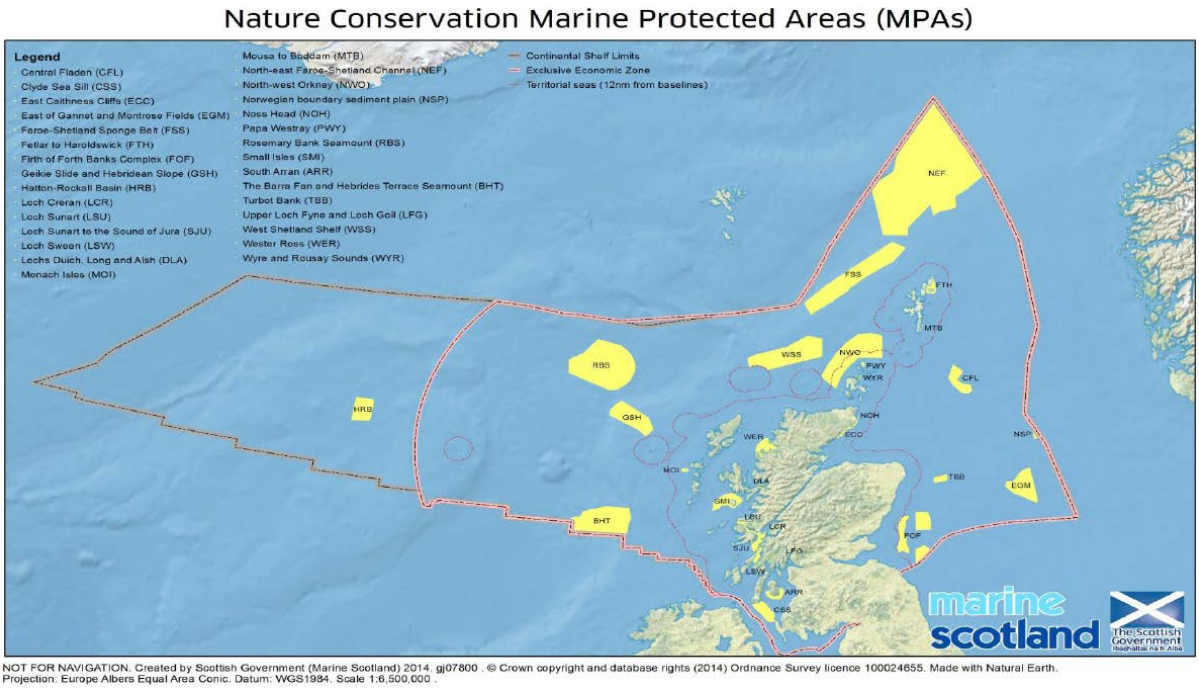


Figure 9 MPAs in Scottish territorial and offshore waters, designated in July 2014 (Marine Scotland, 2014b).

The SEA states that the potential for environmental effects from displacement will depend on the amount of effort displaced, as well as the gear type (Marine Scotland, 2014b). Measures to manage static gears (including creels) will likely result in only limited displacement. The focus of the displacement assessment has therefore been on mobile gear used for nephrops trawling and scallop dredging. Displacement has been assessed by identifying the average annual fishing effort for each gear type, in the MPA and/or SAC, and in the ICES rectangle in which the MPA and/or SAC is located (Marine Scotland, 2014b). Because it was difficult to obtain data on the condition of the seabed in areas that are being fished by mechanical dredge or demersal trawl the SEA made the following assumptions (Marine Scotland, 2014b):

- The use of bottom-contact mobile gear results in a modified benthic environment.
- The abundance of target species (nephrops, scallops) may not decrease as a result of demersal trawling or mechanical dredging, but it is likely that the diversity of non-target species will decrease.
- In existing fishing grounds, it is reasonable to assume that absorption of additional effort, below a certain level, will not result in additional damage to this modified environment. For this assessment, these levels have been assumed as:
    - in MPAs/SACs: 10% additional effort;
    - in ICES rectangle(s): 10% additional effort; and
    - in regions: 1% additional effort.

In case all levels are exceeded, significant adverse environmental effects are expected, comprising increased physical damage to benthic habitats, including priority marine features, resulting from the increased use of bottom-contact mobile gear (Marine Scotland, 2014b).
The potential displacement of trawling and/or dredging activities from MPAs and SACs, for the Scottish fleet under 15m and over 15m was assessed (*Table 2*) based on the above assumptions. According to the results, implementation of proposed measures for Luce Bay and Sands SAC, has the potential to result in significant adverse effects from the displacement of fishing activities. The assumption is that adverse effects occur when displaced effort is more that 1%, and the displaced effort is estimated to be 1.9 and 1.8 % depending on the fisheries (*Table 2*).

Marine Scotland (2014b) concluded that for most sites fishing would move to existing fishing grounds that have already been subject to bottom-contact with mobile gear. For these sites, the levels of additional effort are not considered to be high enough to result in additional effects on the seabed (i.e. over and above those already existing). It is therefore unlikely that such effort would work against the objectives (Marine Scotland, 2014b):

- to safeguard marine and coastal ecosystems, including species and habitats, and their interactions;
- to maintain or work towards achieving good ecological status of water bodies; and
- to maintain and protect the character and integrity of the seabed.

Table 2 Potential displacement resulting from proposed measures and complete displacement for both the under 15m and over 15m Scottish fleet, expressed as additional effort (%) assessed on three levels: MPA/SAC area; ICES rectangle (approximately 30 nautical miles square) and; regional level (i.e. east, northwest and southwest). D = scallop dredging, T = nephrops trawling (Marine Scotland, 2015)

Site	Displacement from proposed measures												Complete displacement							
	MPA/SAC				ICES Rectangle				Region				ICES Rectangle				Region			
	under 15m		over 15m		under 15m		over 15m		under 15m		over 15m		under 15m		over 15m		under 15m		over 15m	
	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
East Region																				
Noss Head	100	0	100		<2	-	<1	-	-	-	-	-	<2	-	<1	-	-	-	-	-
Sanday	100		0		<3		0		-	-	-	-	<3		0	-	-	-	-	-
Wyre and Rousay Sounds	0	0	0		-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Northwest Region																				
East Mingulay	0	100	0	100	0	1.3	0	<1	-	-	-	-	0	1.3	0	<1	-	-	-	-
Loch Laxford	0	0	100	0	-	-	<3	0	-	-	-	-	-	-	<3	0	-	-	-	-
Lochs Duich, Long and Alsh	38		38	0	<1		12	0	-	-	<1	0	<1		33		-	-	<1	-
St Kilda	0	0	0	100	-	-	0	3	-	-	-	-	0	0	0	3	-	-	-	-
Small Isles	11		16	11	<4		1	2	-	-	-	-	34		7	22	5		-	6
Wester Ross	0	11	36	11	0	3	16	2	-	-	<1	-	-	-	45	16	-	-	2	3.5
Southwest Region																				
Loch Creran	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Loch Sunart to Sound of Jura/ Loch Sunart	5		5		-	-	-	-	-	-	-	-	<1		7		-	-	-	-
Loch Sween	8		18		-	-	<1		-	-	-	-	<1		<1		-	-	-	-
Luce Bay and Sands Approach 1	100	0	100	0	63	0	22	0	1.9	0	1.8	0	-	-	22	0	1.9	0	1.8	0
Luce Bay and Sands Approach 2	39	0	39	0	25	0	9	0	<1	0	-	-	-	-	22	0	1.0	0	1.8	0
Luce Bay and Sands Approach 3	12.5	0	-	-	8	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
South Arran	49	26.5	51	27	3	1	5	5	-	-	-	-	7	7	10	17	-	-	2.2	3.8
Treshnish Isles	100		100		<1		<1		-	-	-	-	<1		<1		-	-	-	-
Upper Loch Fyne and Loch	31		34		<1		<1		-	-	-	-	<1		<1		-	-	-	-

Luce Bay and Sands Approach 1 would prohibit mobile gear in the SAC, which would completely displace dredging activity; Approach 2 allows mechanical dredging by vessel during January, February, November and December each year in identified fishing area; Approach 3 allows mechanical dredging by vessel during January, February, November and December each year, apart from in prohibited fishing areas (two).

