Study for the Revision of the plaice box – Draft Final Report

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Contents

Summary

This project has attempted to evaluate the effectiveness of the fisheries management measure known as the "Plaice Box" (PB) for the conservation of plaice and other species of marine organisms in the south-eastern North Sea. The study provides an inventory of existing information and collects new material on the effects of the PB on the conservation of plaice and the impact of the PB on various components of the commercial fishing fleets. Based on an analysis of key processes that affect the impact of the PB, modifications will be explored to improve the positive effect on the conservation of plaice and other species of marine organisms, including catches and by-catches of other marketable fish. An economic assessment of the consequences of those modifications, in terms of their cost-effectiveness, and implications for profitability of the activity is presented. Finally, the data requirements for future evaluations of the effects of the PB on conservation is discussed.

During the project we (IMARES) have had good cooperation with our partners. All datasets promised by the three countries involved (Denmark, Germany and TheNetherlands) have been compiled and aggregated over identical metiers. We have identified key scientific hypotheses to test and decided on some plausible future management changes to investigate. Stakeholder interest in the project has been high and they made extremely useful contributions to the workshop held in October.

The results of the study are summarized below after which we discuss how well we have addressed the specific terms of reference for the evaluation.

1. With support of the flatfish fisheries, the Plaice box (PB) was established as a technical fisheries management measure to protect undersized plaice from discarding, closing the PB for trawl fisheries with vessels >221kW, with the expectation that yield and spawning stock biomass would increase.
2. The PB regulation affected fisheries differentially. The fleets >221kW lost fishing grounds, while the exemption fleets benefited from a reduction in competition with larger vessels.
3. Contrary to expectations, plaice stock biomass in the North Sea decreased from landings of 169 818t in 1989 to only 48 875t in 2008 undermining the credibility of closed areas as a fisheries management tool.
4. Flatfish fishers (see Appendix to Chapter 2) have argued that the PB caused the decrease in yield and stock size since the area deteriorated as a food source due to the decrease in bottom trawling and have asked for a re-opening of the box.
5. Conservationist have argued that the PB positively contributed to conservation objectives because of the reduction in bottom trawling.
6. The main question is whether the decrease in the plaice stock is due to the establishment of the PB or due to a change in the environment unrelated to the establishment of the PB (ocean climate, eutrophication, others)
7. Beam trawl fishing effort (kW hours at sea) in the plaice box area has decreased stepwise since the establishment of the box in 1989 and the full closure since 1994 to ca 35 % and ca 10%, respectively of the estimated pre-closure level (see Grift et al., 2004). According to Dutch logbook data total (both engine size categories combined) fishing effort by beam trawlers targeting finfish inside the PB fell from 38.8 million kWhrs in 1990 to 5.3 million kWhrs in 2008 a reduction of 86%. Total (Denmark, Germany and The Netherlands) beam trawl effort by the exemption fleet of <=221kW fishing for shrimp increased from 68 million kWhrs in 1995 to 177 million kWhrs in 1995. Effort by the exemption fleet targeting plaice and sole, however, fell during the same period (1995 – 2008) from 32 million kWhrs in 1995 to 2.9 million kWhrs in 2008 (see Chapter 4, Fig. 4.1.5a). The proportion of landings of plaice and sole in the PB relative to the North Sea has decreased. Fishing effort by Danish gill netters (both <=221kW and > 221kW) increased between 1987, peaked in the mid 1990s and fell subsequently. Inside the PB effort by the <=221kW category was 3.6million kWhrs in 1987, 25million kWhrs in 1994, falling to 4.7 million

kWhrs in 2008.

