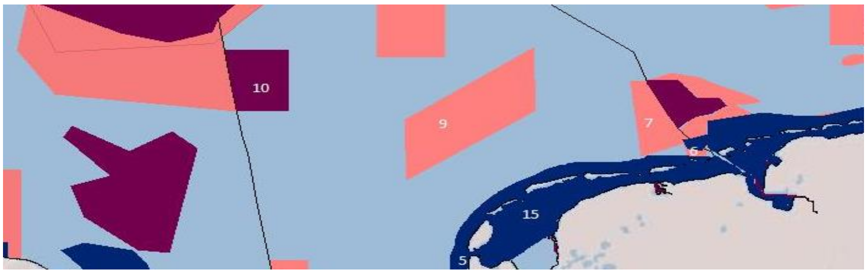
An exploration of potential effects on fisheries and exploited stocks of a network of marine protected areas in the North Sea

T. van Kooten, C. Deerenberg, R.G. Jak, R. van Hal &
M.A.M. Machiels

Report number C093/14



IMARES Wageningen UR

(IMARES - Institute for Marine Resources & Ecosystem Studies)

Client: World Wildlife Fund
Netherlands
P.O. Box 7
3700 AA Zeist

Publication date: 2 July 2015

IMARES vision:

- To explore the potential of marine nature to improve the quality of life.

IMARES mission:

- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.

IMARES is:

- An independent, leading scientific research institute.

Recommended citation format: van Kooten, T., Deerenberg, C., van Hal, R. & Machiels, M.A.M. (2014) An exploration of potential effects on fisheries and exploited stocks of a network of marine protected areas in the North Sea. IMARES Report C093/14.

P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

Contents

Samenvatting

Dit rapport geeft de resultaten weer van een verkennend onderzoek naar de mogelijke visserij-effecten van een voorstel van de opdrachtgever (WWF Nederland), voor een netwerk van beschermde gebieden op de Noordzee (Fig. 1.). In dit onderzoek wordt uitsluitend gekeken naar visserij-effecten van volledige sluiting van deze gebieden voor visserij. Volledige sluiting van alle gebieden is een hypothetische keuze om discussie te faciliteren. Deze keuze vormt geen voorstel tot volledige sluiting, noch van WWF Nederland, noch van IMARES. . Het onderzoek omvat een aantal deelvragen, namelijk

1. Wat zijn de mogelijke positieve effecten van gebiedssluitingen op de visserij in de omliggende zee?
2. Hoe belangrijk zijn de verschillende gebieden voor de opbrengst van de Nederlandse visserij?
3. Wat zijn de ecologische functies van de verschillende gebieden voor de belangrijkste vissoorten die door de Nederlandse vloot op het Nederlands Continentaal Plat worden bevist?
4. In hoeverre zijn de randvoorwaarden voor positieve visserij-effecten van sluiting van toepassing op elk van de voorgestelde gebieden, op basis van de analyse in de punten 1, 2 en 3 hierboven.

Mogelijke positieve effecten van sluiting van gebieden voor de visserij

Positieve effecten van sluiting op de omliggende visserij zijn mogelijk via (a) export van larven uit het gesloten gebied naar het beviste gebied, en (b) export van vangbare vis uit het gesloten gebied naar het beviste gebied. Beide mechanismen leiden tot een direct voordeel voor de visserij, als ze meer vangst opleveren dan zou zijn behaald wanneer de sluiting er niet geweest was. Van beide mechanismen zijn empirische voorbeelden, maar het merendeel hiervan is afkomstig uit zeer kleine reservaten en/of koraalriffen, met een beperkte relevantie voor de Noordzee. Er zijn echter ook voorbeelden (met name Georges Bank) van herstel van vis- en schelpdiersoorten na omvangrijke gebiedssluiting in meer met de Noordzee vergelijkbare ecosystemen. Alle gevonden voorbeelden waarbij het instellen van een gesloten gebied heeft geleid tot hogere vangsten in de visserij, zijn gevallen waarbij de visbestanden ernstig overbevist waren voorafgaand aan de gebiedssluitingen. Over effecten van gebiedssluitingen op visbestanden die niet overbevist zijn is niets bekend.

Het belang van verschillende gebieden voor de Nederlandse visserij

In totaal komt ongeveer de helft van de opbrengst van de Nederlandse visserij uit de gebieden waarvoor sluiting wordt voorgesteld. Tussen de voorgestelde gebieden onderling zijn grote verschillen in de mate waarin ze worden bevist, en de opbrengst die de visserij er genereert. De kustgebieden worden zowel in bevissing als in opbrengst sterk gedomineerd door de garnalenvisserij. In verder van de kust gelegen gebieden hangt de bevissing sterk af van de geschiktheid van de bodem voor bepaalde vistuigen, maar ander factoren zijn ook van belang. Zo wordt op de Centrale Oestergronden nauwelijks met de boomkor gevist, omdat dit tuig niet goed werkt op de daar aanwezige bodem. Tegelijk is de boomkor voor de Nederlandse vloot een zeer belangrijk tuig. Daardoor is automatisch de waarde van dit gebied laag voor de Nederlandse vloot. Zulke patronen kunnen er anders uit zien wanneer vloten van andere nationaliteiten worden geanalyseerd.

Ecologische functies van de voorgestelde gebieden voor commercieel beviste soorten

Alle onderzochte vissoorten (Schol, tong, griet, tarbot, kabeljauw, wijting en een categorie 'overige soorten') komen in meer of mindere mate over het hele NCP wel voor.
De enige niet-vissoort die in deze analyse is meegenomen, de grijze garnaal (*Crangon crangon*), komt uitsluitend langs de kust voor. Voor de vissoorten bestaat over het algemeen een duidelijke ruimtelijke verdeling binnen het NCP, waarbij de kustgebieden als kraamkamer voor de juveniele individuen fungeren, terwijl de broed- en foerageergebieden voor de volwassenen juist verder van de kust liggen. Wel zijn een aantal van de voorgestelde gesloten gebieden die meer offshore liggen, belangrijke paaigebieden voor een aantal van de onderzochte vissoorten.

Conclusies: in hoeverre zijn positieve visserij-effecten te verwachten van de sluiting van de voorgestelde gebieden?

1. Het sluiten van de 'kinderkamergebieden' langs de kust zou kunnen leiden tot verhoogd recruitment van deze soorten, maar of dit gebeurt hangt af van hoe dichtheidsafhankelijkheid in deze bestanden optreedt. Dit is grotendeels onbekend.
2. Er is een duidelijk voorbeeld (Georges bank) dat laat zien dat het sluiten van een groot, productief gebied kan leiden tot snel herstel van overbeviste soorten waarvoor het gesloten gebied van belang is. Eenzelfde resultaat is denkbaar bij sluiting van het Friese Front en de Doggersbank in de Noordzee. Daarbij moet wel worden aangetekend dat slechts een fractie van de commercieel belangrijke vissoorten in deze gebieden (vanuit visserijperspectief) herstel behoeft. Hoe sluiting de overige relevante soorten (die geen herstel behoeven) zal beïnvloeden is niet bekend.
3. In de 'hard substraat gebieden' Borkumse stenen, Centrale Oestergronden en Gasfonteinen (maar niet de Klaverbank) vindt zeer weinig visserij plaats door de Nederlandse vloot, waardoor effecten van sluiting van die gebieden voor de visserij-industrie weinig effect zullen hebben.
4. De Klaverbank is een belangrijk paaigebied, met name voor kabeljauw. Het kabeljauwbestand is ruim beneden de voor visserij optimale grootte. Sluiting van dit gebied zou leiden tot minder verstoring en daardoor mogelijk tot meer paai-activiteit, en zou zo een bijdrage kunnen leveren aan het herstel van kabeljauw in de Noordzee.
5. De overige gebieden zijn erg klein, waardoor visserij-effecten van sluiting klein en lokaal zullen zijn.

1 Introduction

1.1 Background

WWF Netherlands has developed a proposal for a network of Marine Protected Areas (MPAs) in the North Sea. Most of the MPAs in this network are already protected under the Natura 2000 framework and/or the Marine Strategy Framework Directive. WWF Netherlands aims to engage with stakeholders and build support for this proposed MPA network. One of the most prominent of these stakeholders is the fishing industry. To provide input for the discussion with stakeholders, the current study investigates potential fishery effects of a total fishery ban in each of the marine protected areas. This represents a hypothetical choice to facilitate comparison with existing scientific literature and calculations of quantity and value of catches and does not reflect a proposal for a total fishery closure of the entire network by either IMARES or WWF Netherlands.

Although traditionally, MPAs are perceived negatively by fishermen because they limit their freedom to conduct their business, there are examples in the scientific literature which show that implementation of MPAs can also benefit in several ways the fisheries surrounding the MPAs. WWF Netherlands would like to understand how these examples relate to the North Sea and what advantages and disadvantages may be expected for the Dutch fishing industry when the proposed MPAs are implemented.

1.2 Assignment

This project delivers:

1. Insight into the importance of the various parts of the proposed MPA network to a number of different fisheries which operate in the Dutch North Sea.
2. Insight into the potential fisheries benefits of MPAs in the North Sea (and similar temperate waters) and the factors on which such benefits depend, based on empirical and theoretical scientific literature.
3. A qualitative assessment of (a) the extent to which these factors apply to the proposed MPAs, and of (b) the potential effects of the proposed MPAs on the main fisheries operating in these waters.

1.3 Approach

One part of this project comprises an analysis of fisheries data, in which satellite monitoring data from the Dutch fishing fleet are used to assess the size of the various fishery fleets (no. of vessels active in the various types of fisheries), their fishing effort and their catches over the Dutch Continental Shelf (DCS). Effort and catch data are calculated for the most recent four years (2010-2013). The effort will be calculated for each of the polygons (WWF-suggested MPAs) numbered in Figure 1. We use the method described in Hintzen, Coers & Hamon (2013) to calculate the distribution of effort. This method reconstructs likely trawl paths of individual vessels, based on the mandatory satellite tracking data (through VMS, the Vessel Monitoring System) provided by each Dutch fishing vessel. These trawl paths are then combined in a statistical procedure to obtain total trawling intensity on a gridded map. This distribution of effort is then combined with logbook data to calculate total catch by area. Finally, fish price data are factored in to calculate the monetary yield of each area to the fishery. This will also be done for the 'remaining' DCS area, which does not fall within any of the WWF-proposed MPAs.

This analysis will be conducted for a number of relevant fishery types, that are recognized by their gear types, including large beam trawl (>221kw), small beam trawl (<221kw), shrimp trawl, demersal otter trawl and pelagic trawl. The three quantities (effort, catch and economic value) will be assessed both as absolute numbers and as relative contributions to the totals of each gear type.

This analysis gives an estimate of the importance of each of the proposed MPAs to each type of fishery, on a fleet level. It answers item 1 in paragraph 1.2above.

A literature study will be conducted, using the scientific literature indexed in the Web of Science database (Thomson Reuters, 2014). The aim of this study is to compile a list of expected and observed ecological mechanisms by which MPAs can affect fisheries in the North Sea (and similar temperate waters). It addresses item 2 in paragraph 1.2 above.

A second literature study will look into the role and specific function of each of the numbered areas in Figure 1 in the life history of each of the fish species of interest. These species are the main commercially important species on the DCS and will include at least the fish species brill (*Scophthalmus rhombus*), cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), sprat (*Sprattus sprattus*), turbot (*Scophthalmus maximus*) and whiting (*Merlangius merlangus*), and the invertebrate brown shrimp (*Crangon crangon*).

The combination of these two literature reviews and the data analysis will indicate where potential benefits or disadvantages for the fishery, in terms of catches, may occur. The synthesis of the above will hence address item 3 in paragraph 1.2. This last part takes the form of a discussion of each proposed MPA, in relation to the fish and fisheries which occur there.

2 Current and proposed MPAs

In this chapter we briefly describe the various proposed MPAs (Figure 1, Table 1): their status and the arguments for their selection. The numbers associated with the names of the areas refer to the numbers used in figures and tables (if simplification appeared prudent). These areas have been identified as ‘potential MPAs’ by WWF (Hugenholtz 2008, Christiansen et al. 2009).

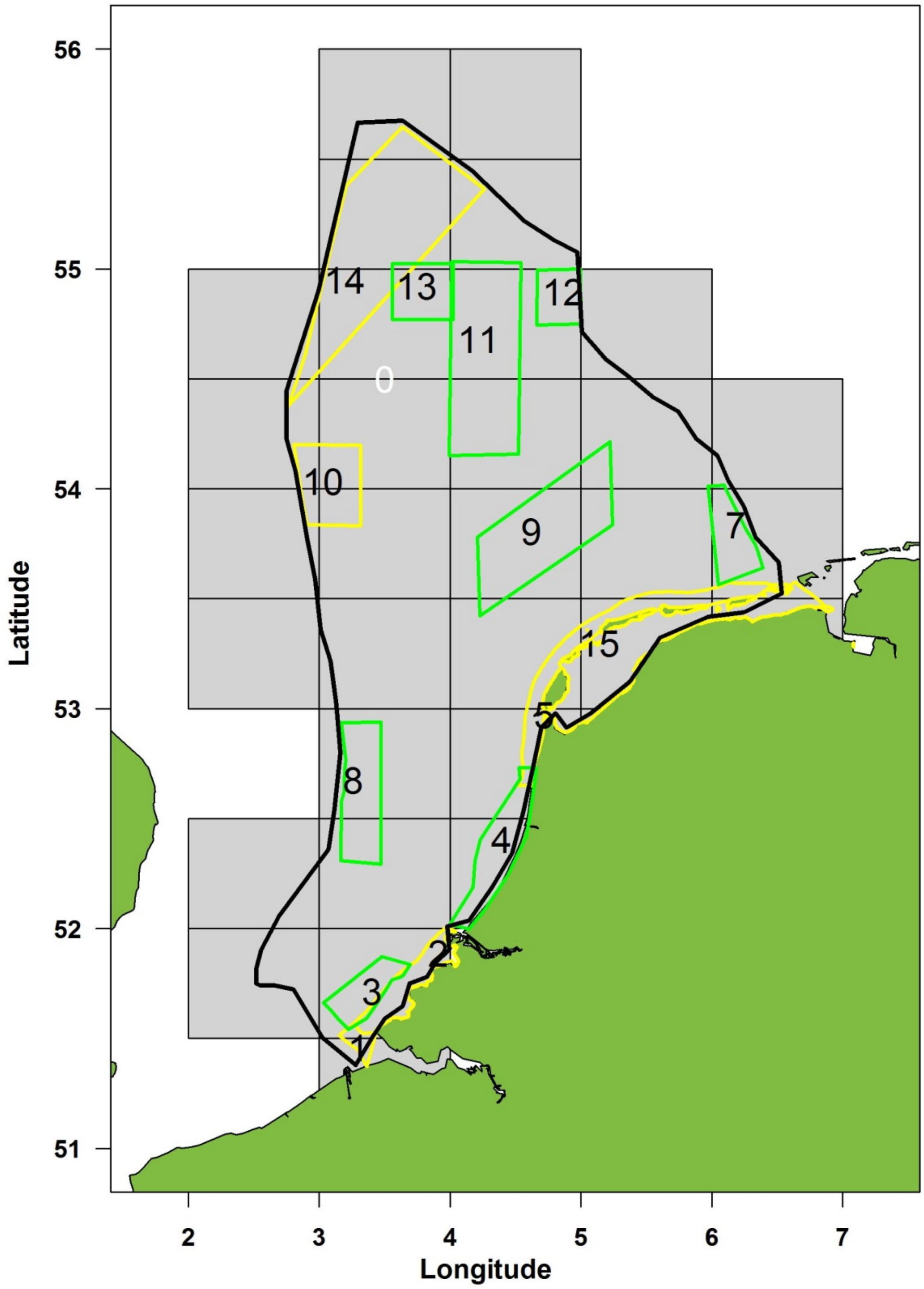


Figure 1 *Overview of current (yellow demarcation lines) and proposed (green demarcation lines) MPAs by WWF (See also WWF Netherlands, 2014). For names of numbered areas, see Table 1.*

The surface area of each of the MPAs is given in Table 1. Most areas comprise less than 2.5% of the total surface area of the DCS. The Wadden Sea and the open sea areas Frisian Front and Central Oyster Grounds each comprise about 5%, while the Dogger Bank comprises about 8% of the DCS surface.

Table 1 Surface areas and percentage of total DCS area of (current and proposed) MPAs and remaining DCS as used in this analysis and their conservation status.

Area	No	Surface (km^2)	% of DCS	Conservation status
remaining DCS	0	34540[1]	60.6	
Vlakte van de Raan	1	175	0.3	designated Natura 2000-area (HD, 30-12-2010)
Voordelta	2	822	1.4	designated Natura 2000-area (BHD, 19-2-2008)
Zeeuwse Banks	3	715	1.3	
Coastal Sea	4	1267	2.2	
North Sea Coastal Zone	5	1410	2.5	designated Natura 2000-area (BHD, 26-2-2009)
Borkum Stones	7	782	1.4	
Brown Bank	8	1408	2.5	
Frisian Front	9	2790	4.9	designated Natura 2000-area (BD), enlisted OSPAR MPA
Cleaver Bank	10	1238	2.2	enlisted Natura 2000-area (HD, 22-12-2008), enlisted OSPAR MPA
Central Oyster Grounds	11	3337	5.9	
Gas Seeps	12	594	1.0	
Arctica islandica Area	13	848	1.5	
Dogger Bank	14	4639	8.1	enlisted Natura 2000 area (HD, 22-12-2008), enlisted OSPAR MPA
Wadden Sea	15	2434	4.3	designated Natura 2000-area (BHD, 26-2-2009)

Below we briefly describe each of the areas. These descriptions are based on information given by Jak et al. 2009, Lindeboom et al. 2005 and – where applicable – in the designation Orders of the Natura 2000-areas.

Vlakte van de Raan – The Vlakte van de Raan is part of the shallow coastal sea of the Zeeuwse and Zuid-Hollandse Delta. It comprises a complex of submerged sand banks that extends into the Belgian coastal zone .The area has been designated as Natura 2000-area in 2010. It holds conservation aims for habitat type H1110 (Sublittoral sandbanks, permanently submerged), the sea mammals harbour porpoise, harbour seal and grey seal, and the fish river lamprey, sea lamprey and twait shad.