As described above, the potential environmental effects from displacement for the Scottish MPA's has been assessed based on the amount of effort displaced without addressing the (local) seabed conditions. The study acknowledges that, given the lack of information regarding existing benthic condition, there is a significant level of uncertainty regarding the conclusions (Marine Scotland, 2014b).

Potential effects of fisheries displacement have also been studied with inclusion of benthic conditions. A spatial dynamic modelling approach incorporating ecological, social and economic criteria has been applied by Ramírez et al. (2015) for a proposed MPA system on fisheries in a biodiversity conservation priority site in northern Chile. The constructed model represents the ecological benthic subsystems (rocky bottom) dominated by kelp beds off the Mejillones Peninsula. Subtidal kelps species and rockfish are exploited by artisanal fishers communities. Effects of fisheries displacement were modelled in an area comprising fishing zones and MPAs. The analyses showed small positive and negative benthic biomass changes and the total biomass slightly increased (Ramírez et al. 2015). Trophic cascade patterns were observable, emphasising the need to take ecological relationships into account in the establishment of MPAs.

3.3 Effects on commercial fish stocks

The model-based DISPLACE quantitative approach has been applied to conduct a spatial, individual vessel-based bio-economic assessment, accounting for stochastic variation in effort allocation (Bastardie et al., 2015). The study focuses on the western Baltic Sea (*Figure 8*). The findings reveal that the effort displacement is beneficial for the stocks under study (herring, sprat, and cod) when some areas are no longer accessible. The closed areas diminish the total landings and prevent a vulnerable part of the stocks from being exploited (Bastardie et al., 2015).

Fisheries displacement could also decrease the size of protected populations and thus the overall benefit in the recovery of the stock, as described for cod (Davis en Lordan, 2011) and highly migratory populations in general (Grüss, 2014 and references therein). Fishers also emphasized that MPAs cannot effectively protect migrating fish such as cod (Suuronen et al., 2010). The reestablishment and

concentration of fishers in new areas can encourage resource depletion (Stevenson et al., 2013). Levels of spillover, induced by area closure (see section 2.3.1) could be subsidised by fisheries displacement (Grüss, 2014 and references therein). It is also possible that fisheries displacement for protection of certain fish stocks could reduce the potential effectiveness of other measures designed to rebuild other stocks (Murawski et al., 2000).

In addition, Forcada et al. (2010) refers to several modelling studies (Babcock et al., 2005; Martell et al., 2005; Kellner et al., 2007 in Forcada et al. 2010) assessing the effectiveness of MPAs in rebuilding or maintaining populations of exploited species. These studies indicate that the effectiveness of MPAs depends on fishing effort in the area before establishment of the MPA, and the new spatial patterns of effort caused by displacement (Forcada et al., 2010). Other studies (McClanahan and Kaunda-Arara, 1996; Halpern and Warner, 2003; Kellner et al., 2007 in Forcada et al. 2010) indicate that if, for example, fishing effort concentrates near the boundaries of an MPA, the effectiveness of the protection could be diminished. Ramírez et al. (2015) suggest that there should be an optimal size and location for an MPA regarding ecological (i.e. species dispersal conditions) and economic (i.e. sailing costs) aspects as a consequence of fishing effort displacement.

Based on analyses of large closed areas in the northeast of the USA, Murawski et al. (2000) identified the spatial distribution and quantity of displaced fishing effort as one of the factors crucial to the efficacy of closed areas for reducing fishing mortality rates, protecting juvenile or undersized animals, and enhancing productivity. Other factors are: the degree of fish movement across closed-area boundaries; the relative catchability (cpue) of the target stock(s) outside the closures; and the level of protection afforded to undersized animals taken by the fishery (Murawski et al., 2000). Ramírez et al. (2015) showed that fish biomass recovery is higher under low species dispersal conditions and large individual reserves. The results highlight that interactions between dispersal rates and reserve sizes are key to MPA efficacy in recovering target species' biomass.

The attraction of more fishing effort after opening of seasonal closed areas than prior to closure could reduce the potential benefit of closed areas for reducing fishing mortality rates, protecting juvenile or undersized animals, and enhancing productivity to zero (Murawskit et al., 2005).

3.4 Increased discards/bycatch

Suuronen et al., 2010 described the effect of displacement on by catch of smaller fish. The pelagic cod fishery on pre-spawning adult cod was partly displaced in 2005 by the enlargement of the MPA in the Baltic Sea and may have markedly contributed to the increased discarding of cod by displacing effort towards areas dominated by smaller sized fish. Also, the displaced small-mesh herring and sprat fleet probably caused substantial but largely unreported by-catch of juvenile cod (Suuronen et al., 2010).

Abbott & Haynie (2012) examined direct displacement effects and indirect effects from adaptations in fishers targeting behaviour after two spatial closures in 1995 in the Eastern Bering Sea designed for red king crab protection. The data showed substantial reductions in red king crab bycatch, caused by relocation of effort. The closure therefore seemed to be successful in protecting red king crab. However, "bycatch" of cod was increased as fishers retained it for landing (Abbott & Haynie, 2012). The closure also spurred dramatic increases in Pacific halibut bycatch resulting from direct displacement effects and indirect effects from adaptations in fishers targeting behaviour (Abbott & Haynie, 2012).

4 Socio-economic effects of displacement

4.1 Potential effects

The (potential) socio-economic effects of MPAs have been widely studied (Adams et al. 2011; Attwood and Bennett 1995; Cinner et al. 2014; Girardin et al. 2015; Halpern et al. 2004; Mangi et al. 2011; Miethe et al. 2014; Richardson et al. 2006; van de Geer et al. 2013). Fisheries displacement could lead to the following socio-economic effects:

- Increased crowding/competition in open areas
- Changed relative fishing effort among different fleets
- Changes in travel distance/steaming time
    - Increasing fishing costs (fuel, time)
    - Decrease in quality of the landed fish because of long trips
    - Long trips could affect family life of the fishers
    - Long trips raises safety concerns
    - Encourage more careless fishing practices and non-compliance
- Effects on fishing gear
    - Increased wear and tear of fishing gears in less favourable fishing grounds
    - Increased gear conflicts (gear collision)
- Changes in CPUE
- Decreased Gross Value Added (GVA)

In the following sub-sections case examples of these different mechanisms are described.

4.1.1 Increased crowding/competition in open areas

Closures of large areas have been identified as a cause for increased competition with fisheries elsewhere (Murawski et al., 2000). The reestablishment and concentration of fishers in new areas can cause competition and conflict between fishers (Stevenson et al., 2013).

During the first week of closure of two protected areas in the North Sea in 2011, the catch rate in the northern open area decreased by 14% (Poos & Rijnsdorp, 2007). This decrease coincided with nearly double the fishing effort and a substantial increase (28%) of the crowding in the area. This suggests interference competition between the beam trawlers studied (Poos & Rijnsdorp, 2007). Fishers without experience in the open areas were affected more compared to fishers with experience (effect of area specialisation, see section 2.3.2).

The enlargement of the MPA in the Baltic Sea in 2005 forced fishers to operate in less favourable fishing grounds, causing overlap in harvesting areas of the different fleets (cod, herring/sprat), reducing the CPUE of both fleets (Suuronen et al., 2010). The profitability of harvests thus decreased.

Displacement of fishing effort in coastal areas could lead to spatial interaction among fishers and other coastal activities, e.g. recreational fishing, tourism, aquaculture, diving (Forcada et al., 2010 and references therein).

4.1.2 Change in relative fishing effort among different fleets

Allocation changes among gear types and fleet sectors have been identified as consequences of area closure (Murawski et al., 2000). An MPA in the Baltic Sea only affected Swedish effort, and swedish fishers therefore considered it an unfair management action (Suuronen et al., 2010). The Swedish fisheries affected largely because they had operate in the less favourable fishing grounds, which reduced the profitability of harvests and increased the by-catch of juvenile cod. Furthermore, the wear and tear of fishing gears increased substantially on these grounds, causing additional costs. Polish gill netters took over the profitable fishing areas. Thus overall fishing effort in this area was redistributed from Swedish trawlers to Polish gill netters (Suuronen et al., 2010).