8. The PB, nevertheless, remains an important fishing area for the fleet of smaller vessel (kW<=221 kW, see table). Especially beam trawlers fishing for shrimps (BEAM.16-31) and the mixed flatfish fisheries (BEAM.>100) are most active and are earning more than 70% inside the PB (see Table 1.1).
9. Fishing effort of shrimpers is concentrated within the 12 nm zone. Only 14%, 4%, and 2% for The Netherlands, Germany and Denmark (mean of 2005 to 2008), respectively, of monetary yield from shrimpers was earned outside the 12 nm zone but within the PB area. Fishing effort by the shrimpers has been fairly stable since 2000, when effort data became mandatory for all countries. The influence of the PB regulation is restricted to the area outside the 12nm zone.
10. Plaice discarding mainly occurs in the fishery for brown shrimps (beam trawl 16-32 mm), sole (beam trawl 80mm) and the 80 mm otter trawl fishery. The shrimp fishery discard mainly 0-group, while the other fleets discard plaice of 1-year and older.
11. In the period 2001-2008, discard fishing mortality is estimated at F=0.05 for 0-group, F=0.16 for 1-group and F=0.55 for 2-group.
12. The level of protection offered by the PB has been far lower than was originally expected in 1989. This is due to the lower growth rate of plaice and the shift of undersized plaice to deeper waters outside the PB. Nevertheless, the proportion of undersized plaice relative to the marketable sized plaice is still higher in the PB than outside. The discard rate in the PB will be higher than outside.
13. Growth rate of plaice decreases with population density. This density-dependent feed-back, however, does not compensate for the increase in density due to a reduced discard mortality. The net result is, however, positive.
14. The change in distribution of undersized plaice in the 1990s is more likely due to a behavioural response to higher temperatures in combination with a decrease in macrobenthos, and less likely due to a decrease in food within the PB due to the decrease in bottom trawling.
15. Given 13 and 14, the reduced effect of the PB is more likely due to changes in the environment and less likely due to the establishment of the PB, although it cannot be ruled out that the change in trawling in the PB has affected the food for plaice.
16. The design of the PB makes it impossible to assess its effectiveness, in particular because of the lack of reference areas. If the politicians decide on modifications to the PB they should select a design, including reference areas, that would help any future scientific evaluations.
17. Given the original objective of the plaice box to reduce discarding of undersized plaice, re-opening of the plaice box is expected to lead to a small (<5%) increase in plaice discard numbers and decrease in yield and spawning stock biomass (<5%). Extending the PB to encompass one extra line of rectangles along the continental coast of the Netherlands would encompass 93%, 70% and 54% of age 0, 1, and 2 plaice respectively and will likely result in a moderate reduction in plaice discards (<10%) and moderate increase yield per recruit and spawning stock biomass (about 10%). Nevertheless any effects will be impossible to detect because of the variability in natural recruitment which we cannot measure accurately.
18. Any change in management will impact the fleets differentially. Extending the PB will benefit the exemption fleets, while re-opening of the PB will benefit the fleet of large vessels and harm the exemption fleets. The shrimp fleet will be marginally affected by a change in the PB since they operate mainly within the 12 nm zone.
19. Real time closure is expected to contribute to a reduction in plaice discarding. The effect can not be evaluated because of a lack of detailed data on the frequency, duration and spatial scale at which local concentrations occur.

Table 1.1: Percentages of effort, catch and earnings inside the PB of total (in and outside the PB) effort, catch and earnings for small (<=221kW) and large (>221kW) vessels (mean of the years 2005 to 2008 for all countries combined, calculated using VMS data).

Power	Metier	Effort	Catch	Earnings
<=221kW	BEAM.16-31	79	82	82
	BEAM.80-99	23	22	19
	BEAM.>100	64	73	71
	GILL-TRAMMI	29	32	34
	OTHER	13	14	14
	OTTER.80-99	3	4	4
	OTTER.>100	20	20	20
>221kW	BEAM.16-31	-	-	-
	BEAM.80-99	-	-	-
	BEAM.>100	-	-	-
	GILL-TRAMMI	31	25	32
	OTHER	19	27	27
	OTTER.80-99	-	-	-
	OTTER.>100	-	-	-