Voordelta – The Voordelta is also part of the shallow coastal area of the Zeeuwse and Zuid-Hollandse Delta. After completion of the so-called Delta Works this part of the coastal area has changed into an extensive system of tidal flats and submerged sand banks intersected with deeper gullies. The area also comprises a few muddy flats, saltmarshes and beaches with scattered early developmental stages of dunes. The area has been designated as Natura 2000-area in 2008. It holds conservation aims for habitat types H1110 (Sublittoral sandbanks, permanently submerged) and H1140 (Mudflats and sand flats not covered at low tide), three saltmarsh types and one dune type, for the sea mammals harbour seal and grey seal, and for the fishes river lamprey, sea lamprey, Allis shad and twait shad, as well as for 30 bird species.

Zeeuwse Banks – The Zeeuwse Banks is an area west of the Voordelta and species richness of benthic species is more or less similar to the Voordelta and North Sea Coastal Zone (H1110, Sublittoral sandbanks, permanently submerged).

However, densities and biomass of the benthos are lower in the Zeeuwse Banks. No bird species qualify for protection under the Birds Directive, although the number of birds including red-throated diver, lesser black-backed gull and sandwich tern are high.

Coastal Sea – The Coastal Sea is also part of the shallow coastal area, bordered by the Voordelta in the south, and the North Sea Coastal Zone in the north. Compared to these two areas, the Coastal Sea has no legal conservation status. It is the most intensively used coastal area for shipping. It holds habitat type H1110 (Sublittoral sandbanks, permanently submerged), but with less morphological diversity and hence lower nature values. Seals and harbour porpoise travel through the area, as do migratory fish species.

North Sea Coastal Zone – The North Sea Coastal Zone comprises the sandy coastal sea, shallows, several sand banks and the beaches of the North Sea on the northern part of Noord Holland and the Wadden islands. The area has been designated as Natura 2000-area in2010. It holds conservation aims for habitat type H1110 (Sublittoral sandbanks, permanently submerged) and H1140 (Mudflats and sand flats not covered at low tide), two saltmarsh types and two dune types, for the sea mammals harbour porpoise, harbour seal and grey seal, and for the fishes river lamprey, sea lamprey and twait shad, and for 20 bird species.

Borkum Stones – The area Borkum Stones is an area adjacent to the German Natura 2000-area Borkum Riffgrund and the Dutch North Sea Coastal Zone. Part of the sea floor is covered by gravel and stones and qualifies as H1170 (Reefs op the open sea). The other part qualifies as type H1110 (Sublittoral sandbanks, permanently submerged). Also harbour porpoise, grey seal and harbour seal visit the area. The area could be considered as a potential Natura 2000-area.

Brown Banks – The Brown Banks are is located offshore west of the Coastal Sea at the border of the EEZ of the Netherlands and the UK. The area is characterized by sand banks and troughs at a depth of about 20 to 40 m, with fine to coarse sands. The area does not meet criteria for habitat types but qualifies for birds under the Birds Directive, in particular for the common guillemot and razorbill that are present during the winter months in high numbers. At present, that area has not been designated as Natura 2000-area.

Frisian Front – The Frisian Front is proposed as Natura-2000 area for bird species. The area is designated as Natura 2000-area for the great and the lesser black-backed gull. In addition, the area qualifies for the great skua and common guillemot. Although the area does not qualify under the habitat directive, its unique abiotic and benthic characteristics may be protected as part of the implementation of the Marine Strategy Directive.

Cleaver Bank – The Cleaver Bank has been proposed as Natura 2000-area for its habitat type H1170 (Reefs op the open sea). The area includes fields with gravel and stones, unique for the Dutch part of the North Sea. In a deeper trench in the area, sea mammals are frequently present. Protection of the area has is also relevant for harbour porpoise, grey seal and harbour seal.

Central Oyster Grounds – The Central Oyster Grounds is a relatively deep muddy area in the centre of the Dutch North Sea, with a high benthic biomass and species diversity. Characteristic are mud dwelling species that form tubes in the sediment. Because of these features, the area is considered as a potential seabed conservation area as part of the implementation of the Marine Strategy Framework Directive.

Gas Seeps – In the far northern part of the Dutch North Sea local areas with pock marks (Gas Seeps) are found. However, no carbonate structures (H1180) are present in these pock marks, and the area does therefor not qualify as a Natura 2000-area.

Arctica islandica Area – The Arctica islandica Area is an area located in between the Dogger Bank and the Central Oyster Grounds. It is a relatively undisturbed area, and therefore densities of the long-lived bivalve ocean quahog (Noordkromp, *Arctica islandica*) is relatively high (Lindeboom et al. 2008). For this reason, the area may be considered for protection of the seafloor.

Dogger Bank – The Dogger Bank is located far north in the Dutch North Sea. It is a large sand bank that qualifies as habitat type H1110 (Sublittoral sandbanks, permanently submerged). It is therefore proposed as Natura 2000-area. Like all offshore areas under the Habitat Directive, also harbour porpoise, harbour seal and grey seal are considered part of the conservation objectives.

Wadden Sea – The Wadden Sea is an enclosed shallow sea with habitat type H1110 (Sublittoral sandbanks, permanently submerged), and H1140 (mudflats and sand flats not covered at low tide). The area has been designated as Natura 2000-area. The area is very important as breeding site and habitat for harbour seals and grey seals and for nesting, foraging and resting of numerous species of birds. The area is also designated for migratory fish species and salt marsh habitat types (1300 series).

3 MPAs as a fisheries management tool - review

3.1 Definitions and scope

In a global meta-analysis, Lester et al. (2009) convincingly show that closing an area to fishery often leads to higher biomass, density, individual size and biodiversity inside the closed area[1]. This is the case in both tropical and temperate systems, in small and large closed areas, and across a wide taxonomic range. Other studies, both theoretical and empirical, confirm the finding that closing fished areas to fishing clearly affects these parameters (Halpern and Warner 2002). However, the focus of this report is not on the effects of closure within the closed area, but on the potential benefits to the surrounding fisheries. In the same study, Lester et al. (2009) show that biomass (but not density, individual size and biodiversity) outside reserves also significantly increases after establishment of closed area. However, as the authors themselves state, caution should be taken because these results are based on only 6 studies. It is unclear if these studies represent fisheries benefits, because the authors do not report whether the species studied are the targets of fishery.

In the ecological and fishery literature using models, a fishery improvement is often taken to be an increased stock biomass or fisheries yield. In literature describing empirical examples of fishery benefits, it is often the catch, or the catch per unit effort. In empirical studies on the fishery benefits of MPAs, generally the focus is on the change in the yields of the fishermen which used to be active inside the MPA, but whose fishing activity has been relocated to areas outside (but usually bordering) the MPA.

---

[1] It is important to realize that Lester et al. (2009) look at average effect sizes. These consist of both successes and failures. Their results describe a general pattern, but cannot be used as an expectation for any particular MPA implementation. It should also be noted that meta-analyses such as Lester et al. are prone to suffer from a publication bias: Negative results (failed MPAs) are less likely to get published than success stories in the scientific literature, including the ecological literature (Jennions and Møller, 2002). This means that collecting published studies does not necessarily lead to a random sample of studies and hence may yield unrepresentative results, overestimating the positive effects of MPAs.

In other words, fishery benefits which have been shown empirically are generally on a local scale (Gell and Roberts 2002).

In this report we focus on the potential increase in yield after closure of the proposed area to all fisheries. Focusing only on yield is to some extent a one-sided view of fishery benefits. Fishermen, at least in the North Sea area, are ultimately motivated by their profits, not by the biomass of fish they catch. These profits result from a positive balance between the monetary value of the catch, and the costs involved in realizing that catch. Hence, real fishery benefits emerge only when MPAs increase profits, not catch biomass (only). This may come about when catch value increases more than the extra costs incurred, or when costs decrease more than the value of the catch. Including these economic considerations in an assessment of potential MPA fishery benefits in the North Sea adds a whole new dimension of complexity to this study, and for that reason we do not consider it here. However, such an analysis is an essential step in decisions about implementing MPAs of which the objective is to generate better fishing results.

3.2 Mechanisms leading to fishery benefits from MPAs

Two distinctly different mechanisms have been shown to potentially lead to positive effects of MPAs on stocks and fishery yield: larval export and spillover. Larval export occurs when larvae produced by the unexploited part of the stock, in the MPA, are transported to fished areas, and there grow up to exploitable size, while spillover means the MPA becomes a source of juvenile and/or adult fish which migrate across the MPA boundary into the fished area (Gell and Roberts 2003).

Spillover may occur when the (per unit area) production of larger individuals is higher in the MPA than outside and the species of interest exhibits a degree of mobility. It may occur either from individuals actively migrating out of the MPA, or by passive (diffusive) movement across the border. There are relatively many examples of spillover, though generally from small reserves in coastal coral reef systems. Lizaso et al. (2000) conclude that "*Despite the potential of biomass export from MPAs ... there is remarkably little evidence of this effect so far*". However, since the appearance of that work in 2000, a number of studies have reported this effect (Gell and Roberts 2002). The majority of these are from very small areas in coral reef ecosystems, and of limited relevance to the North Sea. The most well-known examples where fisheries benefits have arisen through spillover are the Apo reserve (0.225km^2) in the Philippines (Abesamis et al. 2006) and the Soufrière Management area (~1km^2) in St Lucia (Roberts et al. 2001). One of the few studies that has quantified spillover from a relatively large marine reserve, the Columbretes Islands Marine Reserve (~40km^2), shows that additional biomass catches of spiny lobster through spillover more than outweigh the losses from lost fishing grounds through the closure (Goñi et al. 2010). Unfortunately, the authors provide no data from before the closure, which makes it difficult to conclude that the spillover is a direct result of the closure, and not due to differential lobster productivity.

Larval export essentially decouples the harvested stock from its recruitment; even when the stock in the fished area is reduced to zero, there is still an inflow of recruitment from elsewhere and the stock can rebuild quickly. By this mechanism, an MPA with strong larval export can protect a harvested stock from being fished down to such low levels where recruitment becomes too low, so-called recruitment overfishing. The potential for Larval export is stronger at high abundance of individuals in the MPA (which is generally expected to be higher than in surrounding, fished areas), but also by the age and size distribution of the adults inside the MPA, because older and larger females often produce disproportionally more and higher quality eggs (Weigel et al. 2014). It furthermore depends on the quality of the protected area as a spawning site. Another requirement for larval export is the presence of a mechanism (usually water currents) by which eggs and/or larvae are moved across the MPA boundary.

There is relatively little evidence of larval export from MPAs contributing to fishery benefits outside the MPA, presumably because studying the origin of larvae is more difficult than of larger fish which can be tagged. Pelc et al. (2010) even argue that the difficulty in detecting larval export masks the fact that it generally occurs so strongly that it is highly relevant for the surrounding fisheries. The most well-known examples of larval export benefiting surrounding fisheries are the coral reef fishery in the Keppel Island marine reserves, Australia (Harrison et al. 2012) and between no-take and fished reefs on the great barrier reef (McCook et al. 2010) and the scallop fishery on Georges Bank, Canada (Murawski et al. 2000).

The underlying concept of both these mechanisms is the movement of fish biomass, be it larval, juvenile or adult, across MPA boundaries. The potential of MPAs to benefit fisheries and the MPA designs that work, are hence highly dependent on the mobility and the movement patterns of the exploited species (Botsford et al., 2009). Finally, it is important to realize that, as Gruss et al. (2011) write, MPAs are likely to provide fisheries benefits for mobile populations only when these populations are overexploited outside the MPA, so that 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. This point, which is elaborated in Botsford et al. (2003) essentially implies that the establishment of MPAs in fisheries on mobile species which are overexploited (*i.e.* harvested at a rate higher than the rate which produces maximum sustainable yield, or another measure of sustainability) may lead to fisheries benefits in exactly the same way as a 'classical' reduction in fishing mortality, without spatial zoning, would. In accordance with this theoretical result, all empirical examples which we have encountered in the course of this study and where MPAs have led to increased overall yield, are from systems that showed indications of overfishing before the MPAs were implemented.

A final potential indirect fishery benefit of MPAs, which is more difficult to express in terms of value, is that they can work as an insurance policy against uncertainty. In a simplified theoretical model, Mangel (2000) showed that MPAs can decrease the risk of stock depletion under uncertainty, while fishery yield is maintained.

3.3 Aspects of fish ecology and fishery that affect fishery effects of MPAs

A number of ecological characteristics of fish and behaviour of fishers can be identified which affect the possibility for fishery benefits of MPAs.

Spatial niche segregation
Many marine fish change their diet as they grow (Bax 1998). Such diet shifts are often accompanied by a spatial shift, as the new food source is found in another area, leading to a spatial segregation between different size- or age classes. This in turn has important ramifications for the fishery effects of marine protected areas, because it indicates that the effects of MPAs are defined not only by how much of the habitat of a certain stock is closed, but also by which specific locations. Such developmental spatial segregation opens the door to an MPA strategy where the MPA not only protects a certain fraction of a stock, but protects a specific (often juvenile) stage which itself has no commercial value, but does contribute to the replenishment of the harvestable stock outside the MPA. This potentially strengthens the effectiveness of MPAs as a tool to manage fisheries, but can be limited if density-dependent growth limitation occurs (see below).

The presence of a pelagic egg and/or larval stage
In species which do not have a pelagic larval stage, an MPA can never lead to larval export. However, a free-floating pelagic stage (eggs, larvae or both) is the norm in marine fishes (Wootton 1998).

The range over which eggs/larvae in the pelagic phase are dispersed
Generally, species which exhibit egg/larval dispersal over larger distances have a larger potential for fishery benefits through larval export, but do so only at large MPA sizes (Botsford et al. 2009). Thus, the necessary size for an effective MPA depends on the dispersal range of larvae and hence is species-specific. Because of the difficulty to study the origin of eggs and larvae, there is no empirical evidence for this, but Botsford et al. (1997) derive that for larval spillover to increase sustainability in the area surrounding an MPA, its size should at least exceed the mean larval dispersal distance of the species under consideration.

Movement rates of juveniles and adults
Fisheries for species with intermediate movement rates (relative to the size of the MPA) have the highest potential benefit (through spillover) from establishing MPAs (Botsford et al. 2003). Fish with too high movement rates will spend too much of their time outside the MPA where they are subjected to fishing mortality (Gerber et al. 2005), and fish with too low movement rates will not 'spillover' because they never leave the MPA. This principle also means that there is a species-specific optimal reserve size (and shape) for spillover to lead to fishery benefits, depending on the movement rates of juveniles and adults. In general, fish with high movement rates require large reserves in order to generate spillover-based fishery benefits, and vice versa. A mismatch between reserve size and movement rates generally leads to reduced fishery yields after establishment of an MPA (Gruss et al. 2011). As a rule of thumb, reserve size should exceed the home range size (the area in which an individual spends the vast majority of its time) of the species for which the MPA is established (Kramer and Chapman 1999).

Density-dependence
Density-dependence is the phenomenon that the rates at which processes at the level of individuals (*e.g.* growth, mortality) take place, depend on the abundance of all individuals. Though not strictly a life history characteristic, density-dependence is an important determinant of the effects of MPAs on fishery yield (Hastings and Botsford 1999). In the context of MPAs, it is important to distinguish between density-dependence in different processes: Growth, mortality, reproduction and migration. Density-dependent growth and reproduction have been documented for a wide range of fish species. Density-dependent mortality is common in juvenile fishes, but not in adults (Lizaso et al. 2000). Density-dependent migration has not been empirically shown, but is hypothesized to occur whenever a mobile species builds up high density in an MPA (Gruss et al. 2011).

- Density-dependent <u>migration</u> occurs when fish tend to migrate away from areas of high density. This may occur either because they directly interfere with each other (interference competition), or when high density reduces the food availability (resource competition). Density-dependent migration may result in no difference in fish density in- and outside MPAs (Childress 1997). This does not mean that the MPA cannot provide fishery benefits. On the contrary, Kramer and Chapman (1999) conclude that density dependent migration facilitates fishery benefits through spillover.
- In general, density dependent <u>mortality</u> is common in larval and early juvenile stages, but has not been shown for larger juvenile and/or adult marine fish. However, in MPAs such density-dependence is hypothesized to emerge as an aggregation of biomass in an MPA may attract predators and may thus in turn lead to an aggregation of these predators. There is limited empirical support for this mechanism (Lizaso et al. 2000).
- Density dependent <u>growth</u>, where individuals grow more slowly at high density, keeps individuals in the protected population small, so that any spillover will most likely be limited to small individuals. It also inhibits fisheries benefits through larval export, because many small individuals are less efficient at turning fish into fish eggs than fewer larger individuals (Lizaso et al. 2000, Gardmark et al. 2006).

- o Density-dependent reproduction is similar to density-dependent growth. It occurs when mature individuals produce fewer eggs than they are physiologically capable of, because not enough food is available. It hence reduced the potential larval export from MPAs (Lizaso et al. 2000).

Exploitation pattern
Apart from the ecology of the fish, the response of the fishery is another important determinant of the success of an MPA in improving fisheries. This is especially the case for quota-based fisheries, of which there are many examples in the North Sea. If fishing activities are displaced to an area where more effort is needed to fish up the quota, establishment of the MPA may lead to an increased total fishing effort, potentially associated with more bycatch and more seabed disturbance. In response to a temporarily closed area in the North Sea (the cod box), beam trawl fishery displaced (Dinmore et al. 2003), including to areas which were previously rarely fished (Rijnsdorp et al. 2001).

Another important displacement response of fisheries to the establishment of MPAs is a concentration of fishing effort along the boundaries of the MPA, so-called ‘fishing the line’ (Kellner et al. 2007). The underlying assumption to this strategy is that just outside the MPA, the spillover from the reserve is maximized and hence catch rates are most strongly amplified there. Modelling studies indicate that fishing the line is an effective way to reduce population size inside the MPA (for mobile species) and hence may substantially reduce the total protected population. This in turn may reduce the capacity of the MPA to replenish larval, juvenile or adult fish in surrounding unprotected waters. There is very little empirical support for the effectiveness of this strategy (Kellner et al. 2007), but there are well-documented examples of this behaviour, for example along the edges of large closed areas in the Georges Bank (Murawski et al. 2005) and the plaice box (Pastoors et al. 2000).

The picture that emerges from the literature is that MPAs are considered a useful fishery management tool, and that positive effects for the fishery are *possible* when MPAs are well-designed in relation to the considerations above. Generally, documented positive fishery effects of MPAs are those where the establishment of closed areas also led to an overall reduction in the mortality on the fish population. This can be a reduced overall mortality, or in certain life stages (e.g. small or juvenile individuals), and can also be a result of larger survival due to the preservation of secondary structures which enhance survival or breeding success (e.g. macrophytes, corals).