4.1.3 Changes in travel distance / steaming time

Closure of fishing grounds forces fishers to fish in other areas, thereby affecting their steaming time, which could lead to:

- Change in fuel costs
- Decreased overall efficiency by lowering the total fishing time
- Extended time at sea to maintain revenue
- Decrease in quality of the landed fish because of long trips
- Long trips could affect family life of the fishers
- Long trips raises safety concerns
- Encourage more careless fishing practices and non-compliance

Bastardie et al., 2014 modelled the effects of spatial restrictions on fisheries in the Baltic sea due to e.g. wind parks and MPAs in terms of how fishers allocate their effort, and what the consequences would be. They concluded that the energy efficiency of some of the vessels is strongly reduced with the new zonation of restricted areas in the western Baltic Sea (Bastardie et al., 2014). Changes in trip patterns resulted in a smaller proportion of the trip-time being spent on fishing, i.e. higher fuel intensity per landing (Bastardie et al., 2014). When looking at the individual scale, the most impacted fishers are the ones that cannot easily cope with additional steaming time to reach other grounds and return (e.g. within a day trip), which greatly affects their overall efficiency by lowering the total fishing time. These vessels will have to extend the time at sea to maintain their revenue and fish closer to the shore for saving fuel but at the cost of less rewarding catches (Bastardie et al., 2014). There are some downsides mentioned of fisheries displacement (Bastardie et al., 2014 and references therein): longer trips are not usually attractive for fishers in relation to, for example, the quality of the landed fish or the family life; long trips raises safety concerns; short trips may provide higher fish quality and more valuable products.

In 1999 a MPA network in West Hawaii was closed to aquarium fishing. Fishers believed the MPA network in West Hawaii was responsible for increasing fishing cost and distance travelled to fishing sites (Stevenson et al., 2013). The latter point (distance travelled) is likely attributed to the fact that fishers prefer launching their boats in a certain area (harbor effect) but also prefer fishing in other areas further away, which necessitates increased travel and thus increased cost.

4.1.4 Fishing gear

Potential conflicts for deploying various fishing techniques at the same location (e.g. mobile vs. static gears) may increase when more vessels are restrained to smaller areas (Bastardie et al., 2015).

An example of conflicts in gear is the increased loss of gear, and tear to fishing gear. The enlargement of the MPA in the Baltic Sea in 2005 increased gear conflicts (gear collision) between Swedish gill netters and cod trawlers which may have increased the number of lost (ghost) nets (Suuronen et al., 2010). Other fishers complained that they were forced to operate in less favourable fishing grounds, causing increase of wear and tear of fishing gears leading to additional costs (Suuronen et al., 2010).

4.1.5 Changes in CPUE

The effects of two major permanent spatial closures in 1995 in the U.S. Eastern Bering Sea designed for red king crab protection. showed a reduction in rock sole CPUE, which was strongly driven by displacement to less favourable grounds (Abbott & Haynie, 2012). However, an increase in cod CPUE was observed, suggested to be caused by the closure as well. Driven from their prime rock sole fishing grounds, fishers adapted to lower rock sole catch rates by targeting increased "bycatch" of cod and increasingly retaining it (Abbott & Haynie, 2012).

Compensation for the loss of fishing grounds inside a closed area, can be achieved by the benefits of the spillover effects (Greenstreet et al., 2009 and references therein):

- Increasing fishing levels outside the closed area, and/or;
- Increased CPUE outside the closed area.

It should be noted that spillover effects only occur under certain conditions, see section 0.

4.1.6 Decreased Gross Value Added (GVA)

During closure of the Cod Boxes, the number of trips by Dutch beam trawlers targeting common sole and plaice in the North Sea decreased from approximately 140 trips to less than 40 trips per week (Poos & Rijnsdorp, 2007). During area closure vessels either went fishing outside the North Sea, stopped fishing, or concentrated in the remaining open areas.

After total closure of the Plaice Box beam trawl effort in the plaice box in the period 1995-2008 fell to 3% of the “pre-closure” effort , while the exemption fleets of small flatfish beam trawlers, gill netters targeting sole (*Solea solea*) and shrimp (*Crangon crangon*) trawlers increased their effort (Beare et al., 2013). Contrary to the expectation, plaice landings declined in the North Sea (Pastoors et al., 2000). Beare et al. (2013) analysed the changes in the fisheries and tested whether the observed changes are due to the area closure or to changes in the environment unrelated to the ‘Plaice Box’. They conclude that the observed changes are most likely related to changes in the North Sea ecosystem and less likely to the change in fishing. This indicates that when changes in GVA coincide with area closure, it does not necessarily mean that this is caused by fisheries displacement.

Basterdie et al. (2014) evaluated the bio-economic efficiency of vessel movements using a model considering Danish and German vessels harvesting the North Sea and Baltic Sea fish stocks. The impact of the effort displacement caused by area closures (North Sea Dogger Bank, a part of the Norwegian deep in the North Sea and Skagerrak and an area around Bornholm in the Baltic Sea) was expected to cause a decrease in revenue from catches, fuel cost, GVA and VPUF (value per unit of fuel) (Basterdie et al., 2014).

4.2 Conditions for maintaining fisheries profitability after area closure

Closing areas to fishing is economically profitable when the value derived from spillover from the reserve outweighs the value of fishing in the patch (Sanchirico et al., 2006). Whether this is achievable is difficult to predict because it depends on the fisheries displacement and the ecological and economical effects thereof, as described in section 2.3, 3.1 and 4.1, respectively. The factors relevant for achieving economic profitability from area closures are (Sanchirico et al., 2006):

- the settlement success of the dispersing organisms,
- the nature of the costs of the fishing,
- the economic and ecological heterogeneity of the system,
- the discount rate, and
- growth characteristics of the fish population.

In general, it can be assumed that achieving economic profitability from area closures is more likely to be achieved when the closed area is a net exporter of biomass and has higher costs of fishing, and for fish populations with density-independent settlement ("adult movement") than with density-dependent settlement ("larval dispersal") (Sanchirico et al., 2006). Modelling results of Sanchirico et al. (2006) show that there are circumstances whereby closing low biological productivity areas, and even sometimes low cost areas to fish, can result in greater fishing profits than when both areas are open to fishing. However, Greenstreet et al. (2009) concludes that achieving higher CPUE outside the closed area through the spillover effect is difficult enough with MPAs designed specifically to enhance fishery yield and unlikely with MPAs with broader conservation objectives.

The DISPLACE study focussing on the western Baltic Sea (Bastardie et al., 2015), revealed that the effort displacement is beneficial for the stocks under study (see chapter 3) and therefore beneficial for the Baltic fisheries overall, when some areas are no longer accessible. The profitability of the fisheries is not significantly impacted or slightly lowered by the new restricted areas. Stable profits compensate for the additional costs from effort displacement. More efficient use of fuel from higher catch rates is only induced in the medium-to-long term, when the surplus abundance, generated by the positive response of the harvested stocks to the area protection, redistributes over the entire stock distribution areas (Bastardie et al., 2015).

5 Gaps in knowledge and recommendations identified in literature

5.1 Gaps in knowledge

The following gaps and general recommendations were identified while performing the review:

Experts representing the UK fishing sector, offshore renewable energy sector, planning and management and academia, indicated (de Groot et al., 2014):

- a large data gap for assessing effort displacement, considering e.g. potential effects of displaced fishing activity on ecology and socio-economic data
- the need for a standard methodology for assessing effort displacement
- that comprehensive methods for assessing fishing effort displacement are missing; most methods (VMS data; Plotter data; Mapping tools; Marine Spatial Planning) are not specifically developed to assess fishing effort displacement
- that research is needed on specific gear interactions and the dynamics of fishing areas

More specifically, data gaps on specific topics are on ecological drivers vs MPA effects.
The implications of fish movement and larval dispersal ("ecological connectivity") for MPA effects relative to those of fishing-the-line and fishing effort displacement ("fishers movement") have never been rigorously examined (Grüss, 2014). Ramírez et al. (2015) highlighted the importance of the interaction between dispersal rates of target fish species and the size of the closed area to MPA efficacy in recovering target species' biomass. However, quantitative relationships between dispersal rates and area sizes are not available. Also, the potential size of the spillover effect from area closure is unknown.