Comments on terms of reference in the original proposal

1. evaluate the efficiency of the Plaice Box for the conservation of plaice and other species of marine organisms. *The benthos, fish communitygenerally and plaice specifically were examined in detail during the project (see Chapters 6, 7, and 8). Neither benthic nor piscean diversity showed any pronounced changes that could clearly be attributable to the PB managment scenario. Plaice abundance within the PB is now (2008) much lower than it was in 1989 but, again, the downward trends do not seem to be related to the specific timings of effort reductions involved (see Chapter 6). It was thus very difficult to find any clear conservation benefit of the PB. Readers should be reminded here, however, that although beam trawl fishing effort was reduced by xx%, it was never completely stopped (derogated fleets still fish actively and their effort and capacity has increased) in the PB. It is well known that the impact of trawling is most severe the first time the seabed is trawled with successive tows over the same ground having successively less impact.*
2. create an inventory of existing information and collect, if appropriate, new material on the effects of the box on the conservation of plaice. *A large database has been collated during the project. These data include Danish logbook data (1987-2008), Dutch (1990-2008) and German (1995-2008) allowing patterns of landings and effort to be constructed (see Chapter 4). VMS data (2005-2008) were also made available by all three nations and shared among project partners after vessel identification had been 'disguised'. They have helped us identify fine scale patterns in effort and discarding among metiers but the shorter time span available has made estimation of longer term trends in fleet dynamics and behaviour impossible. Discarding data (observer trips) were also shared, although the analyses presented herein depended most heavily on German discard data since the Danish and Dutch observations were made mostly outside the PB on >221kW vessels. Trawl survey data from a range of sources, eg. BTS = Beam Trawl Survey (1987-2008), and SNS = Sole Net Survey(1970-2008), were also used heavily during the project (see Chapters 6, 7,10). Sources of the benthic and environmental data are described in the relevant sections of this report (Chapters 5, and 8). Shapefiles for the PB itself and the 12nm areas around the North Sea aided us in dividing these data into the different areas so that we could explore their trends. The project was only of 9m duration and certain datasets would have been useful. It would, for example, have been beneficial to get more data on primary production in the area, relative to reference area. Similarly the growth rate estimates we made were summaries for the entire plaice population and it would be helpful to explore these in plaice confined to the PB relative to those outside. Most importantly, however, our wish list of future data requirements would not request*

data in themselves; rather data from a designed experiment allowing us to separate competing effects in a more rigorous manner.

4. evaluate whether closed areas of the Plaice Box have a positive impact on the conservation of marine organisms and especially plaice, have no impact, or if the impact is not known. If possible, any possible adverse impacts of the box on conservation should be identified*. No clear positive effects of the PB on marine organisms other than plaice were identified. The effect on plaice was, however, still positive in spite of the migrations and reductions in yield per recruit. We showed that the growth rate of plaice decreased with population density but this density-dependent feed-back, however, did not compensate for the increase in density due to the reduced discard mortality.*
5. propose modifications of the closed areas and associated derogations in order to improve the positive effect on the conservation of plaice and other species of marine organisms. *A range of potential modifications of the PB were proposed and discussed at the October Workshop in Ijmuiden. These potential modifications are described in Chapters 10 and 11. They all involve trade-offs which benefit or is detrimental to certain stakeholder groups. It is, therefore, for policy makers to decide whether and which potential modifications to instigate.*
6. evaluate the impact of the proposed modifications
    a. an assessment of the consequences of those modifications for the catches of plaice and the by-catches of other marketable fish and where possible the stocks from which these catches are taken. *The potential consequences of these modifications on the earnings by different fleet components (and based on VMS and logbook data 2005-2008) are summarized in Chapter 11. It is most straightforward to estimate the detrimental effect that modifications might have on a fleet when it is completely expelled from an area. The large beam trawlers fishing 80-99mm mesh which depend mainly on sole for their income might, for example, lose 45% of their income in the extended PB scenario. Similarly the small shrimp fleet might*
    b. an economic assessment of the consequences of those modifications, in terms of their cost-effectiveness, and implications for profitability of the activity. *This assessment is described in Chapters 4 and 11. The basic conclusion is that the <=221kW fleets have benefited from the PB.*

7. identify the data requirements for the future evaluation of the effects of the Plaice Box on conservation*. In order to settle the continuous debate about competing explanations of the effects of the plaice box (fisheries-climate mechanism) and gain a consensus among stakeholders, a plaice box experiment as developed in the North Sea RAC should be conducted (see Appendix to Chapter 2). This, however, would still not necessarily be conclusive. Manipulating the marine socio-biotic system into a formal designed experiment would still be problematic. Nevertheless it would be possible to manipulate the quantity of fishing effort being exerted relative to the natural gradient of environmental influences, and this would still be an extremely useful exercise.*

Assignment

This is the draft final report that was promised nine months after the signature of the contract by the EU. It summarizes the results achieved.