If fishing effort is displaced to compensate for lost catches or fishing grounds, effects of MPAs can easily be negated, particularly in combination with quota-based management (Horwood et al. 1998).

3.4 Special case: networks of MPAs

The majority of early modelling work regarding the protective effects of MPAs assumes that the MPA protects a fixed fraction of each life stage of a population, from egg to large adult (see for example Mangel 1998 and references therein). Reality is often different, in that for many fish species, the various life stages use different areas, with migration between these areas as individuals progress through their life cycle. For such species, it is impossible to protect the entire life history range in a single protected area, resulting in a mismatch between model and implementation. In order to overcome this problem, *networks* of MPAs are used, which are designed in such a way that they protect a fraction of the entire life history of a species. To be efficient, the degree of protection should be large enough that the population inside the marine reserve network is essentially self-sustaining, and independent of whatever happens outside the reserve (Murray et al. 1999). Well-designed networks of marine reserves hold a promise of enabling the achievement of conservation goals, while not harming, or even benefiting fisheries. However, this promise is currently based almost exclusively on model predictions (Gaines et al 2010), with only few results from implemented networks.

The most well-known of a network of MPAs is that implemented in the Great Barrier Reef in 2004 (Fernandes et al. 2005, McCook et al. 2010). The implementation of this MPA network has been mostly a conservation measure, but the implemented no-take areas have contributed substantially to the larval supply of the fished reefs, so larval export has potentially benefited the fishery. A detailed modelling study of the fishery effects of a network of strategically placed MPAs in Sourthern California predicts that this form of management can lead to higher fishery profitability than optimal non-spatial management (Rassweiler et al. 2012), but the MPA network is specifically designed to enhance fishery profits, without consideration of conservation objectives.

4 Dutch fisheries on the Dutch Continental Shelf

The logging of data on the Dutch fisheries on the Dutch Continental Shelf (DCS) of the North Sea by the Vessel Monitoring System (VMS) and logbook system distinguishes five main types of fisheries based on their gear type: dredges, otter trawls, seines, beam trawls and shrimp trawls. Almost all of the types of fisheries can be split into two categories according to the power employed by the vessel; large – with power up to *c*. 2000 HP (*c*. 1471 kW) and small – with power up to 225 kW (*c*. 300 HP). Only the category of smaller vessels is allowed to fish within the 12-mile zone. Below we describe the five types of fisheries in terms of targeted species, bycatch rates and general distribution pattern. We also provide several general descriptors of the types of fisheries (data restricted to the DCS): number of fishing vessels active, fishing effort and yield (catch weight and monetary yield). We use this analysis to interpret the importance of each of the proposed MPAs for the Dutch fisheries on the DCS.

4.1 Characteristics

Dredges – Van Hal et al. 2010: “This type of gear is used to target shellfish species such as oysters, mussels, Ensis and scallops, and it includes boat dredges and hand dredges. [...]There are two variants of boat dredges; one type scrapes the surface of the seabed, using rakes or teeth to penetrate the top substrate layer, and captures animals that have retracted into the seabed, passing them back into the holding bag. The other type penetrates the seabed up to 10 cm, collecting macro-infauna (animals that live within the sediment and are large enough to be seen with the naked human eye). These infaunal dredges include hydraulic dredges that use water jets to fluidize the sediment, and mechanical dredges, which penetrate the substrate using the mechanical force of long teeth.” These types of gears can have substantial mortality on non-target organisms inhabiting the sea floor (Kaiser et al. 2006).

Otter trawl –The otter board trawl fishery is directed at flatfish and roundfish (large mesh sizes) and *Nephrops* (smaller mesh sizes). Various types of otter board fishing have different rates of by-catch (Deerenberg et al. 2010). The fishery directed at flatfish and roundfish has a low average discard percentage of fish, except for dab and mackerel. The otter boards trawl fishery directed at *Nephrops* (concentrating in the Botney Cut of the Cleaver Bank) has an average discard percentage of fish of 70% (percentages derived from Uhlmann et al. 2013). Despite having less bottom contact then for example beam trawls, otter trawls have been shown to reduce density of non-target biota in certain habitats (Kaiser et al. 2006).

Scottish seine –The Scottish Seine or flyshooting fishery uses long lengths of seine rope to herd fish into the path of the net as the gear is hauled. Seines cannot work on such rough grounds as otter trawls. The demersal purse seine is a preferred technique for capturing all kinds of fish species which live close to the sediment surface, such as cod, plaice, haddock, and red mullet.

Seines are used when there are flat but rough sea beds, which are cannot be trawled (Deerenberg et al. 2010). The Dutch seine fishery has low discards rates of less than 10% (percentage derived from Uhlmann et al. 2013).

Beam trawl –The Dutch beam trawl fishery is directed at flatfish species. Beam trawl fishery directed at plaice uses a lower number of chains and the mesh size of the net is larger than fishery directed at sole. Both large and small beam trawlers switch between sole and plaice gears, depending on location, season, and available quotum, but the small mesh size (80mm) is only allowed south of the 55° parallel. The severity of the effects on the bottom, benthos and fish is related to the intensity of fishing and the specifics of the gear type: the number of tickler chains (more for sole) or the use of a chain mat (smaller beams) or the mesh size (Deerenberg et al. 2010). The beam trawl fishery with the smaller mesh sizes directed at sole has a much higher discard percentage (~75% of all caught fish) than the beam trawl fishery with the larger mesh sizes directed at plaice (15~ of all caught fish, percentages estimated from Uhlmann et al. 2013). For the current analysis the focus is on the importance of areas to the fishery, for which vessels is a more logical distinction than gears. Hence, we only distinguish vessel size, not the actual mesh size used on each trip.

The beam trawl fishery imposes mortality of benthic species in the tracks (5-39% annual mortality of megafauna, Bergman & van Santbrink 2000). Beam trawling has also been associated with reduced benthic productivity (Jennings et al. 2001a), changed trophic structure of the benthic food web (Jennings et al. 2001b), and (depending on substrate type) reduced biodiversity (van Denderen et al. 2014).

The Dutch beam trawl fleet is currently in an important transition, where gears using tickler chains are increasingly replaced by electrical pulses to stimulate the flatfish off the seafloor, so that they can be caught in the trawl (Table 2). The pulse gear is not as effective as tickler chains in catching target fish, but leads to a ~50% reduction in fuel consumption. The associated cost reduction means that net revenues are higher for pulse than for conventional trawls. These gears also have significantly lower bycatch rates of benthos and unwanted fish (van Marlen et al. 2014). The effects of electricity on non-target fish and benthos species are largely unknown.

Table 2: Estimated number of beam trawl vessels in the Dutch fleet using a pulse trawl gear (Source: pers. comm. IMARES fisheries dept. personnel)

Year	# of vessels
2008	0
2009	3
2010	4
2011	31
2012	39
2013	44
2014	59

This transition is relevant in relation to MPAs because the pulse gear is lighter than the traditional beam trawl with tickler chains. As a result, it can be used in areas with softer, muddier ground. This means that as the fleet makes the transition to this gear, other areas of the North Sea may become more important fishing grounds. There is, as a result of the pulse-transition, a potential mismatch between the distribution of the fleet now and that in the future.

Shrimp trawl -Shrimp fisheries are coastal fisheries targeting shrimp with small meshed beam trawls, which use a front rope with bobbins which roll along the seafloor, rather than tickler chains.

The absence of tickler chains means that this gear likely has less severe bottom contact than beam trawls targeting fish, but there is nonetheless concern about the effects on the seafloor ecosystem (Tulp, 2009). A number of research programs are currently under way to study the potential effects of (ceased) shrimp fishing on the benthic ecosystem (e.g. van Kooten et al. 2014). Bycatch of undersized fish and benthos is a problem in the shrimp fisheries. A recent survey found that 9% of the catch (by weight) consisted of benthos and small fish, while 36% was marketable and 54% undersized shrimp. Studies are under way testing various discard reduction devices (Steenbergen et al. 2013).

4.2 Relative importance of types of fishery

The shrimp fishery is the most abundant type of fishery in terms of number of vessels (Table 3). Second in line is the large beam trawl fishery directed at flatfish, especially in terms of fishing effort (days at sea; Table 4) and total catch (Table 5). The fishery with the large beam trawl surpasses the shrimp fishery in terms of monetary yield, however (Table 6). By dividing the values in table 4, 5 or 6 by the corresponding values in table 3, the average effort, biomass yield, or monetary yield per vessel is obtained. These values apply only to the DCF, and it is likely that many vessels spend a substantial additional effort fishing outside the DCF.

Table 3 No. of vessels by type of fishery (gear and power category). Note: the total number of vessels cannot be assessed by summing, because vessels may use more than a single gear type.

Gear type	Power	2010	2011	2012	2013
Boat dredges	large	1	2	1	2
Boat dredges	small	1	1	0	0
Mechanised dredges		1	2	2	3
Otter trawl	large	12	13	10	8
Otter trawl	small	38	34	25	22
Otter twin trawl	large	1	2	3	3
Otter twin trawl	small	5	13	11	11
Scottish seine	large	10	10	9	10
Scottish seine	small	3	3	2	3
Beam trawl	large	85	85	77	73
Beam trawl	small	72	69	43	28
Shrimp trawl	small	174	163	117	177

Table 4 Fishing effort (total days at sea per year) by type of fishery (gear and power type). This is calculated as the sum of the number of days that all vessels in the data used a particular gear type in a particular year.

Gear type	Power	2010	2011	2012	2013
Boat dredges	large	49	79	13	85
Boat dredges	small	57	68	0	0
Mechanised dredges		80	87	124	235
Otter trawl	large	298	193	302	217
Otter trawl	small	1032	836	757	530
Otter twin trawl	large	108	117	120	125
Otter twin trawl	small	296	465	597	487
Scottish seine	large	235	219	221	225
Scottish seine	small	172	192	86	138
Beam trawl	large	8038	7621	6402	6223
Beam trawl	small	2497	2840	2139	1924
Shrimp trawl	small	10601	8791	8970	13765
Sum		23463	21508	19731	23954

Table 5 Yield (weight of fish caught, in megatons, i.e. 10^6 kg) by type of fishery (gear type)

Gear type	Power	2010	2011	2012	2013
Boat dredges	large	0.5	0.7	0.1	0.5
Boat dredges	small	1.1	1.4	0	0
Mechanised dredges		0.3	0.8	1.4	1.8
Otter trawl	large	0.6	0.3	0.8	0.4
Otter trawl	small	1.3	1.0	1.4	0.9
Otter twin trawl	large	0.2	0.1	0.1	0.1
Otter twin trawl	small	0.4	0.5	1.3	0.6
Scottish seine	large	0.5	0.5	0.8	0.6
Scottish seine	small	0.5	0.6	0.3	0.4
Beam trawl	large	18.0	19.5	16.2	15.5
Beam trawl	small	2.2	3.o	2.3	2.2
Shrimp trawl	small	10.6	10.9	7.6	11.7
Sum		36.2	39.3	32.3	34.7

Table 6 Monetary yield (in millions of Euro (10^6 Euro) by type of fishery (gear type)

Gear type	Power	2010	2011	2012	2013
Boat dredges	large	1.5	1.7	0.3	1.7
Boat dredges	small	3.7	3.5	0	0
Mechanised dredges		1.0	2.2	4.3	5.7
Otter trawl	large	1.0	0.7	1.7	1.0
Otter trawl	small	2.5	2.4	2.9	2.0
Otter twin trawl	large	0.3	0.4	0.5	0.4
Otter twin trawl	small	0.9	1.8	4.0	2.1
Scottish seine	large	1.0	1.0	1.4	1.2
Scottish seine	small	0.7	0.9	0.6	0.7
Beam trawl	large	58.5	51.4	52.0	54.0
Beam trawl	small	7.6	8.8	9.6	10.3
Shrimp trawl	small	28.7	18.3	28.2	46.9
Sum		107.4	93.1	105.5	126.0

4.3 Main distribution

Dredges – The main activity of vessels employing dredges is within the coastal zone, especially in the Voordelta and the Zeeuwse Banks. In these areas the dredge fishers realise also the highest monetary yields. Large vessels with dredges also employ part of their fishing in areas scattered over the DCS. Of those, the largest areas are located east of the Doggerbank and north of the proposed areas Gas Seeps, Central Oyster Grounds and Arctica islandica Area.

Otter trawl –This métier is the main fishery in the North Sea and conducted by most countries. Otter trawling targeting whitefish takes place across the entire North Sea with highest levels in the northern part (MAFCONS, 2007). Otter trawling by the Dutch fleet is limited to the Dutch EEZ area and the Channel. The otter trawls with engine power less than 221 kW are allowed to fish in the 12nm zone, but apart from that have a distribution similar to the larger otter trawlers (Van Hal et al. 2010). The Dutch fishery with otter trawls takes places in all proposed MPAs, except in the Brown Bank.

The large otter trawlers fish predominantly on and northeast of the Central Oyster Grounds, in the northern half of the Frisian Front and southeast of the Cleaver Bank (Figure 2 and Figure 3). Otter trawls can be either single or twin trawls, in which case two otter trawls are combined to increase the horizontal net opening.

Seine fishery – Based on the distribution maps of the landings (Figure 2 and Figure 3) and monetary yield (Figure 4 and Figure 5) of the seine fishery or flyshooting, the highest concentrations on the DCS are found on the western edge of the DCS in and around the Cleaver Bank and Brown Bank areas and also in front of the coast of Noord Holland and along the southern edge of the Frisian Front.

Beam trawl, large –Of the beam trawl vessels around 35% fall within the métier large beam trawlers (Taal et al. 2009). The large beam trawlers are not allowed to fish within the 12nm zone and plaice box, but outside these areas they fish almost everywhere in the southern North Sea (Van Hal et al. 2010). The Dutch beam trawlers realise the higher landings immediately outside the 12nm zone and the plaice box, with the highest landings towards the Channel.

Beam trawl, small (eurocutters) –About 65% of the Dutch beam trawl vessels falls in this métier. However, this number does include vessels fishing on shrimp (16-31 mm mesh size). The eurocutters are allowed to fish within the 12nm zones and the plaice box and most of the effort of the Dutch fleet takes place in these areas (Van Hal et al. 2010). The higher yield are realised in the southern coastal areas and towards the English Channel.

Shrimp trawl –Shrimp fisheries are a coastal fisheries targeting brown shrimp, using small meshed beam trawls. The fishery is strongly constrained to the Wadden Sea, the 12nm zone and the plaice box, and is most active in the northern coastal areas, the North Sea Coastal Zone and Wadden Sea (Van Kooten et al 2014).

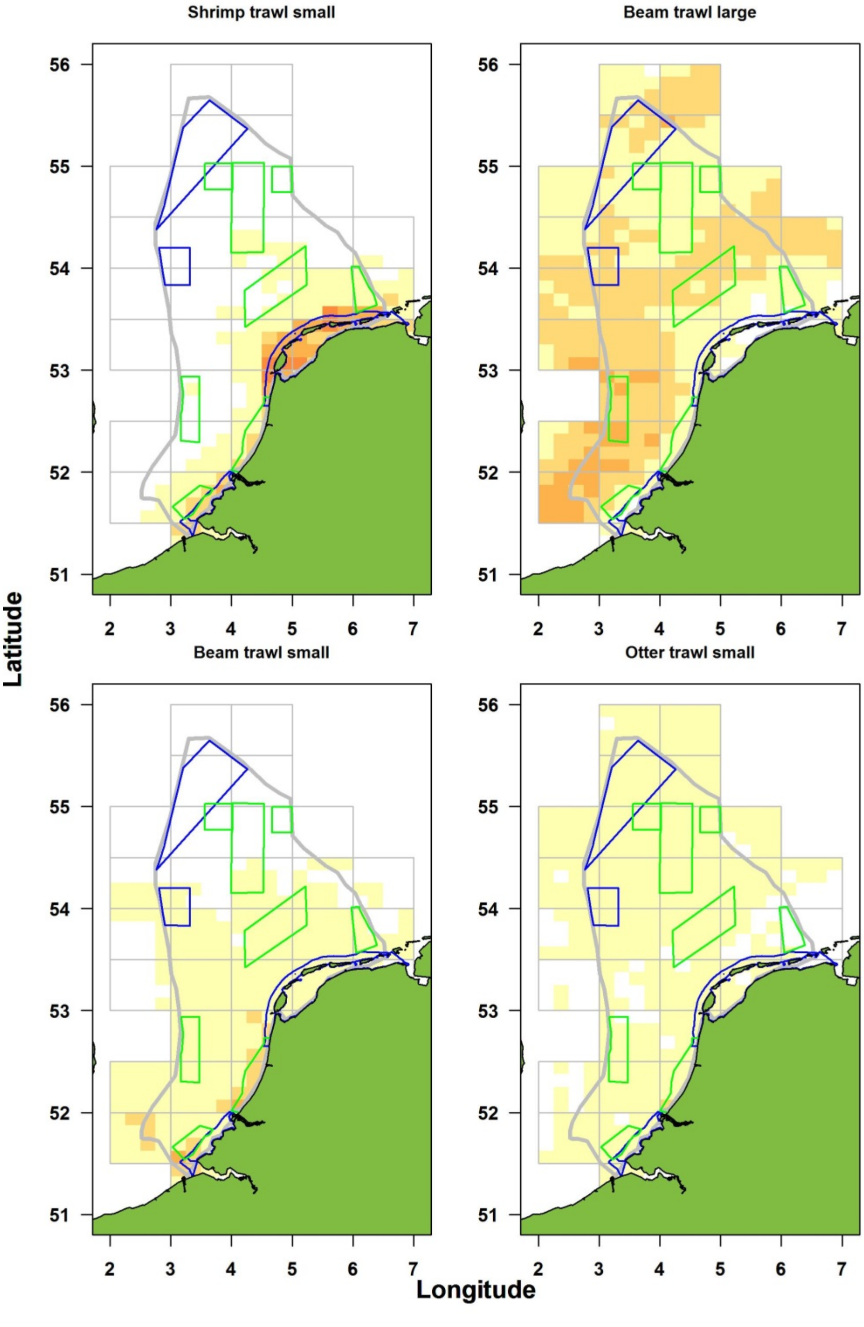


Figure 2 *Distribution (average 2010-2013) of the origin of the landings (total weight in Megaton - 1 MT=1,000,000 kg) for all gear types for which there are >3 vessels registered in the Dutch fleet. Grey rectangles are ICES statistical rectangles, but landings are plotted as 1/16th of that. Legend corresponds to the finer scale. Continued on next page.*