5.2 Recommendations

For assessing fishing effort displacement there is a need for (based on the study of De Groot et al., 2014):

- A variety of accurate data gathered through appropriate assessment methodologies;
- Data to be made available and shared freely whilst respecting commercial sensitivity;
- Assessment guidelines to be developed and distributed at a national level;
- Case studies need to be analysed to inform behaviour rules of various gears, vessels, and skippers;
- Best practice of displacement assessment to be shared.

It has been noted that covariates should be included in studies of closed versus open areas since their inclusion makes detection of effects more likely while their absence could lead to misinterpretation of the results (Jaworski et al., 2010 in Keller et al., 2014).

Quantitative information on the interaction between dispersal rates of target fish species and the potential size of the spillover effect in relation to area size would help establishing efficient MPAs and minimise adverse effects for fishers.

Current practices of MPAs negatively affect at least a number of fishers. To inform policy making, further research must better document and explain variation in the positive and negative impacts of MPAs (Mascia et al., 2010). Another valuable contribution to policy making and to establish efficient measures, is to closely involve fishers (Suuronen et al., 2010; de Groot et al., 2014). De Groot et al. (2014) proposed that consultation with the fishing sector regarding effort displacement consultation should be framed in terms of):

- Identification of locations where the displaced fishers go
- Assessment of new activity in the displacement area
- Assessment of changes in the pressure on fish stocks

6 MSFD measures and displacement on Frisian Front and Central Oystergrounds – workshop results

6.1 Introduction

The general aim of the overall study was to gain knowledge on fisheries displacement and to put this knowledge in perspective of future measures under MSFD. For the latter part of this aim, the results of above literature quick scan were discussed with North sea fishers and fisher representatives in a workshop. The workshop was held in Urk, on August 27 2015.
The aim of the workshop was to discuss possible consequences of closure of parts of the FF and CO (for 6 different variants for closure- see *Figure 10*), in terms of fisheries displacement, based on the knowledge and experience of fishers.

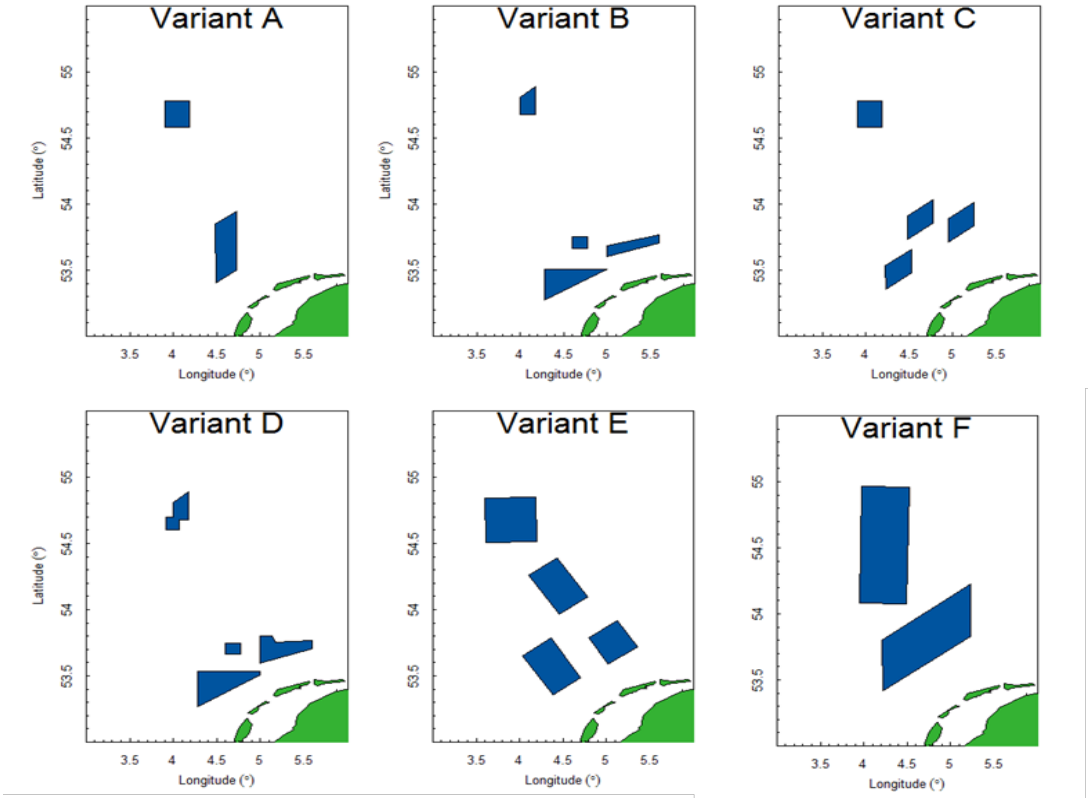


Figure 10 Six variants of closure of defining measures under MSFD. These variants are defined during a stakeholder process lead by the Ministry of I&E. Variants codes and names are defined by Van Oostenbrugge et al., 2015 A= Abelone/ B= Brill/ C= Capelin / D= Dab ./ E= Eel/ F= Flounder. Species names do not reflect target species of each of the areas.

The outcomes of this study and workshop results are used by Van Oostenbrugge et al., 2015 (upcoming) analysing the cost benefits of MFSD measures in the North Sea. More details and subsequent calculations on socio-economic effects can be found in that study. In this chapter, potential ecological consequences are evaluated.

In summary, the workshop focussed on several displacement aspects:

- General experience with displacement and its consequences (this chapter)
- Expected displacement behaviour and consequences per closure variant (this chapter) (see *Figure 10*, extended descriptions of each variant are provided in Van Oostenbrugge et al., 2015)

Fishers and fisher representatives that attended the workshop had been approached by VisNed, and the attendees represent the most relevant fleets/fisheries in the Frisian Front and Central Oystergounds. It is however important to realise that this small group of fishers and fisher representatives can't be seen as representative for the whole Dutch demersal fishing fleet. The summary in this chapter only reflects the discussion and aspects raised during this workshop. Attendees of the workshop are listed in Annex 2.

6.2 Historic closures, displacement and consequences

The representatives have various experiences with closures and subsequent displacement. A short list of historic permanent or temporal closures and restricted areas were mentioned by the fishers[1] are listed in annex 2. Based on this overview and subsequent discussions, fishers expressed that remaining areas for fisheries have become limited in the past decades. In addition, the overall perception is that *"closed areas will not be re-opened and stay closed"* (e.g. the Plaice box). Furthermore, fishers use certain fishing grounds which they know, which are practical (e.g. nearby the harbour), which are well suited for their gear, etc.