Chapter 1 Review of MPAs as a management tool.

Introduction

In the North Sea, plaice (*Pleuronectes platessa* L.) is exploited in a mixed fishery for flatfish using primarily beam trawls but also static nets, seines and otter trawls. A large number of undersized plaice are caught and discarded because of the use of small mesh size needed to catch sole (*Solea vulgaris* L.) which is around 5 times more valuable per kilogram (van Keeken et al. 2007). In order to improve the abundance of mature plaice and reduce discard mortality, an area of 38 000 km2 was set aside in the south-eastern North Sea, in 1989, within which fishing effort was subject to tighter restrictions . In this “Plaice Box”, no fishing was allowed for vessels with an engine power of more than 300 hp (Piet et al. 1998; Piet & Rijnsdorp 1998) but it remained open to smaller vessels providing they observe certaingear and catch specifications .Unfortunately, however, the original management goals for the plaice within the Plaice Box (ie. increased abundance of adults) still haven’t been achieved.

Within the context of evaluating the success or otherwise of plaice box, this review will investigate experiences of using Marine Protected Areas (MPAs) as a tool in fisheries management elsewhere in temperate regions. The focus will be on demersal fish and the benthic ecosystem, distinguishing between the role of MPAs, either as a fisheries management tool, or as a biodiversity conservation tool. Any overlapping effects and benefits, however, will also be considered. A general overview will first summarise current knowledge on the evidence for MPA effects and the experiences gained from combining them with different technical measures and designs. Subsequently a range of case studies of MPAs actually used in fisheries management in the North Atlantic will also be presented.

The use of MPAs has been well-documented in tropical regions, where they have been a popular choice for the protection of species associated with coral reefs. In the North Atlantic region, MPAs have received increasing attention for their potential benefits in the conservation of biodiversity and have also been increasingly used in the management and enhancement of commercial fish stocks. The focus on the potential use of MPAs in fisheries management has really occurred due to continuously declining fish stocks, caused by the following: harvesting over-capacit,y combined with habitat damage; inappropriate fishing techniques; a lack of enforcement; alack of adaptive management; technological developments; poorly defined property rights; and allocation issues (Murawski et al. 2000). A comparison of CPUE between the periods 1906-1909 and 1990-1995 showed general large reductions in stock densities in 18 out of the 19 species examined (Rijnsdorp et al. 1996) . Regulation of gears used, effort deployed and catches landed has so far failed to result in sustainable management of many North Sea stocks (FSBI 2001). MPAs have, however, been heavily criticised by the fishing industry due to their implications for profitability, in addition to a lack of clear, quantitative evidence for their effects.

Many terms and definitions have been applied to the concept of managing marine areas spatially due to the many different objectives for which they have been established. Terms used include, e.g., marine protected area, marine reserve, closed area, fisheries closure, wildlife reserve, habitat reserve, refugium, sanctuary, national park, maritime park, no-take area, etc. For the purposes of this review the term MPA will be adhered to, meaning any area set aside under legislation or other effective means to protect marine values – whether ecological, commercial, scientific or other.

The role of MPAs in environmental and fishery management

Whether a marine MPA will be dubbed "fishery management" or "conservation" is determined by the management objectives selected, and also the legislation in which the MPA is embedded. Management objectives range from the preservation of ecosystem components and attributes (unaffected by human impact) to allowing sustainable use of ecosystem goods and services (Jennings 2009).

On a global scale, the establishment of protected sites for conservation purposes is addressed by international agreements such as the Convention on Biological Diversity (CBD), the World Summit on Sustainable Development (WSSD), and the World Heritage convention. The World Commission on Protected Areas under the World Conservation Union (IUCN) (Resolution 17.38 of the IUCN General Assembly, 1988), and the Programme of Work on Marine Biodiversity under the CBD (COP 7, Decision VII/5) have developed definitions of MPAs and the IUCN protected area concept covers a further, wide range of spatial management measures.