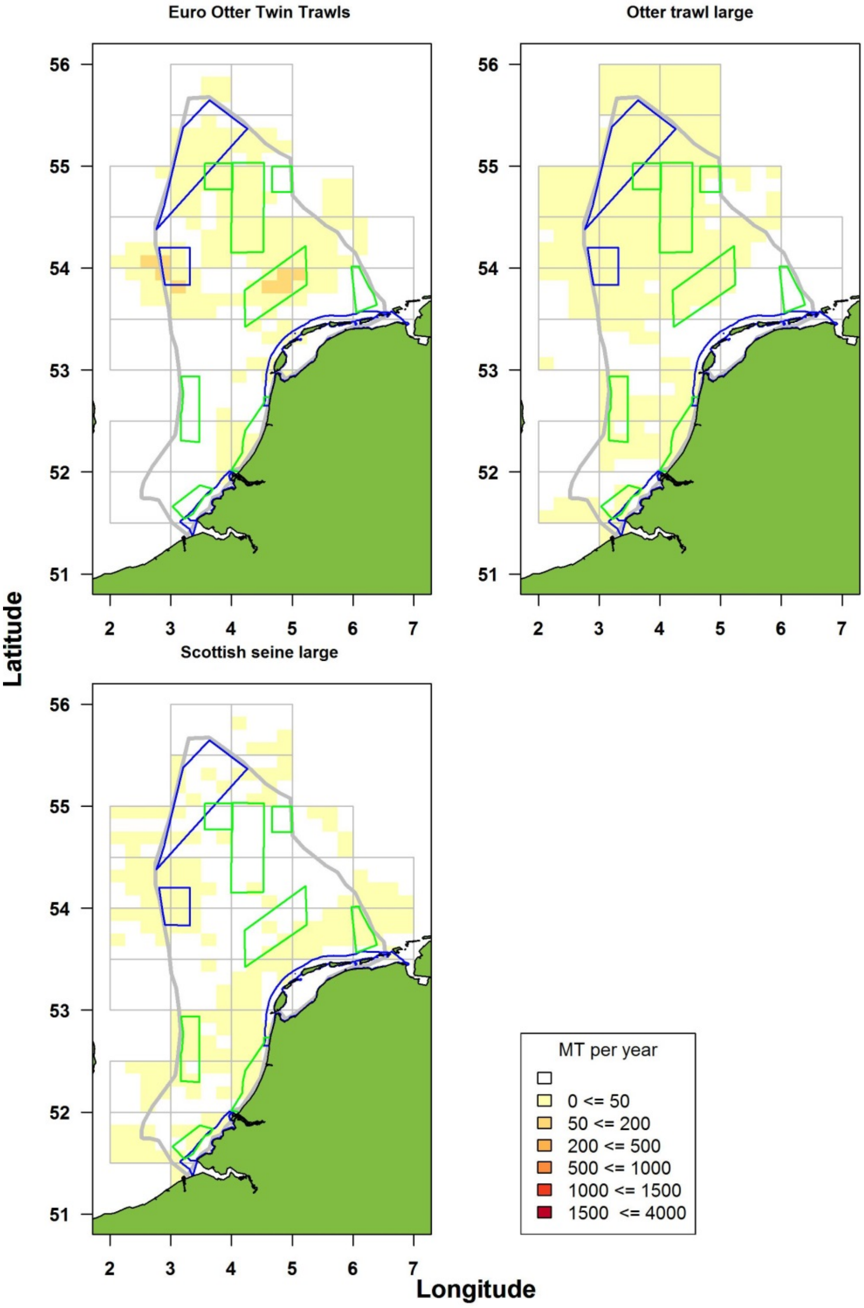


Figure 3 Continuation of Figure 2. See caption there.

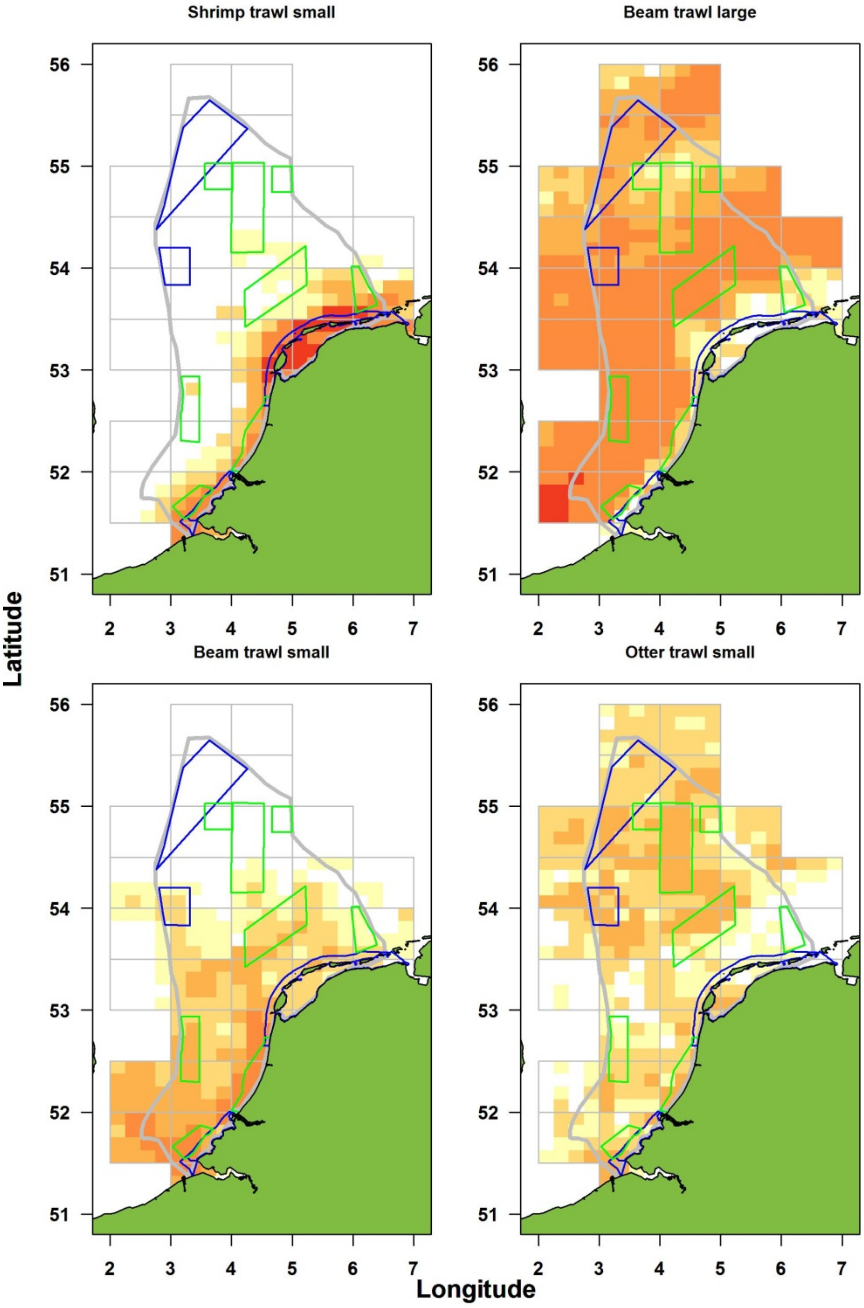


Figure 4 *Distribution (average 2010-2013) of income (derived from catch weights and auction prices, in k€ - 1.000s of Euros) for all gear types for which there are >3 vessels registered in the Dutch fleet. Grey rectangles are ICES statistical rectangles, but income is plotted as 1/16th of that. Legend corresponds to the finer scale. Continued on next page.*

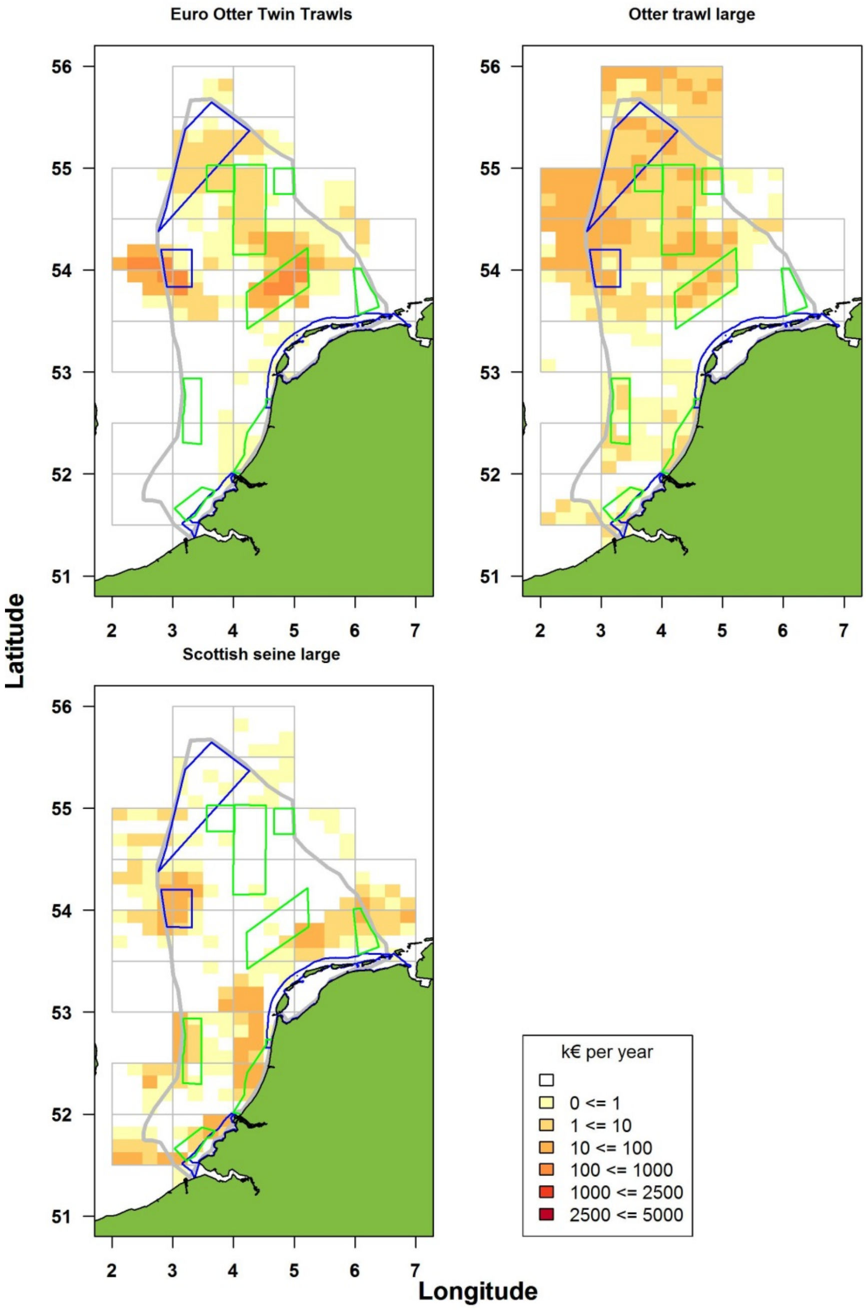


Figure 5 Continuation of Figure 4. See caption there.

5 Characteristics of selected species

In this chapter we describe the eight selected commercially exploited fish species. The ecology of a species determines to a large extent the effect of closing areas to fisheries. We provide the main ecological characteristics of the species and we give special attention to their distribution pattern in the North Sea, spawning and nursery areas. This allows us to assess the potential effects of each of the proposed MPAs on these species. The description of all species except turbot, brill and brown shrimp is derived from Teal et al. (2009), description of turbot and brill is derived from Van der Hammen and Poos (2012) and the description of brown shrimp is derived from Delnortecampos and Temming (1994).

Plaice - Plaice is a demersal boreal species (Yang 1982; Ellis et al. 2002; Ellis et al. 2008) and its distribution ranges from the western Mediterranean Sea, along the coast of Europe as far north as the White Sea and Iceland, with occasional occurrences off Greenland (Nielsen 1986). It is a bottom-dwelling species, mainly feeding on annelids and molluscs (ICES, 2013). Plaice can reach a maximum length of a meter (Yang 1982; Ellis et al. 2002; Ellis et al. 2008), but the common length is around 40cm. Plaice can reach an age of 50 years and matures at an age of 2 to 5 years, males mature earlier than females (Rijnsdorp 1989). Plaice is a determinate batch spawner, which spawns pelagic eggs.

Plaice shows a seasonal migration pattern from feeding areas to spawning areas. These feeding grounds are generally located more northerly than the spawning grounds. The growth rate for plaice is highest in summer/autumn on the more dispersed feeding grounds (ICES 2013A). In the North Sea they spawn in the first quarter of the year. The main spawning area of plaice is distributed around a number of hotspots in the southern North Sea (Harding et al. 1978), including the Southern Bight and the central part of the southern North Sea, which overlap with Dutch waters. The major nurseries are situated in the coastal zones and estuaries in the southern North Sea (ICES, 2013).

Fisheries on plaice –Plaice is predominantly targeted by beam trawlers in the central part of the North Sea with a minimum mesh size of 100–120 mm, depending on the area. In addition, plaice is caught in a mixed fishery which targets sole in the southern North Sea with a minimum mesh size of 80 mm. The mixed plaice and sole fishery is dominated by bottom trawls, with bycatch of both commercial and non-commercial species and a physical impact on the seabed. The catches of this latter fishery include plaice under the minimum landing size of 27 cm, which results in high discard rates. The total fleet discard ratio has gradually decreased since 2000. Catch distribution: Total catch in 2013 was 118.135 t, where 78.905 t were estimated landings (58% beam trawl, 26% otter trawl, and 16% other gears) and 38.700 t (33% by weight) were discards. (ICES 2013A).

An annual quotum is set for plaice to limit exploitation. Catches have been fairly stable over the past ten years. The stock (spawning stock biomass, SBB) is well within precautionary limits, has increased in the past ten years, and reached a record-high level in 2014. Recruitment has been around the long-term average since the mid-2000s. In recent years, fishing mortality (F) has been estimated below FMSY and below the target specified in the management plan (ICES 2013A).

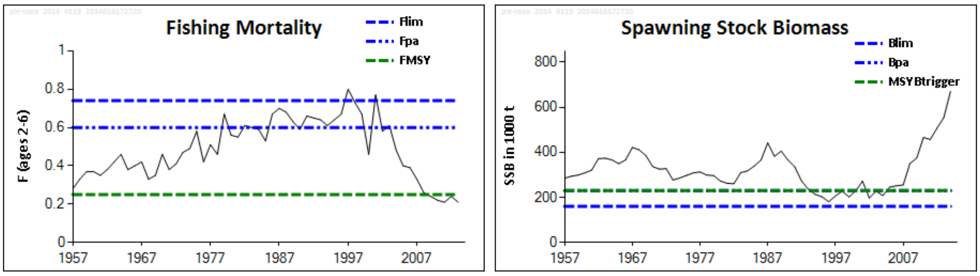


Figure 6 Fishing mortality and SSB in relation to key reference points for North Sea plaice (ICES 2013A)

Sole – The biogeographical range of sole extends from the northwest African coast and Mediterranean in the south to the Irish Sea, southern North Sea, Skagerrak and Kattegat in the north. Sole is mainly found in the southern and eastern North Sea, south of the line from Flamborough to North Jutland. This line corresponds to the position of a steep temperature gradient that, in summer and autumn, divides the North Sea into a cold stratified northern section and a warm mixed southern section (ICES, 2005). The main diet of sole consists of worms and small soft-shelled bivalves. Sole is a long lived flatfish species and can reach an age of over 40 years (ICES, 2013). Length rarely exceeds 60 cm, but females can attain a larger size than males (ICES, 2005).

Older and larger individuals tend to occur in deeper waters than juveniles, but they remain largely restricted to waters <50 m deep. A capture-recapture experiment showed no clear migration pattern during the feeding season (Anonymous, 2001). In cold winters sole withdraw to the deeper, warmer waters of the Southern North Sea. Spawning in the North Sea occurs mainly in southern areas, in the English Channel and along the coast of Belgium, the Netherlands, Germany and Denmark (Russell 1976, van der Land 1991, Bolle et al. in prep). Along the Danish coast and in the German Bight, the adult spawning releases clearly show a seasonal migration pattern, with offshore movement in the feeding season and inshore movement in spawning season. This inshore/offshore movement observed in the eastern North Sea was not obvious in Southern Bight. Within the spawning area, which is usually within the 30 m depth contour, highest egg densities occur in the Helgoland Bight and off the Danish coast (between 55∘ and 56∘ N), as well as off the Belgian Coast (van der Land 1991, Bolle et al. in prep). Nurseries are situated all along the continental and English coasts in waters less than a few metres depth.

Fisheries on sole - Sole is mainly caught together with other species by the beam trawl fleet working with 80 mm mesh. An increasing proportion of the traditional beam trawl fleet is switching to SumWing and/or pulse trawl. The mixed plaice and sole fishery is dominated by bottom trawls, with bycatch of both commercial and non-commercial species and a physical impact on the seabed. High discard rates of small plaice are associated with the small-meshed sole fisheries. Fishing effort by the total beam trawl fleet has reduced by 65% in the last 15 years. Other directed fisheries for sole are carried out with gillnets and otter trawls. Bycatch of sole in other fisheries is small. Catch distribution: Total catches are unknown. ICES landings (2013) = 13.100 t (84.1% beam trawl, 10.4% gill-/trammel nets, 2.2% otter trawl, and 3.3% other gear). Discards (in the order of 20%) are known to take place but cannot be fully quantified (ICES, 2014).

An annual quotum is set for sole to limit exploitation. The stock (spawning stock biomass, SSB) has been increasing since 2007 and is estimated to be above the precautionary limit (Bpa) in 2014. Fishing mortality (F) has declined since 1995 and is estimated to be just above FMSY in 2013 (ICES 2014).