Displacement behaviour and opportunities depend on various aspects, during the workshop, these aspects were raised by fishermen:

- Differences in importance of fishing grounds (depending on the type of fisheries):
    - Key areas for fishers who have specialised in fishing the area: consequences of closure are very large; new areas will have to be sought - in some cases resulting in zero displacement effects as the skipper will stop fishing.
    - Areas that are occasionally fished: these areas will be 'less missed' as they are part of a portfolio of areas.
    - Some areas as used for 'fishing through' on the way to the main fishing grounds[2]: consequences will be that fishers would need to move around or haul their nets.
    - Historic vs future value of fishing grounds: it depends on the fish stock and migration what the actual value of a fishing ground is and where fisheries is absent now, but where it might return in future: this is an unknown factor.
- Is the closure temporary or permanent
    - Seasonality is an important aspect: pulse fishers only fish in autumn/winter in Frisian Front. During other periods, they fish with other gears, other target species, and other fishing grounds. At season level, one can be 100% depended of a fishing ground. However, when these dependency values are displayed on the year level, it seems that a fisher is only 25-30 % depended. Presentation of dependency is thus an important factor in evaluation of consequences.
- Timing, place and size of the closure
    - Change in fisheries due to recent application of innovative gears may lead to underestimation of values of fisheries (which are presented in yearly averages over periods, e.g. 2008-2012). Pulse fisheries recently started on a larger commercial scale (2012) and especially for Urker fishers closures of FF and CO fishing areas leave those fishers with fewer displacement opportunities than fishers of Texel. The reason is that Texel's pulse fishers started in the first round of pulse licences and are allowed to fish between 55-56°. Pulse fishers from Urk, who started later, are allowed to fish only below 55°. This means that Urker fishers depend more on the central North Sea than fishers from Texel.
    - "steaming fishing" or "fishing steaming" means that on the way to fishing grounds, fishers already fish. The area is known, and risk low. Fishermen state that closing such 'steam through fishing areas' means that fishing during steaming cannot be done,

[1] This is the information provided by the fishers. This list was not meant to be inclusive, but to start the discussion on experiences. Hence, the aim was not to complete the list and provide detailed information of each historic measure.

[2] e.g. pulse fisheries fishes during steaming, whereas this is not done due to higher fuel use for traditional bottom trawlers

resulting in higher costs for the fishing trips. It is important to note that when weather conditions are bad, fishers prefer steaming with their nets down as it increases the stability of the vessel.

- Skipper/crew
    - Character of the skipper and loyalty of the crew are important aspects in displacement and its consequences (see next section).
- Harbour/fleet
    - Each harbour and fleet have their own “historic rights” (see next section).
- Quota
    - Depending on the flag/ sea-days/ quota (including by catch quota).
- Fish stock/fishing grounds
    - Fisheries change over time, due to changing rules, regulations, gears, quota portfolio’s and market developments. Therefore also the fishing grounds vary throughout the years; areas that are important now, may become less important in future. And also vice versa: areas with low value now, can become valuable in a few years. Closing areas results in less flexibility in the fishing operations as less area is left for fishing.
    - The Frisian Front is an important turbot area for twinrig fishers. For some vessels this has become a highly specialised targeted by-catch fishery. Depending on the quota-portfolio, turbot can make an important contribution to the income.

The extent and economic consequences of each factor is hard to estimate because of uncertainties and variance of above mentioned aspects. Displacement is discussed for the current situation, and known factors, but factors which may be relevant in 5 years will determine the displacement as well. These are however unknown. Furthermore, additional smaller factors (not mentioned explicitly) will add to the actual displaced fisheries, and its consequences.

Some aspects of displacement and its consequences were discussed in more detail:

- Displacement after closure of the Plaice box
    - The plaice box is a major point of reference for the fishers and fisher representatives when discussing closed areas and displacement. The closure of the plaice box had a certain pathway of first being a temporal closure, then permanent. At first fishers kept fishing in the plaice box, once it was closed permanently the fleet displaced to the borders of the plaice box. Occasionally fishers would fish inside, but as penalties rose they stopped doing this. Nowadays fishers are not interested to fish inside anymore as there are no catches to be made anymore. So also vessels that are allowed to fish within the plaice box (<300 HP) don’t fish there for flatfish anymore. Also the borders of the plaice box are less interesting to fish nowadays than they were in the past. The pattern that was seen thus is: 1) fishing inside once open again (when it was temporary); 2) fishing the borders, 3) fishing elsewhere.
- Effect and consequences of size of a closed area
    - How fisheries will be displaced depends on the type of fisheries and on the size of the area. First, fishers will try fishing at the borders. Based on the experience of the Plaice box the fishers / fisher representatives assume that catches within other closed areas will decline, and that fishing the borders will eventually not be efficient. The fishers expect that fishers will be tempted to keep on fishing within the closed areas, how long this will be done depends on the penalties and chances to be caught.
- Effect and consequences of specialisation (skipper)
    - Some fishers only fish at fishing grounds that they learned from their fathers (“*where they grew up*”), others like to explore. Whether or not a skipper likes to explore (seek new grounds) or prefers fishing the grounds he knows, depends on tradition, and the personality of the skipper. If you are heavily specialised in a certain area and you need to displace it will imply that new grounds need to be explored resulting in higher costs. These can be considerable if a lot of time is needed to adjust the gear to the new grounds (e.g. gear can also be damaged as the result of objects on the ocean floor that are not known to the skipper) and to find the target species. Skippers with a more flexible state of mind are likely to adapt quicker than skippers with a less explorative way of fishing.

    - It is assumed that fishers who depend > 75% of their revenue on a certain fishing ground (this can be seen as year round but also seasonal) are specialist, and less adaptable, and will have a larger probability of quitting as a result of closures compared to those who are less specialised.
- Effect of harbour
    - Fishers from the same harbour have their fishing grounds often in the same area. E.g. Texel fishers fish more west than other fishers. 'New' fishers are not easily accepted when they search for new grounds. This is seen as a kind of historic right, although all fishers know that every fisherman has the right to fish in any open fishing ground. When closing areas, this "chain reaction" of searching new grounds by a specific part of the fleet, and interacting and conflicting with established fishers is often observed. In practice, fishers will oppose to new-coming exploring fishers.
    - Distance to harbour is an important aspect as most fishers want to be back in the port at the (beginning) of the weekend. Also, steaming distance is part of the costs, and less steaming means more profit.
      However, not all fishers or fleets are tied to a harbour. E.g. The Urker fleet does not have their own 'hometown' harbour, and are more flexible in landing at different harbours than fishers from other villages.
- Consequence: Change of gear
    - Some fishers decide to change or adapt their gear, others do not. Consequences of changing gear are large as nets can be torn, one has to learn how to fish in another area, resulting in lower catches. General rules cannot be drawn as one fisherman can have higher catches on the same grounds than another fisherman, with the same gear type and target species, due to differences in experience and fine-tuning the fisheries.
    - Fishers whom have multiple gears and / or nets, and who fish at various grounds are likely more flexible in displacing their fisheries than more conservative / specialised fishers.
    - It is important to realise that fishers often have different nets and in some cases also different gears per season. If viewed from an annual perspective one might conclude that closure will not affect these fishers as they have alternatives. But these 'flexible' fishers can be highly dependent on certain grounds from a seasonal perspective. In addition it is good to realise that seeking new grounds in a seasonal timeframe is more limited due to the shorter period available to secure the catches.
- Consequence: mobility of crew
    - Fisher crew always compare earnings/revenues and work load between vessels[3]. When a vessel would need to displace and catches subsequently decline, the skipper risks losing his crew. The fishers / fisher representative state that the presence of foreign crew members on a vessel could be seen as an indication for a fishing company being less competitive in this respect. Crew are less inclined to 'calculate' the costs of damage of gear as these costs are always borne by the skipper-owner.

6.3 Expected displacement on Frisian Front and Central Oystergrounds for six closure variants

Expected displacement per variant (see *Figure 10*) is discussed for three types of fisheries. During the workshop the following three fihsieres were discussed with the present fishers: Twinrig on nephrops- Flyshoot on mullet- pulse- mixed fisheries.

The discussion on expected displacement is summarized in *Table 3*. More detailed socio-economic consequences of displacement are described in the cost benefit study of Van Oostenbrugge et al. (2015).

[3] It is likely that other aspects also play a role, but these two are mentioned in this respect.

Table 3 Overview of expected displacement per variant for three types of fisheries. Input is provided during the workshop, in bilateral discussions (1 fisherman and 1 researcher taking notes). It should therefore be taken as first reflections, which are not evaluated with a larger group of fishers using the same specifications.