Within the EU, the establishment of MPAs for conservation purposes is mostly covered by the EU Habitats and Birds Directives, which together form the Natura 2000 network of protected areas. The Natura 2000 network is considered to be the EUs primary response to the CBD goal of halting Biodiversity decline by 2010. The use of MPAs for conservation purposes is also addressed under regional conventions such as OSPAR and HELCOM. On a member state level, many Natura 2000 sites have been established over a foundation of existing national nature reserves. In most member states, however,only a small minority of nature reserves have been designated to protect purely marine species and habitats and, as a result, Natura 2000 has become the main driver for protection of marine biodiversity in EU seas.

MPAs established as a technical measure for management of commercial fish species are covered for by the EU Common Fisheries Policy (CFP), according to whichareas can be closed to reduce fishing effort. Closures can be either for a set period of time, for certain vessels fishing for certain species, or even permanently to protect certain vulnerable species or important fish habitats. In recent years, there has been much focus on placing fisheries management in an ecosystem context, referred to as the ecosystem-based management of fisheries. Sustainable development of fishing activities was also included in the 2002 reform of the CFP on an international level, and the concept of ecosystem-based fisheries has been addressed in a number of treaties and non-binding agreements such as the 1995 FAO Code of Conduct for Responsible Fisheries, and the FAO 2001 Reykjavik declaration. Global technical guidelines on the use of MPAs as a tool in fisheries management are being prepared by FAO under the Code of Conduct for Responsible Fisheries.

Although established for purposes of either conservation or fishery management, the objectives of MPAs may overlap in situ – for example can a stone reef or sandbank be home to a number of vulnerable flora and fauna , while at the same time constituting an essential habitat for commercially important fish.
Historically, however, the distinction between establishing MPAs for protection of biodiversity or for fishery management was clearer, since fishery management objectives focused almost exclusively on the role of fisheries in providing food, income, and employment (Jennings 2009). With the advent of the ecosystem approach to fisheries, a wider range of fishery management objectives were introduced; many comparable to those adopted by conservation organizations which are often based on policy drivers such as the CBD or WSSD (Jennings 2009). Most current calls for large scale implementation of MPAs argue that they will provide both biodiversity and fishery benefits, although potential costs are rarely mentioned (Hilborn et al. 2004). Examples of management objectives that seek to reconcile fisheries and conservation are those set by the North Pacific Fishery Management Council for the Gulf of Alaska groundfish fisheries (NPFMC, 2006).

The effects of fishing on fish stocks and the role of MPAs

Fishing activities and high exploitation levels can have several implications for fish stocks. In addition to increased mortality and low abundance levels, it is well-established that the size structure of fish populations changes with increasing exploitation towards lower abundance of larger individuals (e.g. Daan et al. 2005). This selective removal of the larger individuals of a population can lead to changes in population structure, recruitment processes, genetic make-up, community composition, predator-prey relationships and habitats (e.g. Pope et al. 1988; Smith et al. 1991; Rijnsdorp et al. 1996; Birkeland & Dayton 2005; Conover et al. 2009, Kuparinen et al. 2009, Baum & Worm 2009). Over time this can further reduce the resilience of stocks to fishing pressure, although resilience will also be governed by natural recruitment and mortality processes (Daan et al. 2005).

Whether the establishment of MPAs can lead to increases in abundance, age, size and fecundity of depleted stocks will depend on a number of factors, particularly the role of natural mortality and recruitment , relative to scales and effects of exploitation, as well as the nature of the target species concerned, the size of the MPA and enforcement issues. Species may respond differently to protection depending on the intensity of exploitation to which they are subject outside the reserve, and prior to its establishment, their life history characteristics, and their larval, juvenile, and adult dispersal patterns (Micheli et al. 2004).
MPAs are generally thought to influence adjacent fish stocks through two main mechanisms: Spill-over and export (e.g. Higgins et al. 2008; Gell & Roberts 2003). "Spill-over" is the net emigration of adults and juveniles across the reserve borders into the surrounding areas, while "export" assumes that when protected individuals reach maturity and spawn, their eggs and larvae will be carried to unprotected regions, supporting and enhancing populations outside the marine reserve boundary that may not have the same density of spawning adults (Gell & Roberts 2003). However, since dispersal characteristics and the scale at which dispersal occurs is largely unknown for many species (Carr & Reed 1992; Gell & Roberts 2003; Paddock & Estes 2000) export is often difficult to estimate. Also spill-over, which is a more well-established phenomenon, is specific to particular habitats and species , and can, therefore, be assumed (Codling 2008; Murawski et al.2005) . It will, for example, depend on the site fidelity demonstrated by adult fish (Higgins et al. 2008).