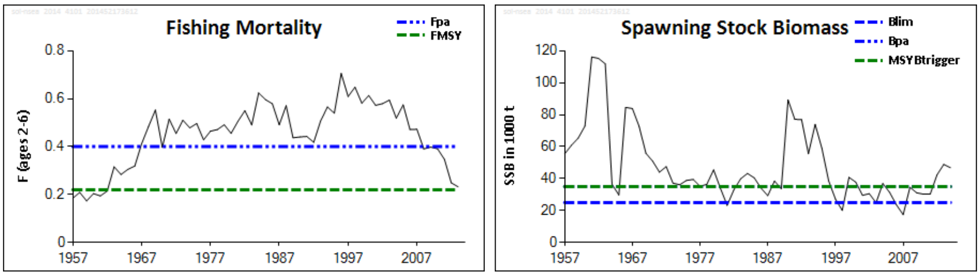


Figure 7 Fishing mortality and SSB in relation to key reference points for North Sea sole (ICES 2013A)

Turbot – Teal & van Keeken 2011: "The geographical range of turbot extends from the Mediterranean and North Atlantic Ocean in the south to the Irish Sea, North Sea, Skagerrak and Kattegat in the north (Wheeler, 1969). Turbot is a demersal boreal species that lives in sandy and rocky habitat. It can reach a maximum length of 100 cm. [...] Young turbot feed on a variety of benthic prey, but at a length of approximately 20 cm they switch to a diet consisting almost entirely of fish. [...]

In the North Sea, the turbot's main distribution area is found to be to the west of Denmark and in the Skagerrak and Kattegat (Knijn et al., 1993). Around the age of 3-4 years, depending on sex, turbot matures and undergoes offshore spawning migration. Turbot is a determinate batch spawner and spawns between April and August at 10-80 meters depth. Important spawning grounds in the North Sea are found around the Aberdeen Bank and the turbot Bank in the north, and to the north of the Dogger Bank in the South (Knijn et al. 1993). [...] After settling, the juveniles remain in the shallow coastal zone, but gradually increase their preferred depth as they increase in size. [...]Turbot disperses to deeper water at older age."

Fisheries on turbot - Turbot is a valuable bycatch in the fishery for flatfish and demersal species using beam trawl, otter trawl, and static gear. There is a targeted gillnet fishery that takes less than 10% of the total catch. Discarding in the trawl fisheries for turbot is low. Currently the catches are comprised predominantly of immature fish. No official minimum landing size has been set, but Belgian and Dutch producer organizations have adopted voluntary minimum landing sizes between 25 and 30 cm. A reduction in fishing effort on target flatfish species such as plaice and sole may have influenced the turbot catches. . Catch distribution: ICES estimated catch in 2013 is 3.008 t, where 100% were estimated landings (~90% beam and otter trawls, ~10% gill- and trammel nets; ICES, 2014).

There is no annual quotum for turbot to limit exploitation. ICES advice is based on the data limited approach. Recruitment is variable around the long-term average. Since 2002 fishing mortality (F) has declined. Spawning-stock biomass (SBB) is at a low level, but has been gradually increasing in recent years (ICES 2013A).

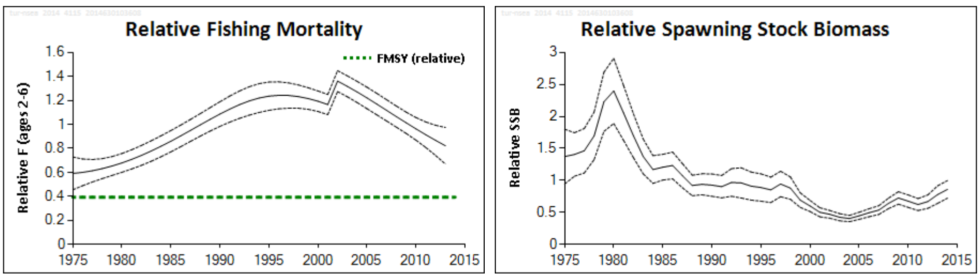


Figure 8 Relative fishing mortality and spawning stock biomass of turbot in the North Sea. Median and 95% confidence limits (dashed lines) (ICES 2013A).

Brill – Teal & van Keeken 2011: "The biogeographical range of brill extends from the Mediterranean and North Atlantic Ocean in the south to the Irish Sea, North Sea, Skagerrak and Kattegat in the north (Wheeler, 1969). Brill is a demersal boreal species that usually lives in a sandy habitat and can reach a maximum length of 75 cm." [...] Brill is an active predator which feeds largely on fish.

Brill is mostly caught in the southern part of the North Sea as well as in the Skagerrak and Kattegat. The spawning period overlaps with that of turbot and can occur between March and August. Newly hatched young appear in the very shallow waters of the Dutch coast [...] most brill have moved to deeper water by the age of 3 (Knijn et al. 1993)."

Fisheries on brill - Brill is mainly caught as a valuable bycatch species in the beam-trawl fisheries targeting flatfish, and to a lesser extent in the otter trawl and fixed-net fisheries. No official minimum landing size has been set, but Belgian and Dutch producer organisations have adopted voluntary minimum landing sizes between 25 and 30 cm (ICES, 2013). Catch distribution: ICES estimated catch in 2013 is 1.390 t, of which 100% were estimated landings (ICES 2013A).

Cod – Cod is a roundfish that lives near the bottom in diverse habitats. Cod occurs throughout the boreal region of the North Atlantic and they are widely distributed throughout the North Sea, but there are indications of subpopulations inhabiting different regions of the North Sea. In the North Sea cod may be found from shallow coastal waters to the shelf edge (200 m depth) and even beyond. Larvae of cod feed pelagically, but their diet changes as they grow larger. When the juveniles become demersal, their diet is dominated by crustaceans. As they grow larger they increasingly prey on fish. Cod can reach a maximum length of 2 meter, but the common length is around 40cm. Cod can live up to 25–30 years. Some cod mature in their second year of life, but it is not before they are six years old that they are all mature. Length at first maturity varies spatially and temporally. Males mature slightly earlier than females, and there is a tendency for cod in the southern North Sea to mature at a younger age than in the northern North Sea (ICES, 2005, 2013).

Sub-adult cod occur throughout the North Sea, Skagerrak and Kattegat. Adult cod are caught in lesser quantities over large parts of the area, with highest densities in the north, between Shetland and Norway, along the edge of the Norwegian Deep, in the Kattegat, around the Dogger Bank and in the Southern Bight. The distribution of adult cod does not seem to change much throughout the year, although they seem to leave the warmer water of the Southern Bight during summer. Although an off-shore migration to deeper water has been described for 1- and 2-year-old cod, this is not obvious from distribution maps. Spawning grounds appear to be wide-spread and not restricted to specific areas. From 1985 to 1995, the highest abundance of 1-year-old cod was found along the south-eastern continental coast in the German and Southern Bights, off northeast England and in Skagerrak and Kattegat. Since then, the south-eastern North Sea has almost completely lost its importance as a nursery area. In recent years, the highest abundances are found in Skagerrak and Kattegat, and north of the 50 m depth contour (ICES, 2005).

Fisheries on cod – Cod are taken by towed gears in mixed demersal fisheries. Cod are targeted by some fleets, but are also caught as part of a mixed fishery catching haddock, whiting, *Nephrops*, plaice, and sole. Cod discards relative to catch have declined from 49% in 2007 (the highest on record after the UK Buyers and Sellers regulation was introduced) to 21–28% in 2010–2013 (weight of cod discarded from the total estimated cod catch). Catch distribution: Total catch (2013): 45.500 t, where 32.600 t were estimated landings (65% demersal trawls and seines >100 mm, 15% gillnets, 8% *Nephrops* trawls 70–99 mm, 5% beam trawls, and 7% other gears) and 12.900 t (28% by weight) estimated discards (ICES, 2014).

An annual quotum is set for cod to limit exploitation. Fishing mortality (F) declined from 2000 and is now estimated to be around 0.4, between the precautionary level (Fpa) and the MSY level (FMSY proxy) of fishing mortality. The stock (spawning stock biomass SSB) has increased from the historical low in 2006, and is now in the vicinity of the precautionary limit (Blim). Recruitment has been poor since 2000 (Figure 9).

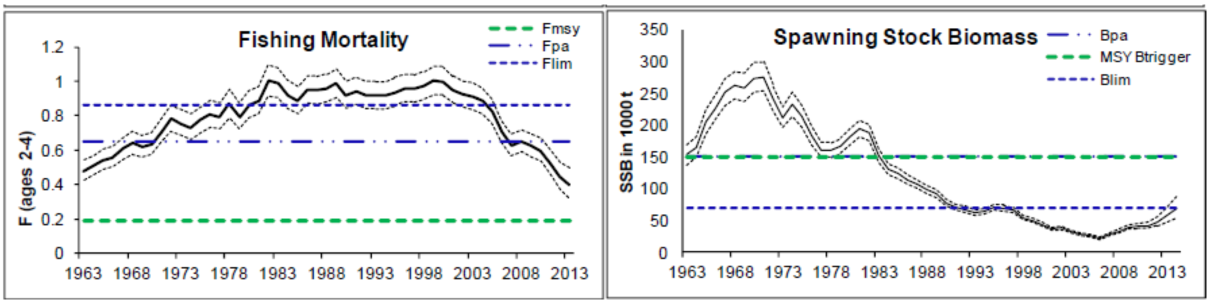


Figure 9 Cod in the North Sea, Eastern Channel and Skagerrak. Fishing mortality and Spawning Stock Biomass (with 95% confidence band) in relation to key reference points (ICES 2013A).

Whiting – Whiting is a demersal roundfish species, It is distributed in the North-east Atlantic and is also present in the western Mediterranean Sea, Black Sea, Aegean Sea and Adriatic Sea. The species is commonly found near the bottom in waters from 10 to 200 m, but may move into midwater in pursuit of prey. Immature whiting (< 20 cm) feed on crustaceans and shrimps; their diet varies according to season. Whiting >30cm feed almost entirely on fish. Whiting feeds more on bottom-dwelling prey at night, whereas pelagic and free swimming prey are captured mainly during daylight. Whiting grow relatively slowly after their first year of life, and there is a great individual variation in growth rates. They can reach a maximum length of about 70 cm and have a maximum reported age of 20 years. Most whiting are sexually mature when they are two years old.

High densities of both small and large whiting may be found almost everywhere, with the exception of the Dogger Bank, which generally shows a marked hole in the distribution. Movements of whiting in the northern North Sea are directed mainly along the Scottish coast, rather than inshore/offshore as in the South-eastern area. Part of the Skagerrak population is thought to migrate into the north-eastern North Sea to spawn. Furthermore, movements occur between the southern North Sea and the eastern Channel. Spawning takes place from January in the southern North Sea to July in the northern part. During summer, juveniles are particularly abundant in the German Bight and off the Dutch coast (ICES, 2013; Kerby, 2013).

Fisheries on whiting – Whiting are caught in mixed demersal roundfish fisheries, fisheries targeting flatfish, *Nephrops* fisheries, and as bycatch in the industrial sandeel and Norway pout fisheries. Industrial fisheries have reduced considerably since 1995 due to low TACs. The quota for this stock has been restrictive for some fleets for which whiting have been commercially very important since 2010. Fleets with lower commercial interest in whiting can have higher discard rates (ICES 2013A). Large quantities of the whiting catch are discarded due to e.g. high-grading or once the species quota is reached (Catchpole et al., 2005; Cotter et al., 2002; Enever et al., 2009; Stratoudakis et al., 1999). Catch distribution: Total catch (2013) = 26.965 t, where 19.335 t are landings (~51% demersal trawls and seine with mesh size ≥120 mm [North Sea], 16% demersal trawls mesh size 70–99 mm [North Sea], 19% demersal trawls mesh size 70–99 mm [Eastern Channel], and 14% other gears), 5.976 t (22% by weight) discards, and 1.654 t industrial bycatch (ICES 2014).

An annual quotum is set for whiting to limit exploitation. The stock (spawning stock biomass SSB) has declined in recent years and is close to the minimum value of the time-series, while fishing mortality (F) has been declining over most of the time-series. The average level of recruitment has been low since 2003 (*Figure* 10).

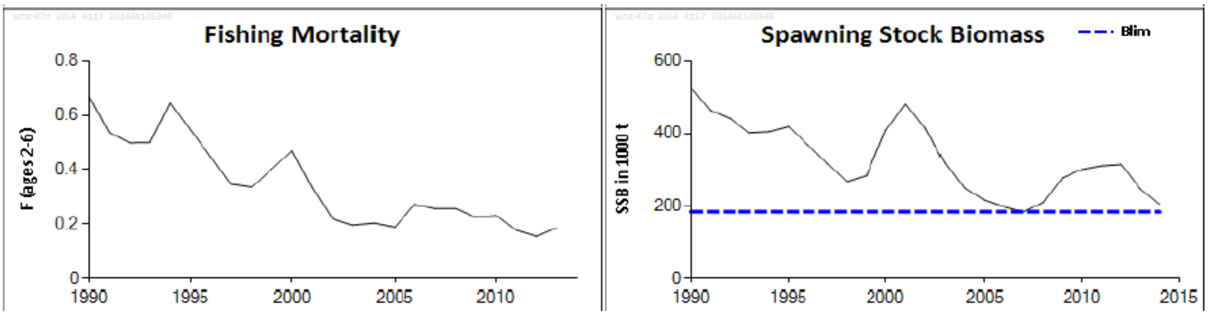


Figure 10 Whiting in the North Sea and Eastern Channel. Fishing mortality and Spawning Stock Biomass in relation to key reference points (ICES 2013A).

Fisheries on sprat – Sprat in Subarea IV is mainly fished together with juvenile herring and the exploitation of sprat is limited by the herring bycatch restrictions imposed on the fisheries. Discarding and slippage of sprat is understood to occur when the bycatch percentage of herring in the catch is higher than the allowed percentage. The majority of sprat landings are taken in the Danish small-meshed trawl fishery, which has about 10% bycatch of herring. The Norwegian sprat fishery is carried out by purse-seiners and small-meshed trawlers. Norwegian regulations for the North Sea sprat fishery allow for a maximum 10% (by weight) bycatch of herring. The bycatch percentage in this fishery is unknown (ICES 2013A). There is no directed fishery on sprat by Dutch fishers on the DCS. Catch distribution: Total catch (2013) is unknown. Official landings were 70.600 t (all gear types) of which all were industrial catch. Discards are known to take place but cannot be quantified (ICES 2013A).

Two regulations potentially limit the sprat trawl fishery in addition to the sprat TAC, one being the bycatch ceiling for herring and the other the herring bycatch percentage limit in industrial fisheries. The spawning stock has been at or above the precautionary level (Bpa) since 2005. Fishing mortality (F) has shown an overall decreasing trend since 2004. Spawning stock biomass (SSB) in 2013 is estimated to be at the precautionary level (Bpa). Recruitment in 2013 is estimated to be one of the highest in the time-series (ICES, 2013A).

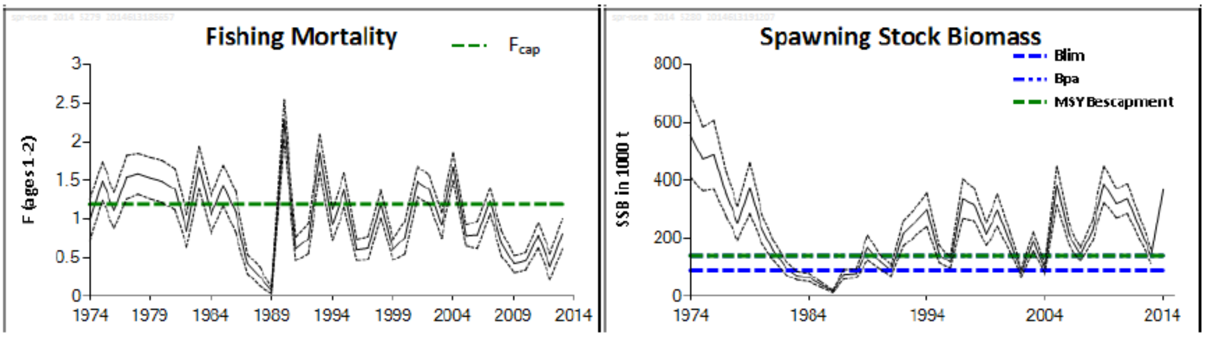


Figure 11 Sprat in the North Sea. Fishing mortality and Spawning Stock Biomass (with 95% confidence band) in relation to key reference points (ICES 2013A).

Brown shrimp – Shrimp are small benthic invertebrates with a strongly coastal distribution from the south of the Scandinavian peninsula down to the Mediterranean. Eggs are produced year-round but there is a peak in spawning around January and around July. Females release eggs in the water column, which are transported to very shallow water by the currents, where they hatch. Juveniles spend a few years in the shallows, and then move out to deeper waters. Shrimp have a very opportunistic diet, ranging from algae to predation on juvenile fish (Delnortecampos and Temming 1994).

Fisheries on brown shrimp

Trawling for brown shrimp is one of the major fishing activities practised in The Netherlands. Fishery on brown shrimp takes place year-round, but is concentrated in autumn. Exploitation is concentrated within the 12nm zone and is conducted by small trawlers (<300hp) using small mesh size nets. Annual catches from the North Sea are currently ~30,000 tons, of which a substantial part comes from the Dutch Wadden sea and North Sea coastal area. There is no quotum for brown shrimp, but fishing is restricted to weekdays, and because the bulk of the fishing in Dutch waters occurs in Natura2000 areas, fishing requires a legal permit. This method of fishing has substantial bycatch of juvenile fish, especially flatfish, which use the coastal shrimp habitat as nursery grounds. There is an ongoing research effort to develop gear adaptations which reduce this bycatch (Steenbergen et al 2013).

6 Fishing activity, yield and revenues by proposed MPA

In this chapter we provide several numerical characteristics of the various types of fisheries by proposed MPA area.

We first give an overview of the average monetary yield by area (Table 7). Next, we give for each of the MPAs an overview of the selected characteristics by type of fishery (gear type; Table 8 – Table 22): days at sea (DAS), monetary yield, total catch weight (tonnes). In these tables, the catch weight is split up into six categories: plaice, sole, turbot and brill combined, cod, whiting and a rest category. The latter may comprise the majority of the catch, e.g. brown shrimp for the shrimp trawl fishery and razor clams for the dredges.

The coastal areas are the most important to the fishery in terms of monetary yield. Especially the North Sea Coastal Zone (area 5) stands out, with a high yield-to-area ratio (almost 1/5 of the total yield obtained in the DCS, whereas it comprises only 1/40 of the DCS surface area, Table 7). All other coastal areas (areas 1, 2 and 4) and the Wadden Sea (area 15), also have yield-to-area ratios of >1.

Of the present and proposed MPAs outside the coastal zone, the Brown Bank (area 8) and the Frisian Front (area 9) have the highest relative importance to the fishery. Of these, only the Brown Bank (area 8) has a >1 yield-to-area ratio similar to the coastal areas.

Table 7 Monetary yield (in thousands of Euro (10^3 Euro) for 2010-2013 by area.