Variant	**Twinrig**	**Flyshoot**	**Pulse**
Generic comments	Discussed from twinrig fisheries targeting nephrops, only UK flag ships point of view Specific fishing grounds for Nephrops have to be drafted in the maps in order to determine the actual consequences/variant. Generally Nephrops fishers fish fairly close to each other in the same area. The consequence of displacement may however be different among fishers (e.g. depending on port, and its dependence on neprhops fisheries). Generally it can be said that consequences of displacement consist of circumnavigate (time, fuel costs and increased risks (wrecks, tearing nets, ammunition) and less effective catches in new search areas. This is relevant for all variants (except Brill and Dab). Twinrig vessels (fishing) cruise with a speed of 3 miles/hour, and circumnavigate therefore takes a long time (depending on the variant). Fishing in these areas takes place in April / May and August / September, and is co-dependent of quota when there will be fished exactly (e.g. if a ship has a larger plaice quota one is more flexible to fine adjust its fisheries elsewhere for plaice, compared to those with a smaller plaice quota.	The flyshoot fishery chases red mullet and mullet on their yearly migration across the North Sea. In the period May-July these fish are in the area of the Frisian Front and can then be caught by 5-6 flyshoot ships. Then the fish migrate through to the German Bight and in the autumn they migrate on the English side, returning to the channel. Fisheries follow the fish on their route. The Frisian Front is therefore an important area for these fisheries in the period May - July, as there is little / no alternatives. In addition, more easterly on the North Sea plans exist to create offshore wind farms, so opportunities to displace are also limited. An alternative fishing area is dependent on the fishing quotas concerned for each individual fisherman/vessel: with enough plaice quota the fisherman can displace to the Dogger Bank, with sufficient cod quota he is able to displace to areas like Skagerrak (hence, this is a limited option). Regarding displacement to the Dogger Bank it is expected that the catches in the first year after displacement will be no more than 50% of that of twinrig fishers and a lack of knowledge of the area. In the following years this percentage is expected to rise to 75%. It should be taken into account that the trip to the Dogger has an extra	The Frisian Front is the biggest problem. The more north (Central Oyster grounds) IF it has to be done, then the CO can be missed. The importance of the Frisian Front is that there are some great fishing grounds to be found, longer hauls can be made (relative 'easy' fishing), it is relatively nearby which is important for smaller vessels but also for larger vessels in winter time and when weather is rough (safety). Catches at the Frisian Front fishing grounds are good and mixed. This latter point is important as for many fishers, their sole quota is not large enough so they need to have mixed catches in order to be able to fish year-round. But also it lies right 'in front' of the Northern Harbours (Den Helder, Harlingen). 70-80% of the Urker fleet hails from Harlingen (due to the facilities there) and the Frisian Front is right on the doorstep. The main focus point is the 30m depth line, it goes right through the Frisian front and is the border between harder and softer grounds. Fishing vessels often fish through the Frisian Front following that line. The biggest issue with any closure on the Frisian Front are the specialist fishers,

	Additional time will be (depending on the ship and the options) fished elsewhere on sole / plaice with e.g. pulse/beam/flyshoot. Even shrimp fishing can be an option for some fishers. However, displacement to other neprhops fishing grounds depends on factors such as season (temperature) and distance. It cannot be said that fishing in April / May can be displaced to eg Botney Cut because then there are no lobster to fish because the temperature is too low which affects the nephrops in the area. Change to other gears is no option (generally spoken). Investments in costs, effort and time to adjust fisheries now pays in contracts for delivery (which must also be guaranteed) . Developments in fish stocks may result in less effective fishing value in the future in areas that remain open. Closed areas may have more value in the future , but are then no longer accessible.	eight hours of steaming time (one way) and fishing is more dependent on the weather. To fish freely in the remaining areas of the North Sea it is expected that the revenues are 40% lower.	smaller vessels often. They fish there from September – March. They have their main fishing areas on the FF. These are fishers that are less adventurous, have built up in-depth knowledge of these areas and have always been satisfied with their routines – they haven't innovated, invested heavily, risked a lot etc. they are peaceful fishers doing what they do. If they need to move, they have no knowledge of other areas and due to their limited HP, their action radius is smaller. The expectation is that if they will have to move, they will quit. For the whole fleet the displacement of vessels will result in increased competition.
Flounder	Typically, fishing during cruising is done in order to arrive at the actual fishing grounds. From Harlingen you cannot do this in this variant, to arrive at the more northerly grounds while fishing. Fishing during steaming from east to west or vice versa to get to the other side of a closed area is no option anymore. This results in a great loss in time to spend fishing and thus yield. Because time at sea is limited because of trips from Monday to Saturday because of religious principles(for Urk fishers), there is no	The eastern side of the closed area is located in the fishing ground of the flyshoot ships in summer. For 5-6 ships , this means a considerable decline in fishing opportunities. This has the above described consequences as a result .	The main problem is the absolute and total closure of the Frisian Front. The area specialists will be out of business. The majority of the fleet of the Northern harbours will need to fish around or steam through (without fishing) a considerable area. The latter is in fact never done. For the pulse fleet the area is mainly important from September till March. Due to the depth, it is always possible to fish here and it is relatively nearby.

	opportunity to compensate by increasing trip periods. This variant seems impossible to continue nephrops fisheries.		
Eel	In this variant , it is somewhat easier to displace compared variant Flounder because the areas are slightly separated and fishing during steaming seems a possibility. But basically the same consequences and factors remain as described above. If the fishing grounds are exactly in the closed areas other grounds should be searched for.	This variant allows more opportunities to remain in the fishing grounds, but the fisheries on the borders of, -and thus the area between the closed areas- also means risk to move out of in the area (chance on violation when entering closed area) by flow , etc. There is not enough space for six ships to navigate around the areas.	See Capelin.
Capelin	In this variant a bit more room for movement (both circumnavigate and seek new specifications) is assumed compared with the variants in which larger areas are presented. In this variant the entire space between Ff and CO will be available which seem to be also good grounds. The consequences seem less than in the above discussed variant, but did not say with certainty.	Also this variant lies in the fishing area (eastern part of the FF) from May to July, but this variant does provide more fishing opportunities in the area. This variant is worse than variant D because of the position of the closed sub -area in the east of the FF (somewhat more north). South of this area is, however, more open area, to which the fisheries may be displaced. This is probably not an option for all ships.	More details are needed to evaluate this variant (see the remark under 'general' about the 30m line). These are areas containing good fishing grounds. But it is at least positive that it provides corridors for these fishers to fish through.
Abelone	There seems to be space in the area between FF and CO to continue fishing for crawfish, but without good map WHERE fisheries takes place, an estimate on the extent of the consequences cannot be done. In particular, the FF sub areas are a problem, the CO sub-area is of a lesser problem . FF is mainly a problem because of circumnavigation the area at a rate of 3 miles takes an awful lot of extra steaming time (irt the length of the	No problem	We would like to be able to fish on along the 30 m line (see general). These areas are at least not too big (relatively) so there is room to talk about this.

	region up to 800 km additional distance) which is at the expense of effective fishing time.		
Dab	Especially for Twinriggers this variant pose minimal impact and can be fished as usual (including nephrops , sole and plaice Twinriggers). For eurokotters it is unclear what the consequences could be, this depends on the trends in stocks.	No problem	Same as Brill – but this is a bit larger.
Brill	No problem, see previous	No problem	This scenario has the least impact for us. Mostly small vessels will be impacted as they currently fish there. Some pulse vessels as well. But this scenario is what is doable for us, and for the area-specialists amongst us there will be alternative fishing areas in the near vicinity.

7 Ecological effects of expected displacement in context of MSFD measures

The expected displacement in *Table 3* is translated into ecological and socio economic consequences. During the workshop, future displacement was discussed, and it depended on the variant and fisheries whether the expected displacement could be specified in more detail or not.

As the displacement behaviour in time and place are unknown, 2 concepts are evaluated based on the two potential situations described by Greenstreet e al., (2009):

- displacement is spread equally over the NCP- and additional disturbance is limited
- displacement is concentrated along the boundaries of the closed areas and in the same fishing grounds, with exception of the closed areas. Additional disturbance is substantial.

Socio-economic consequences are included and described in the study of Van Oostenbrugge et al. (2015).

7.1 Displacement spread equally over DCS

The various fishers will displace to other areas where they will fish in addition to the fishing pressure already present.