Area	No.	2010	2011	2012	2013	average	%	area (% of DCS)
remaining DCS_NL	0	58498.8	52013.1	54043.5	62162.1	56700	52.5	60.6
Vlakte van de Raan	1	3204.4	4023.3	353.2	900.5	2100	1.9	0.3
Voordelta	2	3232.1	2979.4	2673.6	8024	4200	3.9	1.4
Zeeuwse Banks	3	2948.5	1440.1	1300.1	2000	1900	1.8	1.3
Coastal Sea	4	2777.3	3202.2	4163.4	4651.9	3700	3.4	2.2
North Sea Coastal Zone	5	14308.3	11334.8	17208.2	19732.8	15600	14.5	2.5
Borkum Stones	7	123	151.6	345	431.6	300	0.3	1.4
Brown Bank	8	4702.9	3798.4	3385.4	3544.9	3900	3.6	2.5

Frisian Front	9	4347.8	3363.7	5824.3	3419.1	4200	3.9	4.9
Cleaver Bank	10	2216.4	2253.1	3126.2	1581.7	2300	2.1	2.2
Central Oyster Grounds	11	717.1	1291.2	1502.1	862.5	1100	1.0	5.9
Gas Seeps	12	12.1	31.8	62.3	70.9	0	0.0	1.0
Arctica islandica Area	13	52.5	39.5	131.3	182.5	100	0.1	1.5
Dogger Bank	14	399.4	1291.9	3492.4	2545.5	1900	1.8	8.1
Wadden Sea	15	9835.1	5814.9	7943.9	15948.1	9900	9.2	4.3
Sum		**107375.7**	**93029**	**105554.9**	**126058.1**	**107900**	**100.0**	**100**

In **most of the DCS** (area 0) and outside the various present or proposed MPAs the (large) beam trawl fishery aimed at flatfish is by far the most important fishery, followed by the shrimp fishery. Whereas the beam trawl fishery mainly takes place over a wider area in the southernmost North Sea (Figure 2, upper left), the shrimp fishery is concentrated in the coastal zone just outside the North Sea Coastal Zone (area 5; Figure 2, upper right).

The fishery in the **coastal proposed MPAs** (areas 1-7) and the Wadden Sea (area 15) is dominated by shrimp fishery. Only on the Zeeuwse Banks (area 3), small beam trawl fishery is more important than the shrimp fishery. The other important type of fishery in the coastal MPAs is the shellfish fishery with dredges (areas 1-3, 5), except in the Wadden Sea and the Coastal Sea (present, but not important) and the Borkum Stones (absent). In addition, in the Coastal Sea (area 4), like on the Zeeuwse Banks, the small beam trawl fishery appears of relative importance.

The fishery in the **other proposed MPAs outside the coastal zone** (areas 8-14) is dominated by a combination of beam trawl and otter trawl fishery, in their various occurrences. Only on the Oyster Grounds (area 11) and the Arctica islandica Area (area 13), otter trawl fishery is more important than the beam trawl fishery.

Table 8 Numerical characteristics of fisheries in area: ***remaining DCS (area no. 0)***

Fishery type (gear type)		**Days at sea**	**Yield (10^3 Euro)**	**Weight (tonnes) total**	**Weight (tonnes)**					
					plaice	**sole**	**brill / turbot**	**cod**	**whiting**	**other**
Boat dredges	large	9.2	0	1	0	0	0	0	0	1
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		5.2	105	40	0	0	0	0	0	40
Otter trawl	large	113.8	508	258	191	1	3	13	2	48
Otter trawl	small	303.3	1030	457	194	1	7	62	31	162
Otter twin trawl	large	25.6	86	22	8	0	0	2	1	11
Otter twin trawl	small	100.9	365	98	44	1	3	3	1	46
Scottish seine	large	159.1	770	407	23	1	1	14	7	361
Scottish seine	small	93.4	489	244	17	0	0	17	11	199
Beam trawl	large	5717.1	44489	13662	7098	2467	672	243	54	3128
Beam trawl	small	1278.2	4594	1263	344	324	25	22	9	538
Shrimp trawl	small	1568.3	4244	1409	2	7	0	2	0	1398
Sum		9374.1	56680	17861	7921	2802	711	378	116	5932

Table 9 *Numerical characteristics of fisheries in area:* ***Vlakte van de Raan (area no. 1)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	19.7	452	169	0	0	0	0	0	169
Boat dredges	small	20.9	1036	347	0	0	0	0	0	347
Mechanised dredges		2.3	55	19	0	0	0	0	0	19
Otter trawl	large	1.5	2	1	0	0	0	1	0	0
Otter trawl	small	21.1	33	18	0	0	0	10	1	7
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	0	0	0	0	0	0	0	0	0
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	0	0	0	0	0	0	0	0	0
Beam trawl	small	41.7	226	58	8	18	1	0	0	31
Shrimp trawl	small	92.5	318	111	0	1	0	1	1	109
Sum		199.7	2122	723	8	19	1	12	2	682

Table 10 *Numerical characteristics of fisheries in area:* ***Voordelta (area no. 2)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	19.6	696	215	0	0	0	0	0	215
Boat dredges	small	5.4	534	203	0	0	0	0	0	203
Mechanised dredges		34.5	991	314	0	0	0	0	0	314
Otter trawl	large	1.1	1	1	0	0	0	0	0	0
Otter trawl	small	12.2	21	16	0	0	0	3	1	12
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0.5	1	1	0	0	0	0	0	1
Scottish seine	large	0.4	3	3	0	0	0	0	0	3
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	1.2	10	3	2	0	0	0	0	0
Beam trawl	small	56.1	229	69	8	16	1	0	0	44
Shrimp trawl	small	530.1	1741	626	0	1	0	2	1	622
Sum		661.1	4227	1451	10	17	1	5	2	1414

Table 11 *Numerical characteristics of fisheries in area:* ***Zeeuwse Banks (area no. 3)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	5.9	180	54	0	0	0	0	0	54
Boat dredges	small	5.1	218	62	0	0	0	0	0	62
Mechanised dredges		2.7	57	21	0	0	0	0	0	21
Otter trawl	large	0.5	0	0	0	0	0	0	0	0
Otter trawl	small	5.2	10	4	0	0	0	2	0	2
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	3.4	11	8	0	0	0	0	0	8
Scottish seine	small	0	0	0	0	0	0	0	0	0

Beam trawl	large	62	402	80	23	29	5	1	0	22
Beam trawl	small	240	875	194	45	70	4	3	1	71
Shrimp trawl	small	71.1	169	61	0	0	0	1	0	60
Sum		395.9	1922	484	68	99	9	7	1	300

Table 12 Numerical characteristics of fisheries in area: ***Coastal Sea (area no. 4)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		9.8	221	72	0	0	0	0	0	72
Otter trawl	large	5.5	7	7	0	0	0	0	1	6
Otter trawl	small	49.5	104	90	0	0	0	16	2	72
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0.6	1	0	0	0	0	0	0	0
Scottish seine	large	10.1	70	57	0	0	0	0	1	56
Scottish seine	small	25.2	119	115	1	0	0	1	1	111
Beam trawl	large	4.6	14	5	1	1	0	0	0	3
Beam trawl	small	557.6	2567	654	39	218	7	1	0	389
Shrimp trawl	small	187.9	596	218	0	2	0	3	1	212
Sum		850.8	3699	1218	41	221	7	21	6	921

Table 13 Numerical characteristics of fisheries in area: ***North Sea Coastal Zone (area no. 5)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		71.7	1650	546	0	0	0	0	0	546
Otter trawl	large	0.6	1	1	0	0	0	0	0	1
Otter trawl	small	16.1	11	3	0	0	0	0	0	3
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	0	0	0	0	0	0	0	0	0
Scottish seine	small	0.3	0	0	0	0	0	0	0	0
Beam trawl	large	1.4	11	4	1	1	0	0	0	2
Beam trawl	small	86	302	70	2	19	0	0	0	49
Shrimp trawl	small	4921.5	13671	4742	1	19	0	1	0	4721
Sum		5097.6	15646	5366	4	39	0	1	0	5322

Table 14 Numerical characteristics of fisheries in area: ***Borkum Stones (area no. 7)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0

Otter trawl	large	0	0	0	0	0	0	0	0	0
Otter trawl	small	0	0	0	0	0	0	0	0	0
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	9.1	24	14	1	0	0	0	0	12
Scottish seine	small	0.1	0	0	0	0	0	0	0	0
Beam trawl	large	0.8	5	1	0	0	0	0	0	0
Beam trawl	small	1.1	1	0	0	0	0	0	0	0
Shrimp trawl	small	102.2	233	69	0	0	0	0	0	69
Sum		113.3	263	84	1	0	0	0	0	81

Table 15 Numerical characteristics of fisheries in area: ***Brown Bank (area no. 8)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill/turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	3.6	10	6	1	0	0	1	3	1
Otter trawl	small	9.2	25	14	0	0	0	5	4	4
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	5.3	19	10	0	0	0	0	1	9
Scottish seine	small	13	62	28	1	0	0	2	4	21
Beam trawl	large	498	3637	1275	613	201	51	30	7	373
Beam trawl	small	32.4	102	49	23	5	1	2	1	17
Shrimp trawl	small	0.5	3	1	0	0	0	0	0	0
Sum		562	3858	1383	638	206	52	40	20	425

Table 16 Numerical characteristics of fisheries in area: ***Frisian Front (area no. 9)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill/turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	24.9	110	33	7	0	1	0	0	25
Otter trawl	small	97.2	373	97	22	1	3	1	1	68
Otter twin trawl	large	34.1	128	31	7	0	1	0	0	23
Otter twin trawl	small	194.9	1220	386	39	2	6	2	0	337
Scottish seine	large	4.2	17	8	2	0	0	0	0	6
Scottish seine	small	1.5	6	3	1	0	0	0	0	2
Beam trawl	large	374.7	2281	705	372	116	34	20	2	162
Beam trawl	small	32.4	102	26	9	7	0	1	0	9
Shrimp trawl	small	0.5	1	0	0	0	0	0	0	0
Sum		764.4	4238	1289	459	126	45	24	3	632

Table 17 Numerical characteristics of fisheries in area: ***Cleaver Bank (area no. 10)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill/turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	23.7	72	34	11	0	0	1	1	20
Otter trawl	small	72.4	215	87	27	1	1	9	4	46
Otter twin trawl	large	52.7	174	65	19	1	1	4	3	38
Otter twin trawl	small	121.9	465	142	43	1	2	8	3	85
Scottish seine	large	31.1	231	95	12	0	0	20	5	58
Scottish seine	small	13.3	71	33	4	0	0	5	3	21
Beam trawl	large	126.9	1048	412	291	31	23	6	2	59
Beam trawl	small	6.5	17	5	3	0	0	0	0	1
Shrimp trawl	small	0	0	0	0	0	0	0	0	0
Sum		448.5	2293	873	410	34	27	53	21	328

Table 18 Numerical characteristics of fisheries in area: ***Central Oyster Grounds (area no. 11)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	Sole	brill/turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	30.3	158	68	40	0	1	0	0	27
Otter trawl	small	95.4	369	200	172	1	3	3	0	21
Otter twin trawl	large	4.9	13	6	4	0	0	0	0	1
Otter twin trawl	small	26.3	66	28	22	0	0	1	0	5
Scottish seine	large	1.8	0	0	0	0	0	0	0	0
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	64.5	484	202	159	19	8	2	0	13
Beam trawl	small	2	2	1	0	0	0	0	0	0
Shrimp trawl	small	0.3	0	0	0	0	0	0	0	0
Sum		225.5	1092	505	397	20	12	6	0	67

Table 19 Numerical characteristics of fisheries in area: ***Gas Seeps (area no. 12)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill/turbot	Cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	1.2	2	1	1	0	0	0	0	0
Otter trawl	small	3.6	5	3	2	0	0	0	0	0
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	0	0	0	0	0	0	0	0	0
Scottish seine	small	0	0	0	0	0	0	0	0	0

Beam trawl	large	4.6	37	16	13	1	1	0	0	1
Beam trawl	small	0	0	0	0	0	0	0	0	0
Shrimp trawl	small	0	0	0	0	0	0	0	0	0
Sum		9.4	44	20	16	1	1	0	0	1

Table 20 *Numerical characteristics of fisheries in area:* ***Arctica islandica Area (area no. 13)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	0.3	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	7.5	33	20	18	0	0	0	0	2
Otter trawl	small	8.5	46	23	14	0	0	0	0	10
Otter twin trawl	large	0.1	0	0	0	0	0	0	0	0
Otter twin trawl	small	3.6	13	8	8	0	0	0	0	0
Scottish seine	large	0	0	0	0	0	0	0	0	0
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	0.9	9	5	4	0	0	0	0	1
Beam trawl	small	0	0	0	0	0	0	0	0	0
Shrimp trawl	small	0	0	0	0	0	0	0	0	0
Sum		20.9	101	56	44	0	0	0	0	13

Table 21 *Numerical characteristics of fisheries in area:* ***Dogger Bank (area no. 14)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	Cod	whiting	other
Boat dredges	large	1.8	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		0	0	0	0	0	0	0	0	0
Otter trawl	large	38.4	181	114	94	0	0	3	0	17
Otter trawl	small	32.5	147	90	78	0	0	2	1	10
Otter twin trawl	large	0.1	0	0	0	0	0	0	0	0
Otter twin trawl	small	12.6	59	36	32	0	0	0	0	3
Scottish seine	large	0.7	2	2	1	0	0	0	0	1
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	210.6	1543	922	840	12	6	2	0	62
Beam trawl	small	0	0	0	0	0	0	0	0	0
Shrimp trawl	small	0	0	0	0	0	0	0	0	0
Sum		296.7	1932	1164	1045	12	6	7	1	93

Table 22 *Numerical characteristics of fisheries in area:* ***Wadden Sea (area no. 15)***

Fishery type (gear type)		Days at sea	Yield (10^3 Euro)	Weight (tonnes) total	Weight (tonnes) plaice	sole	brill / turbot	cod	whiting	other
Boat dredges	large	0	0	0	0	0	0	0	0	0
Boat dredges	small	0	0	0	0	0	0	0	0	0
Mechanised dredges		5.2	222	68	0	0	0	0	0	68

Otter trawl	large	0	0	0	0	0	0	0	0	0
Otter trawl	small	62.5	51	14	0	0	0	0	0	13
Otter twin trawl	large	0	0	0	0	0	0	0	0	0
Otter twin trawl	small	0	0	0	0	0	0	0	0	0
Scottish seine	large	0	0	0	0	0	0	0	0	0
Scottish seine	small	0	0	0	0	0	0	0	0	0
Beam trawl	large	3.6	12	4	1	1	0	0	0	2
Beam trawl	small	16	37	13	0	0	0	0	0	13
Shrimp trawl	small	3056.8	9563	2966	0	3	0	0	0	2962
Sum		3144.1	9885	3065	1	4	0	0	0	3058

7 Potential effects of closure of proposed MPAs to fisheries

In this chapter we combine by area the information provided in all previous chapters. We provide a qualitative assessment of the extent to which the factors and mechanisms that affect potential fishery benefits apply to the area. Based on this we describe the potential effects (short term and long term) of (the hypothetical situation of) total closure of the area on the main fisheries operating in these and the surrounding waters.

From the review in chapter 3 it appears that various aspects affect the possibility of fishery benefits (larval export and/or spillover) of MPAs:

- the presence of spawning grounds or nursery areas;
- the potential for density independent growth (high production areas) and
- the size of the MPA in relation to the movement rates of the fish.
- whether or not displacement of fishing activities takes place.

Most of the selected fish species occur all over the DCS. Except for brown shrimp, which is confined to the coastal zone, sole, which reaches the northern boundary of its distribution area towards the northernmost edge of the DCS, and whiting, which shows a marked hole in its distribution in the Dogger Bank area.

Locations of spawning and nursery areas are generally indicative, e.g. “southern North Sea” for plaice and sole, and “coastal areas” for flatfish (and many other) species. The current and proposed MPAs are relatively small compared to the size of these indicative areas. Therefore, based on the current knowledge, it is impossible to attach specific importance of each of these MPAs to the life cycle of the various selected fish species.

Table 23 summarizes the general knowledge to our best expert judgement.

Table 23 Presence of spawning grounds (S) and/or nursery areas (N) of selected species over MPAs and remaining DCS. Based on consultation of experts in IMARES (R. van Hal – project leader IBTS survey, Dr. H. Heessen – former project leader BTS survey, Dr. I. Tulp – coastal ecosystem expert, Prof. A.D. Rijnsdorp – flatfish expert, Dr. T. van der Hammen, turbot/brill expert). Question marks indicate area/function combinations which are suspected but unknown.

Area	Plaice	Sole	Turbot	Brill	Cod	Whiting	Herring	Sprat	Shrimp
remaining DCS_NL	S[1]/N	S[1]/N			S/N	S/N?	N	S/N	
Vlakte van de Raan	N	S[1]/N	N	N	N[2]	N[2]	N	S/N	S/N
Voordelta	N	S[1]/N	S?/N	S?/N	N[2]	N[2]	N	S/N	S/N
Zeeuwse Banks	N	S[1]/N	S?	S?	N[2]	N[2]	N	S/N	S/N
Coastal Sea	N	S[1]/N	N	N	N[2]	N[2]	N	S/N	S/N
North Sea Coastal Zone	N	S[1]/N	N	N	N[2]	N[2]	N	S/N	S/N
Borkumse Stones	S[1]				N		N	S/N	S/N
Brown Bank	S[1]	S?			S	S/N	N	S/N	
Frisian Front	S[1]				N	S/N	N	S/N	
Cleaver Bank	S[1]				S	S/N			
Central Oyster Grounds	S[1]				S	S/N			
Gas Seeps	S[1]				S	S/N			
Arctica islandica Area	S[1]				S	S/N			
Dogger Bank					S	S/N			
Wadden Sea	N	N			N	N	N	N	S?/N

[1] Spawning in "southern North Sea"; spawning not assessed in specific areas
[2] Currently not, but historicaly (25 years ago) this area did have this function

The various areas considered in this study can be clustered according to whether or not each of the four abovementioned factors apply. The first cluster consists of the **coastal areas**. These are in general high production areas and they all encompass nursery areas for many commercially relevant fish species (Table 23). The second cluster consists of high production areas that are relatively large in size (**large areas**). The third cluster comprises areas that are selected for their specific habitat characteristics, but they are of no specific relevance to the fisheries (**habitat areas**). The fourth cluster combines areas that are selected as a result of a high local density of one or several species (**species areas**), and they are also of no specific relevance to fisheries.