We can assume that displacement effects on ecology outside the future closed areas is unsure but likely to be very small when effort is spread over the DCS or North Sea. It is assumed that when the horsepower's are spread evenly over the North sea or DSC, the additional effort per km2 becomes negligible, and causes relatively little additional mortality of benthic invertebrates (hence Greenstreet et al., 2009). It is thus expected that outside the closed areas the ecosystem will not change due to displacement of this part of the fleet. The ecosystem will be set back to early successive state of development after each disturbance. This effect is of relatively lower significance in ecosystems with higher natural dynamics (shallow, areas with more wave action) compared to ecosystems that have intrinsic lower dynamics (deeper areas with less wave action). The addition is expected to be negligible.

7.2 Displacement concentrated along borders

Fishing the boundaries of closed areas aiming at the spillover effects is not likely to happen in the different scenarios of closure at FF and CO. Lizaso et al. (2000) concluded that although there is potential biomass export from MPA's, but in practise, little empirical evidence has been reported. In addition, closed areas are likely to provide fisheries benefits for mobile populations only when these populations are overexploited outside the MPA (Gruss et al., 2011). In that case, fish biomass inside the reserve is (in comparison) so much higher, that the fishery benefits through recruitment subsidy and spillover are larger than the potential catch which is lost by creation of the MPA. However, the target species plaice and sole are not overexploited at the NCP level, and this effect in thus not likely to occur due to targeting of the spillover of fish.

As was drafted during the workshop (*Table 4*, which is based on results in *Table 3*), it is likely that some fleets will displace themselves to similar fishing grounds close by- assuming the fishing ground is the same. A worst case scenarios then is that the fisheries concentrate along the borders as this habitat is most likely to be the same as inside the closed area- rather than due to spillover effects.

In addition to the above, it should be mentioned that as the fleet is in transition from larger beam trawl vessels towards innovative gear types, and gear related effects on benthic system in this fishing grounds are largely unknown with respect to fishing pressure it is not possible to quantify the effect of additional

fisheries in the area. In general, nothing changes outside the closed areas. Where the ecosystem within the closed area benefits from the measure and returns to natural dynamics and structure and functioning, the ecosystems outside the closed area might still be placed into an early successive state of development after disturbance. A potential increase of fishing pressure will most likely not steer large differences compared to the current situation. It can be assumed that the generic decrease in fishing pressure over the last decade potentially led to increased ecological health. The increase of (concentrated) fishing pressure outside the closed areas might eliminate the assumed positive effects. However, this latter part is highly speculative, and cannot yet be evaluated with data.

Initial effects of fisheries in unfished areas have disproportional impact on benthic communities (Dinmore et al., 2003). As the area near the Frisian Front is highly fished already, these disproportional effects are not expected for already trawled areas. One side effect can be expected however. Fishing intensity in an area is not homogeneously distributed (Piet & Quirijns, 2009). Patchiness of fisheries on the smaller scale is known to be present, also in this area. According to Dinmore et al., (2003) this patchiness has an effect on the patchiness of benthic populations as well. At the larger patches, species are capable of survival. Additional fishing pressure will potentially lead to more homogenous pattern of disturbance, decreasing this effect of patchiness, and potentially lead to impact on species that had benefit of the patchy fisheries distribution. To determine the fishing-induced mortality of a particular species, the trawling frequency needs to be determined at those spatio-temporal scales that are appropriate considering the species' spatial processes (e.g., dispersion) or temporal processes described by life history characteristics (Piet & Quirijns, 2009), and a generic effect of displaced fishing pressure is thus not yet defined.

Table 4 Ecological consequences due to displacement per closure variant, for three types of fisheries.

Variant	Twinrig (nephrops)	Flyshoot	Pulse
Generic comments	Generally fishers fish fairly close to each other in the same area in periods April/May and August/September due to catchability of nephrops in that period. As fisheries on the FF is seasonal, displacement is seasonal as well, and not year-round. It can be assumed that displacement will be explorative and heterogeneous in open areas, or around the borders if actual fishing grounds are positioned close to the border. After exploring fisheries will concentrate in areas when proper fishing grounds are found.	Fisheries follow the fish on their route and displaced fisheries depends on these routes. . The Frisian Front is an important area for these fisheries in the period May - July, as there is little / no alternatives due to the migration of fish. In addition, more easterly on the North sea plans exist to create offshore wind farms, so opportunities to displace are limited. Displacement probably focusses on the open areas. In case of enough plaice quota the fisherman can displace to the Dogger Bank, with sufficient cod quota he is able to displace to areas like Skagerrak (hence, this is a limited option). These latter two options can be evaluated as a heterogeneous distribution of fisheries with low additional ecological impact.	The Frisian Front is the biggest problem, pulse fishers fish in this area from sept-march The main focus point is the 30m depth line, it goes right through the Frisian front and is the border between harder and softer grounds. Fishing vessels often fish through the Frisian Front following that line. Specialist have no idea where to fish after closure of FF.
Flounder	Seems impossible to displace nephrops fisheries. Ecological effects cannot be evaluated.	For 5-6 ships , this means a considerable decline in fishing opportunities, and unknown displacement behaviour. It depends on the quota where they will displace to. Ecological effects cannot be evaluated.	The majority of the fleet of the Northern harbours will need to fish around or steam through. Displacement of the fisheries is most likely to the borders, around 30 m depth line. Depending on the additional fishing pressure on the 30 m depth line, ecological effects will locally be enlarged.
Eel	Displacement to open areas between the closed areas. Change to even more concentrated fisheries, and explorative fishing of remaining	This variant allows more opportunities to remain in the fishing grounds, but the fisheries on the borders of, -and thus the area between the	See Capelin.

	grounds. Displaced fishing effort leads to and localised effects in ~4 months per year. Effects depends on the additional fishing pressure.	closed areas probably has not enough space for six ships to navigate around the areas. Unknown of every ship will do so. IF all ships would displace to this area, localized effects on ecology are assumed to increase, but effects depends on the additional fishing pressure.	
Capelin	Displacement to open areas between the closed areas. Change to even more concentrated fisheries, and exploration of grounds. Effects on ecology might be a local in the open areas due to displaced fishing effort in ~4 months per year. Effects depends on the additional fishing pressure.	South of this area the fisheries may be displaced to. This is probably not an option for all ships. Depending on the additional fishing pressure, ecological effects will locally be enlarged but yet unsure as this depends on the species and local habitat.	Displacement to open areas as these are areas containing good fishing grounds and fishing through the corridors. Depending on the additional fishing pressure on the 30 m depth line, ecological effects will locally be enlarged.
Abelone	Displacement to open areas between the closed areas. Change to even more concentrated fisheries, and exploration of grounds. Effects on ecology might be a local in the open areas due to displaced fishing effort in ~4 months per year. Effects depends on the additional fishing pressure.	No large change in fisheries and no changed effects on ecology	Displacement along the 30 m line. Depending on the additional fishing pressure on the 30 m depth line, ecological effects will locally be enlarged.
Dab	no changed fisheries and no changed effects on ecology	no changed fisheries and no changed effects on ecology	Same as Brill – but this is a bit larger.
Brill	no changed fisheries and no changed effects on ecology	no changed fisheries and no changed effects on ecology	Only slightly displaced fisheries close to the area, no changed effects on ecology expected

8 Summary and conclusions

8.1 Displacement - where and why

Displacement in time and space depends highly on the importance of the closed fishing grounds (size and place), the expertise and character of the skipper, distance to the fishing harbours, and the quota for the different fish. These factors all result in a certain level of specialisation of the fisherman/fisheries. The more specialized, the harder it is to displace or to predict where displaced effort will be allocated.

The extent of displacement in terms of location and effort is hard to forecast because of uncertainties in this phase of the process of implementing the closed areas. Moreover, factors which may be relevant in 5 years will determine the extent, spatial and temporal dimensions of displacement in future as well. These are however unknown, in definition and extent.

In general, a few rough estimates on displacement were drafted during the workshop by a small selection of fishers and representatives. We emphasize that these conclusions are not widely discussed and confirmed within the fisheries sector, and reflect only a first attempt to qualify displacement.

- Twinrig nephrops fishers might first explore near/at the borders of the closed area, in case this is nearby their original grounds. Displacement will probably be explorative and heterogeneous in the remaining open areas when fishing grounds are all closed. After exploring, fisheries will concentrate in areas when proper fishing grounds are found.
- Flyshoot fishers may follow the fish on their route and displaced fisheries depend on these routes. As a result, the Frisian Front is an important area for these fisheries in the period May - July. Displacement probably focusses on the open areas, nearby the optimum concentration of fish stocks. Displacement also depends on the amount of quotas. In case of enough plaice quota fishers can displace to the Dogger Bank, with sufficient cod quota they will be able to displace to areas like Skagerrak.
- Pulse fisheries may displace to the remaining open areas of 30 m depth. This depth line goes right through the Frisian front and is the border between harder and softer grounds. Specialists probably have no idea were to displace to in case the largest variants for closure (Flounder) is implemented.

The above scenarios show that displacement cannot be generalized for near future, as well as on the longer term, nor it can be predicted for the whole fleet. Factors such as growth of a certain fleet has not been taken into account.

8.2 Displacement - consequences

Understanding the spatial-temporal patterns of fishing-effort allocation around closed areas is essential for assessing their effectiveness (Forcada et al., 2010). As described in this review there are many factors influencing fisheries distribution after area closure. Also the effect of fisheries displacement depends on many different factors. Increased effort in lightly- or unfished areas would cause substantial additional mortality (Greenstreet et al., 2009), whereas increased effort to an already heavily fished area causes relatively little additional mortality of benthic invertebrates. This would also be the case for the North Sea (Dinmore et al., 2003). It has been concluded in literature that closed areas alone appear inefficient at reducing fishing impact on the overall North Sea benthic invertebrate community (Greenstreet et al., 2009). Measures concerning the closure of areas should therefore be combined with additional management measures, such as TAC in order to compensate for the additional fishing pressure in the remaining areas. In addition, fisheries on larger fish within the best fishing grounds could shift to

catch of smaller fish in less fishing grounds. This effect of displacement on the (by) catch of smaller fish could also affect fish stocks.

The literature study in general, and the discussions during the workshop, emphasize the need for gear specific high resolution VMS data for use in spatial planning when managing both fisheries (this study) and seabed habitats for e.g. biodiversity conservation (Campbell et al., 2014). The lack of gear type specific (and flag specific) spatial and temporal maps was put forward as essential input for proper discussions. The effort to produce these high resolution maps was not available in this first attempt to outline displacement. Hence, it is hard to make high resolution estimates on consequences as well.

The consequences of displacement (after closing areas), both in ecological as in economic terms, depend largely on the level of specialisation of the fisheries. The level of specialisation results in choices on where and when to fish elsewhere. On the North Sea level, it is yet uncertain where which fisheries will exactly displace to and with what effort. Ecological impact of displaced fisheries depends on the type of habitat, the historic fishing pressure, the additional fishing pressure, and the gear type of displaced fisheries.

In the context of the MSFD potential closures local additional effects on ecology are possible on the borders of some of variants **IF** all fisheries would concentrate along the border of the MPA. Although a (long term and structural) concertation of fisheries along the borders is unlikely to happen, this might temporally be possible for MSFD measure variants Abelone, Capelin, Eel and Flounder- related to flyshoot and twinrig fisheries. For pulse fisheries, additional effects are expected along the 30 m line- along the or in the region of the Frisian Front. The extent of the additional impact is however hard to quantify due to limited information in this phase of the study. Flyshoot fisheries exploring the e.g. Skagerrak will most probably display a heterogeneous distribution, resulting in a low or negligibly additional ecological impact on the benthic community.

Economically, the consequences are drafted in Van Oostenbrugge et al., (2015). Yet, we can state, that fishers without experience in the open remaining areas will be affected more compared to fishers with experience and more generalised way of fishing (exploring and adapting).

9 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Rapport C170/15
Project Number: 4315810001

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Dr. Jan Jaap Poos
Senior researcher

Signature: 

Date: 9th of December 2015

Approved: Dr. Luc van Hoof
Department head Fish

Signature: 

Date: 9th of December 2015

Annex I Overview of MPAs of which fisheries displacement has been described

Area	Purpose of closure	Year of closure	Size	Period closure	Reference
Northeast USA	Groundfish protection	1994	More than 22 000 km^2	Partly year-round, partly temporal closure	Murawski et al. (2005)
Northeast USA (Georges Bank and areas in the Southern New-England)	Groundfish protection	1994	ca. 17 000 km^2	Year-round	Murawski et al. (2000)
West coast USA	Rockfish protection	2003 - 2011	Permanent closed area is ca. 134 000 km^2	Variable in time and space and gear restrictions	Keller et al. (2014)
MPA (Marine Protected Area) network in West Hawaii	Reeffish protection	1999	Not reported	Permanent closures	Stevenson et al. (2013)
Two areas in the North Sea (Cod Box)	Cod protection	2001	More than 40 000 square miles	Closed during spawning season	Poos & Rijnsdorp (2007); Dinmore et al. (2003)
Plaice Box in the North Sea	Plaice protection	1989	42,000 km^2	Year-round	Pastoors et al. (2000); Beare et al. (2013)
The Browns Bank on the Scotian shelf	Groundfish protection	1970	Not reported	Closed from 1 Feb to 15 June each year (spawning)	van der Lee et al. (2013)
Tabarca Marine Reserve (western Mediterranean Sea)	Commercial species protection	1986	1400 ha	Permanent closures	Forcada et al.(2010)
The Arrábida Marine Park (AMP) on the west coast of Portugal	Habitat protection	2005	53 km^2	Year round	Horta e Costa et al. (2013)
Two potential closed areas in the UK (Wave Hub and Haig Fras)	Enabling renewable energy (Wave Hub) and nature conservation (Haig Fras)	Not relevant	Energy park Wave Hub is 8 km^2 and Haig Fras, a proposed N2000 area is a 45 km long reef	Permanent closures	Campbell et al. (2014)
Baltic Sea (Bornholm	Habitat	1995	Not reported	In 1995	Suuronen et

Area	Purpose of closure	Year of closure	Size	Period closure	Reference
Deep, Gdansk Deep and Gotland Deep)	protection			seasonal (June-August) closure and in 2005 permanent closed areas	al. (2010)
Two areas in the U.S. Eastern Bering Sea (Red King Crab Saving Area and Pribilof Islands Habitat Conservation Area)	Red King Crab, marine mammals and birds protection	1995	RKCSA ca. 13 700 km^2 and PHCA not reported	Permanent closures	Abbott & Haynie (2012)

Annex 2 Workshop information

Attendees

- Hein Nijntjes NL schip = DU vlag kotter- member of the board of Visned
- Wouter de Boer UK224 flyshoot member of the board of Visned
- Wouter van Broekhoven Visned Science and policy advisor
- Maarten Drijver TX30; fisher representative – member of the board of Visned
- Andries de Boer owner 3 UK vlagkotter- member of the board of Visned
- Geert Meun Visned and CVO secretary.

The workshop was coordinated and reported by LEI and IMARES researchers (Kraan, Van der Valk, Van Oostenbrugge, Slijkerman).

List of closures of which the attendees have experience with:

- The plaice box
- Real Time closures (RTC's), e.g. for cod
- Offshore wind parks (safety zone of 2 mile, in practice 5 mile)
- HP Above 55° --> closed for vessels >2000 hp
- Pulse 55° --> pulse fisheries first selection are allowed to fish up to 56°, 2nd selection up to 55°
- "Cod Box" measures
  - Only 100 mm mesh allowed
  - 6 months ~1990-1995, quarters 1+4
- Offshore oil and gas platforms
  - Safety zone of 500-1000 meters
  - In practice 4 mile: contact/call stand by vessel to inform the skipper

- Restrictions in
  - < 3 mile (Dutch coast- Dutch fleet allowed, Danish, UK and German not allowed. Relevant for those Dutch fisherman that fish under foreign flag)
  - < 12 mile (1976)
  - Shipping lanes/Traffic Separation Schemes