7.1 Coastal areas

All coastal areas – Vlakte van de Raan, Voordelta, Zeeuwse Banks, Coastal Sea, North Sea Coastal Zone and Wadden Sea, are high productivity areas, which are also important nursery areas for many (flat-) fish species. These coastal areas are the prime (and almost exclusive) domain of activity of the (largely Dutch) shrimp fishery. The shrimp fishery has substantial bycatch of juvenile flatfish. Closing this area to all fisheries would remove this mortality factor and may lead to higher numbers of juveniles recruiting to the catchable adult population, elsewhere in the North Sea (Revill et al. 1999). Such an increased inflow of recruits could enhance the stock, which is exploited by other fisheries (in particular the large beam trawl fleet). However, the calculation by Revill et al. (1999) was made for a period when plaice was considered overfished, whereas currently, the North Sea plaice stock is at a historically high level (ICES, 2013).

Whether the reduced mortality would indeed lead to increased recruitment and stock size depends on whether, and at what sizes,density-dependent mortality or growth affect the juveniles in these coastal areas. If the reduced bycatch mortality leads to increased density-dependent mortality, or reduced growth of the juveniles, the effect may be dampened or even negated. A positive contribution to the stock as a result of reduced bycatch mortality is more likely when the bycatch mortality occurs at larger sizes/ages than the density-dependent mortality. There is evidence for density-dependent growth reduction in the Dutch Wadden sea (Teal et al. 2008). Given the high abundance of plaice, and the fact that density-dependent effects are more likely to occur at high abundance, it is uncertain whether an increase in survival would, currently, lead to an increased stock size.
Another possible (but speculative) scenario is that closing the coastal areas to the shrimp fishery would lead to substantially more brown shrimp in these areas (30.000 tons are caught annually) (ICES, 2013B), which feed on juvenile flatfish (Delnortecampos and Temming 1994). It is possible that in that case the additional mortality of (flat-) fish through shrimp predation would be substantial, and larger than the current bycatch mortality. Under these conditions, closing the coastal zone would increase juvenile flatfish mortality and hence not lead to a stock increase.

The effects of shrimp fisheries on the benthic ecosystem, other than removal of shrimp, are currently not well known (Tulp, 2009). If shrimp fisheries would turn out to have a detrimental effect on other species inhabiting the seafloor, which form food and/or shelter for juvenile fish, closing the area to fishing could enhance the nursery area function of these fish. However, increased predation by increased shrimp abundance after ceased fishery could overwhelm such secondary effects. It has been shown in the Wadden Sea that shrimp abundance is an important determinant of the recruitment success of bivalve species (Philippart et al. 2003), which are prey for juvenile flatfish, and also can have an effect on flatfish recruitment (Van der Veer et al. 1997).
In terms of economic yield, the shrimp fishery in the coastal areas is a large fishery. When we compare the relative value of shrimp from the coastal areas with that of flatfish caught elsewhere on the DCS, it seems unlikely that a complete ban on shrimp fishery would sufficiently increase the yield of other fisheries to make up for the economic loss of the coastal shrimp fishery (as the shrimp fishery amounts to approximately 30% of the entire Dutch revenue inside the DCS). This would still be the case, even if there would be no density-dependent mortality and all juvenile fish that are currently discarded by the coastal shrimp fishery would grow into the fishable stock.

The Zeeuwse Banks area is an extension of the coastal areas, further offshore. The sole fishery in the area deserves special notice. The Zeeuwse Banks consists of sand banks, interspersed by deeper gullies. It is a seasonal fishing ground for sole, which is economically important for the beam trawl fleet, as it yields much higher prices than plaice. Sole migrate through this area seasonally, on the way to the coastal area to spawn. Closing this area could increase the number of sole reaching the spawning grounds, which could enhance sole recruitment. It is unclear however to what extent density-dependence in the early life stages of sole (in the nursery grounds) limits recruitment. There is no stock-recruitment relationship for sole (ICES 2013), but recruitment patterns are to some extent climate related (Rijnsdorp et al 2009). It should be noted that during the seasonal fisheries, sole reach high density in this area, so that fishing is relatively efficient. Closing this area could easily lead to displacement of sole fishery, to areas where it is less efficient, leading to higher costs for fishermen, and more catches of other species per sole caught.

The sole stock and its exploitation in the North Sea is currently very close to its MSY target. Strong benefits of MPAs to the fishery (increased the stock size or catches) are predicted only in overexploited fisheries, so the scope for this effect is limited in this case. On the other hand, the healthy state of the

stock may give room for careful implementation of MPAs without adversely affecting stock or fishery, so that other MPA goals (conservation) can be attained while fishing quota could be maintained.
Some of the (Dutch, German and Danish) coastal areas in the North Sea are part of the so-called plaice box. This area was closed to large beam trawl fisheries (>300Hp) in the early 1990's, with the aim of protecting juvenile plaice from discard mortality, resulting in an increased plaice stock (Beare et al. 2013). Contrary to expectations, the plaice stock was not increased following the implementation of the plaice box. The question remains whether the failure of this protected area to achieve its aim is due to an incorrect understanding of the ecosystem, an incorrect implementation of the MPA (closing it only to large beam trawl vessels), or other factors which have independently changed (for example reduced nutrient loading, increased temperature) (Beare et al. 2013). The main reason for this unclarity is that there has been no monitoring plan implemented aimed at measuring the efficacy of the plaice box. Although the case offers no argument for the establishment of an MPA, it shows that monitoring is of utmost importance when implementing closed areas.

7.2 Large areas of high productivity

Apart from the coastal zone areas, none of the other areas are of specific importance for particular life stages of the selected fish species. For those other, non-coastal areas, size and high productivity are of prime interest as a precondition to generate possible fishery benefits. The occurrence of high productivity in an area means that density-dependent growth limitation will only occur at very high density, facilitating the potential for adult spillover when such areas are closed to fisheries (See 3.2). When high-productivity areas are also relatively large, this further enhances the likelihood of spillover. Two of such areas can be identified: The Dogger Bank and the Frisian Front. Although the Wadden Sea and Central Oystergrounds are also large, they are of special interest for conservation primarily for other reasons, and are therefore discussed under different headings.

Closing large areas of a soft-sediment habitat to bottom fisheries has been part of a successful strategy to rebuild fish and shellfish stocks in the Georges Bank fisheries in the USA. In 1994, approximately 25% of the groundfish fishing grounds in the area were closed to all gears capable of catching groundfish, including scallop dredges. In the 5 years following closure, many of the heavily depleted fish stocks showed a clear upward trend (Murawski et al. 2000). Scallops reacted most strongly, with densities reaching in excess of 10-fold those in the fished areas, within 5 years after closure. The area closures on the Georges Bank were part of a range of measures aimed at reducing the exploitation rate of the depleted groundfish stocks in the area, allowing them to rebuild. It is evident that the closures have contributed to this goal. The question is to what extent the rebuilding was caused by the closures per se, or by the reduced exploitation rate. The evidence points towards the former. Analysis of fishing patterns, catches and biophysical models indicates that the areas where the larvae from the protected areas settled after their pelagic phase, scallop fishing activity and catch rate were higher, suggesting larval export from the closed areas (Lewis 1999). Otter trawl fisheries showed a clear concentration along the edges of the closed areas, where catches were substantially higher than further away from the closed areas (Murawski et al. 2005), which is an indication of spillover of catchable individuals from the MPAs. The Georges Bank example shows clearly that closing large areas to bottom fishing can be an effective element of a strategy to rebuild overfished demersal fish and shellfish stocks, and that adult spillover from an MPA can provide the surrounding fishery with harvestable biomass.

The Dogger Bank and the Frisian Front areas most closely resemble the closed areas in the Georges Bank, and it is relevant to ask if closing these areas can have similar fishery benefits. They represent substantial fractions of the DCS (8% and 5% respectively). Because the Dogger Bank and the Frisian Front areas are not of particular importance as spawning area, larval export is unlikely to occur.

However, both are areas of high productivity of phytoplankton, which is the basic fuel of the marine food web. As a consequence, such areas can potentially support a high density of fish.
Because of this high productivity, closing the area to fishing is likely to lead to increased fish abundance compared to the surrounding areas. This in turn could lead to spillover to the surrounding space. For the less mobile species this spillover may lead to increased yields along the edges of the area. Stocks of ighly mobile species, the individuals of which would spend relatively little time inside the reserve, may also benefit, even if dilution of the spillover effects over the entire stock area would make the beneficial effects hard to detect.

An important difference between the Georges Bank example and the current situation in the North Sea is that many of the commercially exploited fish stocks in the North Sea are in a much better state than the Georges Bank groundfish stocks were in 1994. While some North Sea stocks (notably cod) remain below target, many are now at or above target levels, and harvest is at or near MSY. The Georges Bank closure proved to be a successful element of a strategy to rapidly rebuild stocks in a strongly overfished ecosystem, the question in the North Sea is more subtle. While certain stocks are exploited at or near MSY, others still need rebuilding, Whether or not MPAs are useful tools in such selective rebuilding has, to our knowledge, never been studied. However, the unrecovered North Sea stocks, especially cod, could benefit from closure of the Doggerbank and Frysian Front areas.

Another question relevant to the North Sea is whether or not MPAs can increase yield at or near MSY. Theory shows that equivalent yields can be attained using either MPAs or traditional control of fishing mortality (Hastings and Botsford 1999), but to our knowledge there is no work which shows that the yield taken from a healthy stock can be enhanced by the implementation of MPAs. The most well-known example where this has been attempted is the 'plaice box' in the North Sea, where the coastal nursery areas were closed to heavy beam trawling to protect undersized plaice, which was thought to lead to an increase in the harvestable stock size. In the years following closure, the plaice stock in the North Sea declined rapidly. A causal link between the decline and the installation of the plaice box has never been shown, but it is generally perceived as a failure by stakeholders (Beare et al. 2013).

Currently a number of stocks in the North Sea are near target levels and exploitation is near MSY. For this situation there are no indications that closures will enhance stock size. However, there are indications, based on parallels with the Georges Bank system, that closing large feeding areas such as the Dogger bank and Frisian Front could lead to fisheries benefits through spillover effects, and rapid rebuilding of depleted stocks, from low densities, if the closure is part of a larger set of measures which prevent fishing intensity to rise in areas that remain open.

An important consideration of closing large areas to fisheries is the potential displacement that is associated with it. Even a low fishing intensity can be a lot of fishing effort if it is multiplied over a large area. This brings a large amount of uncertainty into the effects of such closures, unless they implemented as part of a larger suite of measures to regulate the fishing in the area which remains open. Associated with this displacement issue is the potential economic effect. Displacement to further away areas, areas where fish are present in lower density, or where gears are less efficient, all have an effect on the profitability of the fisheries. This is beyond the scope of this study, but should be part of any consideration to close areas, especially large areas.

Finally, closing very large areas to fishing could also be part a management strategy where they function as an 'insurance policy'. While not enhancing catches directly, the indirect fishery benefit could be a higher resistance against imperfect effort management, effects of uncertainty in stock assessments and environmental variability.

7.3 Habitat areas

A number of the proposed MPAs (Figure 1) are selected on the basis of specific habitat characteristics under Natura 2000. The Cleaver Bank, Central Oyster Grounds, and Borkum Stones areas are characterised by (potential[2]) hard substrates. In the gas seeps, natural gas escapes in bubbles from the seafloor. This potentially supports a unique microbiological flora, and such areas often contain carbonate structures with a unique associated flora and fauna (but see van Bemmelen and Bos, 2011). On the Borkum Stones, Gas Seeps and Central Oystergrounds, there is little fishing activity and the areas are of very limited value to the fishery, either in relation to their size (Central Oystergrounds), or in an absolute sense (Borkum Stones and Gas Seeps) (Table 7). Closing these areas will not have a significant effect on fishing intensity or spatial distribution, so that no fishery benefits can be expected if these areas become MPAs. On the other hand, closure will not lead to large costs for the fishery in terms of lost yield.

The Cleaver Bank is characterised by a more diverse bottom structure, including coarse sediments, than the surrounding area. The seafloor supports a large number of benthos species. The Cleaver bank is a more important fishing ground than the other 'habitat areas', in particular for various types of otter trawls, and large beam trawls (Table 17), though it is not a fishing hotspot. The fishery is mostly concentrated in the Botney Cut, a muddy trench which runs through the area. It is also the most important potential spawning and nursery area for cod (Fox et al. 2008) and whiting (Loots et al. 2010) on the DCS, two species of which the stocks are currently below target in the North Sea. It is likely that closing the Cleaverbank area to fishery would increase its spawning and nursery function for these species. Such a measure could well be an important part of a larger strategy to rebuild these stocks. Despite the short-term loss in fishing opportunity, the recovery of cod and whiting in the long run would constitute a major fishery benefit.

7.4 Other areas

The Arctica islandica area is selected for the occurrence of the ocean quahog (*Arctica Islandica*), a large and very long-living bivalve species (up to hundreds of years). There is very little fishing activity from the Dutch fleet in this area, which may be one of the reasons for the relatively high abundance of ocean quahog. Closing it will not lead to any redistribution of fishing effort, and hence no effect on fisheries, beneficial or otherwise, are to be expected.

The Brown Bank area qualifies for protection under the birds directive for its high abundance of guillemots and razorbills. The area is used by the large beam trawl fleet, for which it is also important in terms of monetary yield (Table 15). This area has a relatively high abundance of benthic meiofauna, including groups that are food for plaice (Witbaard et al. 2008) Closing this area to the fishery could lead to a local population build-up of plaice, with potential local spillover effects, but the area is relatively small (compared to other proposed MPAs such as the Dogger Bank), and spillover would most likely lead to only local effects ('fishing the line'). Furthermore, with the currently very large plaice stock, it is uncertain to what extent density-dependent growth limitation in closed areas will prevent any beneficial effects of locally increased densities to the fishery.

---

[2] Potential, because many of these hard substrates are formed either by biogenic structures (Central Oystergrounds), which are currently much less abundant than in the past, or by large boulders, of which many have been removed by fisheries (Borkum Stones).

8 Conclusions

8.1 Fishery benefits of marine protected areas

1. Fish populations in MPAs can contribute to the harvestable stock in 2 ways: Export of larvae to the surrounding harvestable stock and migration (spillover) of harvestable individuals into the surrounding area.
2. MPAs benefit the fishery directly when the above mechanisms lead to more harvestable fish than is lost through the MPA closure.
3. For the mechanisms above to work, the size and location of MPAs has to be adapted to the life history of the fished species, including their home range.
4. Fishery benefits are more likely when MPAs protect under-sized or under-aged individuals of harvested species, but density-dependent effects can complicate or even reverse this relationship.
5. MPAs can be used as a way to control fishing effort. The primary effect of closures on the stock and yield is similar to that of traditional effort control (licensing, quota, days at sea limitations, etc.).
6. Strategically tuning MPA design to the life history of specific species, by protecting high-quality habitat or essential spawning or nursery grounds, can lead to secondary effects (additional to effort reduction), increasing the likelihood of fishery benefits.
7. Proper design of MPAs as an effort control measure for harvested species is more difficult to implement than other effort control mechanisms, but uniquely allows for simultaneous pursuit of conservation objectives inside the MPA.
8. Properly designed MPAs are an effective tool to rebuild overfished stocks. Effects on stocks that are not overfished are unknown.
9. It has been shown in mathematical models that MPAs can reduce the risk of stock depletion in the face of uncertainty.

8.2 Potential fishery effects of DCS area closures

1. Approximately half the revenue generated by the Dutch fleet on the DCS originates from the proposed MPA areas.
2. From the areas proposed, the coastal areas (North Sea Coastal Zone, Wadden Sea, Voordelta, Vlakte van de Raan and Coastal Sea) all provide a higher percentage of total revenue than expected based on their proportional surface area. This is a result of the fishery on brown shrimp, which is a large fishery in the Netherlands and which occurs only along the coast.
3. These coastal areas are an important nursery ground for many fish species. Closing them to fishery would reduce bycatch and hence increase juvenile survival. Higher juvenile survival could lead to higher stocks depending on at what size it occurs. The larger the size of bycaught fish, the larger the probability of positive effects on the stock.
4. There is a clear precedent (the Georges Bank closure) that closing large areas of high productivity can lead to rapid rebuilding of overharvested fish stocks for which the area is important habitat. These results potentially apply to the Frisian Front and Dogger bank in the North Sea, which are important areas for cod and whiting, two of the commercially harvested species in the North Sea which require rebuilding. How closure of these areas would affect the stocks which are doing well cannot be assessed based on available literature, but no negative effects on stocks are expected.

5. There is very little fishing in the ‘hard substrate areas’ other than the Cleaver Bank (Borkum Stones, Central Oystergrounds, Gas Seeps), so effects (positive or negative) of closure on the fishing industry as a whole will be small.
6. The Cleaver Bank is an important spawning ground, in particular for cod, of which the stock is currently well below target. Closing this area would lead to less disturbance of the seabed, potentially enhancing cod spawning, which could contribute to rebuilding of the cod stock.
7. The other proposed MPAs (Arctica Islandica Area and Brown Bank) are very small, and fishery effects of closure are expected to be local, if at all present.

References

Abesamis, R. A., A. C. Alcala, and G. R. Russ. 2006. How much does the fishery at Apo Island benefit from spillover of adult fish from the adjacent marine reserve? Fishery Bulletin 104:360-375.

Anonymous, 2001. Migration, distribution and spatial dynamics of plaice and sole in the North Sea and adjacent areas, EU FAIR Programme, Project PL9662079. Final report to the Commission of European Union

Bax, N. J. 1998. The significance and prediction of predation in marine fisheries. Ices Journal of Marine Science 55:997-1030.

Beare, D., A. D. Rijnsdorp, M. Blaesberg, U. Damm, J. Egekvist, H. Fock, M. Kloppmann, C. Rockmann, A. Schroeder, T. Schulze, I. Tulp, C. Ulrich, R. van Hal, T. van Kooten, and M. Verweij. 2013. Evaluating the effect of fishery closures: Lessons learnt from the Plaice Box. Journal of Sea Research 84:49-60.

Botsford, L. W., D. R. Brumbaugh, C. Grimes, J. B. Kellner, J. Largier, M. R. O'Farrell, S. Ralston, E. Soulanille, and V. Wespestad. 2009. Connectivity, sustainability, and yield: bridging the gap between conventional fisheries management and marine protected areas. Reviews in Fish Biology and Fisheries 19:69-95.

Botsford, L. W., J. C. Castilla, and C. H. Peterson. 1997. The management of fisheries and marine ecosystems. Science 277:509-515.

Botsford, L. W., F. Micheli, and A. Hastings. 2003. Principles for the design of marine reserves. Ecological Applications 13:S25-S31.

Catchpole, T.L., Frid C.L.J., and Gray T.S. 2005. Discards in North Sea fisheries: causes, consequences and solutions. Marine Policy 29: 421–430.

Childress, M. J. 1997. Marine reserves and their effects on lobster populations: report from a workshop. Marine and Freshwater Research 48:1111-1114.

Christiansen, S.; Lutter, S. 2009. Towards good environmental status: A network of Marine Protected Areas for the North Sea. WWF Germany: Frankfurt. 104 pp.

Corten, A., 1996. Ecoprofiel haring, RIVO/DLO-rapport. Rijksinstituut voor Visserij. Onderzoek, IJmuiden.

Cotter, A.J.R., Course, G., Buckland, S.T. and Garrod, C. 2002. A PPS sample survey of English fishing vessels to estimate discarding and retention of North Sea cod, haddock, and whiting. Fisheries Research 55: 25-35.

Deerenberg, C., Teal, L.R., Beare, D. and van der Wal, J.T. 2010. FIMPAS project – Pre-assessment of the impact of fisheries on the conservation objectives of Dutch marine protected areas. IMARES report C071/10.

Delnortecampos, A. G. C. and A. Temming. 1994. Daily Activity, Feeding and Rations in Gobies and Brown Shrimp in the Northern Wadden Sea. Marine Ecology Progress Series 115:41-53.

Dinmore, T. A., D. E. Duplisea, B. D. Rackham, D. L. Maxwell, and S. Jennings. 2003. Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. Ices Journal of Marine Science 60:371-380.

Ellis, J.R., Armstrong, M.J., Rogers, S.I., Service, M., 2002. The distribution, structure and diversity of fish assemblages in the Irish Sea. In Marine biodiversity in Ireland and adjacent waters (J.D.Nunn, ed.). Ulster Museum, Belfast, 93-114.

Ellis, J.R., Engelhard, G.H., Pinnegar, J.K., 2008. RECLAIM; Report of WP1 Chapter 3 – Ecotypes; http://www.climateandfish.eu/default.asp?ZNT=S0T1O-1P177.

Enever, R., Revill, A.S. and Grant, A. 2009. Discarding in the North Sea and on the historical efficacy of gear-based technical measures in reducing discards. Fisheries Research 95: 40–46.

Fernandes, L., J. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De'ath, B. Mapstone, H. Marsh, H. P. Possingham, I. Ball, T. Ward, K. Dobbs, J. Aumend, D. Slater, and K. Stapleton. 2005. Establishing representative no-take areas in the Great Barrier Reef: Large-scale implementation of theory on marine protected areas. Conservation Biology 19:1733-1744.

Fox, C. J., M. Taylor, M. Dickey-Collas, P. Fossum, G. Kraus, N. Rohlf, P. Munk, C. J. G. van Damme, L. J. Bolle, D. L. Maxwell, and P. J. Wright. 2008. Mapping the spawning grounds of North Sea cod (Gadus morhua) by direct and indirect means. Proceedings of the Royal Society B-Biological Sciences 275:1543-1548.

Gaines, S. D., C. White, M. H. Carr, and S. R. Palumbi. 2010. Designing marine reserve networks for both conservation and fisheries management. Proceedings of the National Academy of Sciences of the United States of America 107:18286-18293.

Gardmark, A., N. Jonzen, and M. Mangel. 2006. Density-dependent body growth reduces the potential of marine reserves to enhance yields. Journal of Applied Ecology 43:61-69.

Gell, F. and C. M. Roberts. 2002. The fishery effects of marine reserves and fishery closures. WWF-US, Washington DC, USA.

Gell, F. R. and C. M. Roberts. 2003. Benefits beyond boundaries: the fishery effects of marine reserves. Trends in Ecology & Evolution 18:448-455.

Gerber, L. R., S. S. Heppell, F. Ballantyne, and E. Sala. 2005. The role of dispersal and demography in determining the efficacy of marine reserves. Canadian Journal of Fisheries and Aquatic Sciences 62:863-871.

Goñi R, Hilborn R, Díaz D, Mallol S, Adlerstein S. 2010. Net contribution of spillover from a marine reserve to fishery catches. Mar Ecol Prog Ser 400:233-243

Gruss, A., D. M. Kaplan, S. Guenette, C. M. Roberts, and L. W. Botsford. 2011. Consequences of adult and juvenile movement for marine protected areas. Biological Conservation 144:692-702.

Halpern, B. S., and R. R. Warner. 2002. Marine reserves have rapid and lasting effects. Ecology Letters 5:361-366.

Harding, D., Nichols, J.H., Tungate, D.S., 1978. The spawning of plaice (*Pleuronectes platessa* L.) in the southern North Sea and English Channel. Rapports et Procès-verbaux des Réunions du Conseil International pour l'Exploration de la Mer 172, 102-113.

Harrison, H. B., D. H. Williamson, R. D. Evans, G. R. Almany, S. R. Thorrold, G. R. Russ, K. A. Feldheim, L. van Herwerden, S. Planes, M. Srinivasan, M. L. Berumen, and G. P. Jones. 2012. Larval Export from Marine Reserves and the Recruitment Benefit for Fish and Fisheries. Current Biology 22:1023-1028.

Hastings, A. and L. W. Botsford. 1999. Equivalence in yield from marine reserves and traditional fisheries management. Science 284:1537-1538.

Horwood, J. W., J. H. Nichols, and S. Milligan. 1998. Evaluation of closed areas for fish stock conservation. Journal of Applied Ecology 35:893-903.

Hugenholtz, E. 2008. The Dutch Case. A Network of Marine Protected Areas. WWF, Zeist, The Netherlands.

ICES, 2005. ICES Atlas of North Sea Fishes (ICES-FishMap) Eds.: Heessen, H.J.L., Eastwood, P.D., Fletcher, N., Larsen, L.I., Ellis, J.R., Daan, N. and ter Hofstede, R. Electronic publication, www.ices.dk/marine-data/Documents.

ICES, 2007. Report of the Working Group on Ecosystem Effects of Fishing Activities. ICES CM 2007/ACE:04. 162 pp.

ICES, 2013A. Report of the ICES Advisory Committee 2013. ICES Advice, 2013. Book 6, North Sea.

ICES, 2013B. Report of the Working Group on Crangon Fisheries and Life History (WGCRAN), 3-7 June 2013, ICES HQ, Copenhagen, Denmark. ICES CM 2013/SSGEF:12 . 25 pp.

ICES. 2014. Report of the Working Group for the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 30 April–7 May 2014, ICES HQ, Copenhagen, Denmark. ICES CM 2014/ACOM:13. 1493 pp.

Jennings, S., T. A. Dinmore, D. E. Duplisea, K. J. Warr, and J. E. Lancaster. 2001a. Trawling disturbance can modify benthic production processes. Journal of Animal Ecology 70:459-475.

Jennings, S., J. K. Pinnegar, N. V. C. Polunin, and K. J. Warr. 2001b. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Marine Ecology Progress Series 213:127-142.

Jennions, M.D. and Møller, A.P. 2002. Publication bias in ecology and evolution: an empirical assessment using the "trim and fill" method. Biol. Rev. Camb. Philos. Soc. 77, 211-222.

Kaiser, M. J., K. R. Clarke, H. Hinz, M. C. V. Austen, P. J. Somerfield, and I. Karakassis. 2006. Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series 311:1-14

Kellner, J. B., I. Tetreault, S. D. Gaines, and R. M. Nisbet. 2007. Fishing the line near marine reserves in single and multispecies fisheries. Ecological Applications 17:1039-1054.

Knijn, R.J., Boon, T.W., Heessen, H.J.L. and Hislop, J.R.G. 1993. Atlas of North Sea Fishes. ICES Cooperative Research Reports. Copenhagen. ICES. 194. 268pp.

Kramer, D. L. and M. R. Chapman. 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes 55:65-79.

Lester, S.E., Halpern, B.S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D., Airamé, S., Warner, R. R. 2009. Biological effects within no-take marine reserves: a global synthesis. Mar Ecol Prog Ser 384:33-46

Lewis, C. V. W. 1999. Biological-Physical modeling of sea scallop fishery closures.

Lindeboom, H.J.; Dijkman, E.M.; Bos, O.G.; Meesters, H.W.G.; Cremer, J.S.M.; Raad, I. de; Hal, R. van; Bosma, A., 2008. Ecologische atlas Noordzee ten behoeve van gebiedsbescherming. Wageningen IMARES, Den Burg, The Netherlands.

Lizaso, J. L. S., R. Goni, O. Renones, G. Charton, R. Galzin, J. T. Bayle, P. S. Jerez, A. Perez-Ruzafa, and A. A. Ramos. 2000. Density dependence in marine protected populations: A review. Environmental Conservation 27: 144-158.

Loots, C., S. Vaz, B. Planque, and P. koubbi. 2010. Spawning distribution of North Sea plaice and whiting from 1980 to 2007. Journal of Oceanography, Research and Data 3:77-95.

Mangel, M. 1998. No-take areas for sustainability of harvested species and a conservation invariant for marine reserves. Ecology Letters 1:87-90.

Mangel, M. 2000. On the fraction of habitat allocated to marine reserves. Ecology Letters 3:15-22.

McCook, L. J., T. Ayling, M. Cappo, J. H. Choat, R. D. Evans, D. M. De Freitas, M. Heupel, T. P. Hughes, G. P. Jones, B. Mapstone, H. Marsh, M. Mills, F. J. Molloy, C. R. Pitcher, R. L. Pressey, G. R. Russ, S. Sutton, H. Sweatman, R. Tobin, D. R. Wachenfeld, and D. H. Williamson. 2010. Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences of the United States of America 107:18278-18285.

Murawski, S. A., R. Brown, H. L. Lai, P. J. Rago, and L. Hendrickson. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. Bulletin of Marine Science 66: 775-798.

Murawski, S. A., S. E. Wigley, M. J. Fogarty, P. J. Rago, and D. G. Mountain. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. Ices Journal of Marine Science 62: 1150-1167.

Murray, S. N., R. F. Ambrose, J. A. Bohnsack, L. W. Botsford, M. H. Carr, G. E. Davis, P. K. Dayton, D. Gotshall, D. R. Gunderson, M. A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D. A. McArdle, J. C. Ogden, J. Roughgarden, R. M. Starr, M. J. Tegner, and M. M. Yoklavich. 1999. No-take reserve networks: Sustaining fishery populations and marine ecosystems. Fisheries 24:11-25.

Nielsen, J.G., 1986. Bothidae. In: Whitehead, P.J.P., Bauchot, M.L., Hureau, J.C., Nielsen, J.G., Tortonese, E. (Eds.), Fishes of the North-eastern Atlantic and the Mediterranean, Paris, pp. 1294-1298.

Pastoors, M. A., A. D. Rijnsdorp, and F. A. Van Beek. 2000. Effects of a partially closed area in the North Sea ("plaice box") on stock development of plaice. Ices Journal of Marine Science 57: 1014-1022.

Pelc, R.A., Warner, R.R., Gaines, S.D. and Paris, C.B. 2010. Detecting larval export from marine reserves. PNAS,107(43): 18266–18271.

Rassweiler, A., C. Costello, and D. A. Siegel. 2012. Marine protected areas and the value of spatially optimized fishery management. Proceedings of the National Academy of Sciences of the United States of America 109:11884-11889.

Philippart, C.J.M., Van Aken, H.M., Beukema, J.J., Bos, O.G., Cadee, G.C. and Dekker, R. 2003. Climate-related changes in recruitment of the bivalve Macoma balthica. Limnol. Oceanogr. 48, 2171-2185.

Revill, A.S., Pascoe, S., Radcliffe, C., Riemann, S., Redant, F., Polet, H. and Damm, U. 1999. The economic and biological consequences of discarding in Crangon fisheries (The ECODISC Project - EU (DG XIV A:3) Project 97/SE/23). Final report to the European Commission, University of Lincolnshire and Humberside project No. 97/SE/025. 118 p

Rijnsdorp, A.D., 1989. Maturation of male and female North Sea plaice (*Pleuronectes platessa* L). Journal du Conseil International pour l'Exploration de la Mer 46, 35-51.

Rijnsdorp, A., G. Piet, and J. J. Poos. 2001. Effort allocation of the Dutch beam trawl fleet in response to a temporarily closed area in the North Sea.

Rijnsdorp, A. D., Peck, M. A., Engelhard, G. H., Möllmann, C., and Pinnegar, J. K. 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66: 1570–1583.

Roberts, C. M., J. A. Bohnsack, F. Gell, J. P. Hawkins, and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science 294:1920-1923.

Russell, F.S., 1976. The eggs and planktonic stages of British marine fishes. Academic Press, London, 524 pp.

Schmidt, J.O., van Damme, C.J.G., Rockmann, C., Dickey-Collas, M., 2009. Recolonisation of spawning grounds in a recovering fish stock: recent changes in North Sea herring. Inst. Ciencias Mar. Barcelona, pp. 153-157.

Steenbergen, J. ; Hammen, T. van der; Rasenberg, M.M.M. ; Tulp, I.Y.M. (2013) Tussenrapportage onderzoek Effecten van garnalenvisserij - onderdeel bijvangst. IJmuiden : IMARES, (Rapport / IMARES C047/13) - 39 p.

Stratoudakis, Y., Fryer, R. J., Cook, R. M. and Pierce, G. J. 1999. Fish discarded from Scottish demersal vessels: Estimators of total discards and annual estimates for targeted gadoids. ICES Journal of Marine Science 56: 592–605.

Taal, C., H. Bartelings, R. Beukers, A. J. van Duijn, A. J. Klok, J. A. E. van Oostenbrugge, and J. P. G. Smit. 2009. Visserij in cijfers 2009. LEI Wageningen UR, Den Haag.

Teal, L.R., de Leeuw, J.J., van der Veer, H.W. and Rijnsdorp, A.D. 2008 Effects of climate change on growth of 0-group sole and plaice. Mar. Ecol. Prog. Ser. 358:219-230

Teal, L.R., van Hal, R., van Damme, C.J.G., Bolle, L.J. and ter Hofstede, R. 2009. Review of the spatial and temporal distribution by life stage for 19 North Sea fish species. IMARES report C126/09.

Teal, L.R. and van Keeken, O.A. 2011. The importance of the surf zone for fish and brown shrimp in the Netherlands. A literature review. IMARES report C054/11.

Tulp, I. 2009. Onderzoeksagenda ‘duurzame garnalenvisserij’. IMARES report 102/09.

Uhlmann, S.S. ; Coers, A. ; Helmond, A.T.M. van; Nijman, R.R. ; Bol, R.A. ; Reijden, K. van der (2013) Discard sampling of Dutch bottom-trawl and seine fisheries in 2012. IJmuiden : Centrum voor Visserijonderzoek, (Report / Centrum voor Visserijonderzoek 13.015) - 76 p.

Van Bemmelen, R., O.G. Bos, 2011. Gasfonteinen, pockmarks en Habitat 1180 – Aanvullende beschermde gebieden. IMARES rapport C082/10.

Van Denderen, P. D., A. Rijnsdorp, N. T. Hintzen, and P. Ruardij. 2014. Habitat-Specific Effects of Fishing Disturbance on Benthic Species Richness in Marine Soft Sediments. Ecosystems. DOI: 10.1007/s10021-014-9789-x

van der Land, M.A., 1990. Distribution and mortality of pelagic eggs of by-catch species in the 1989 surveys in the southern North Sea. ICES Doc. C.M. 1990/H:19.

van der Land, M.A., 1991. Distribution of flatfish eggs in the 1989 egg surveys in the Southeastern North Sea, and mortality of plaice and sole eggs. Netherlands Journal of Sea Research 27, 277-286.

Van der Veer, H.W., Ellis, T., Miller, J.M., Pihl, L. & Rijnsdorp, A.D. 1997. Size-selective predation on juvenile North Sea flatfish and possible implications for recruitment. In: Early life history and recruitment in fish populations, R.C.Chambers & Trippel E.A. (Eds.): Chapman Hall, London, 279-303.

van Hal, R., Teal, L.R., Asjes, J., Jak, R.G., Scheidat, M., Craeymeersch, J.A.M., van Bemmelen, R.S.A., Quirijns, F.J., van Polanen-Petel, T. and Deerenberg, C. 2010. Data availability for the fisheries impact assessment of the FIMPAS project. IMARES report C052/10.

Van Kooten, T. ; Troost, K.; Asch, M. van; Machiels, M.A.M.; Chen, C. 2014. T0 monitoringplan voor effectmeting van VIBEG maatregelen in natura 2000 gebied Noordzeekustzone. IMARES report C208/13A.

van Marlen, B., J. A. M. Wiegerinck, E. van Os-Koomen, and E. van Barneveld. 2014. Catch comparison of flatfish pulse trawls and a tickler chain beam trawl. Fisheries Research 151:57-69.

Weigel, J. Y., K. O. Mannle, N. J. Bennett, E. Carter, L. Westlund, V. Burgener, Z. Hoffman, A. S. Da Silva, E. Abou Kane, J. Sanders, C. Piante, S. Wagiman, and A. Hellman. 2014. Marine protected areas and fisheries: bridging the divide. Aquatic Conservation-Marine and Freshwater Ecosystems 24:199-215.

Wheeler, A.C., 1969. Fishes of the British Isles and North West Europe. MacMillan, London.

Witbaard, R., O.G. Bos, H.J. Lindeboom, 2008. Basisinformatie over de Borkumer Stenen, Bruine Bank en Gasfonteinen, potentieel te beschermen gebieden op het NCP. IMARES rapport C026/08.

Wootton, R. J. 1998. Ecology of teleost fishes. 2nd edition. Kluwer Academic Publishers, Dordrecht ; Boston.

Worm, B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz, and R. Watson. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790.

WWF Netherlands. 2014. Wereldnatuur in Nederland.

Yang, J., 1982. The dominant fish fauna in the North Sea and its determination. Journal of Fish Biology 20, 635-643.

Quality Assurance

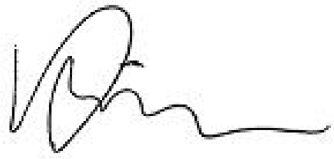
IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical 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.

Justification

Report: C093/14
Project Number: 4305206901

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

Approved: N.T. Hintzen
Scientist

Signature: 

Date: 2 July 2015

Approved: Dr. ir. N.A. Steins
Head of Fisheries Department

Signature: 

Date: 2 July 2015