Several studies have specifically investigated the role of MPAs for fish populations, with different outcomes. Cases of positive benefits for fish populations include increased abundance, size and improved sex ratios, and also improved spawning stock biomass for some species, particularly where closures occur at nursery grounds (e.g. Goñi et al. 2001; Horwood et al. 1998). Work by Micheli et al. (2004) indicated benefits of MPAs to target species of commercial fish, showing increased abundances and higher trophic levels inside protected areas. Syntheses of data from these diverse sets of assemblages (studies from 31 temperate and tropical locations) showed that MPAs are effective in enhancing local abundances of exploited species and restoring the structure of whole communities, although these changes occur via a series of transient states and, for some communities, over longer time frames (decades). Some species (19% on average) appeared to be negatively affected by protection, indicating that indirect effects of protection through competitive or predatory interactions may be common.

In a large-scale study of southern European MPAs, Claudet et al. (2008) identified increased abundances of typically targeted individuals, both in terms of species and size range within reserves. Also Forcada et al (2008) observed a spill-over effect, and although the spatial scale of the spillover-induced density gradient was very localized, it was nevertheless, sufficient to provide local benefits to artisanal fisheries (through juvenile and adult spillover) and possibly regional benefits (through greater larval export).
However, while there are numerous studies of MPA benefits in the Mediterreanean, the evidence is more sparse for northern temperate regions, although some effects of MPAs have been observed (e.g. change of size structure of plaice in the plaice box). At Georges Bank in the US, which has been subject to a series of closures (see case study), an apparent spill-over near the closed area boundaries became apparent especially in the cases of haddock, yellowtail flounder, and winter flounder, but did not have universal positive impacts on the abundance and spill-over potential of all groundfish stocks (Murawski et al. 2005). Larval transport and export can also have implications for MPA design and spatial management in the North Sea (Christensen et al. 2007; 2008; 2009).

MPAs and fisheries

The establishment of MPAs can have several effects on fisheries, by influencing yield, acting as a buffer zone, reducing collateral ecological impacts, providing a method for managing multispecies fisheries, and also for improving knowledge as scientific reference areas (Hilborn et al. 2004).
Setting aside a marine reserve initially reduces the area that can be fished, thus reducing yield, but the question is whether the yield in the area outside the MPA will increase enough to make up for any losses (Hilborn et al 2004). Although studies investigate the benefits MPAs can offer to fisheries, they often illustrate the benefits of protection to populations rather than actual benefits to the fishery itself, e.g. by demonstrating the difference between protected and un-protected fish populations. This is typically done by experimental fishing inside the no-take zones (e.g. Claudet et al. 2006; Harmelin et al.1995; Rius 1997). It is not,however, a given that any beneficial changes inside an MPA will become available to the fishermen. In the case of the Plaice Box, for example, effects of the MPA on the size structure have been shown, but the expected positive effects on the fisheries have been difficult to demonstrate because it is impossible to disentangle the effects of the reduction in fishing effort from large natural environmental changes in the ecosystem (FSBI 2001)

The persistence of populations in marine reserves and their ability to replenish surrounding areas, depends on the reserve configuration and larval dispersal patterns (Hilborn et al 2004). Detailed knowledge of, e.g. habitat aggregations and larval transportation patterns can, therefore, improve MPA design (Christensen et al. 2009) for the ultimate benefit of fisheries.

The predictability of benefits accruing to a target stock from an MPA is reliant on knowledge of oceanographic conditions, the effects of these on mortality, recruitment and migration, and the mobility of the species. If the fish (or invertebrates) of concern are sessile, for example, they will not move into the fished open area, while on the other hand, if they are too mobile, virtually all may move out into the fished open area, thus removing any anticipated benefit. For sedentary species, however, it has long been recognized that spatial management can be more easily understood, accepted and implemented than catch limits (Hilborn et al 2004).
A demersal species such as cod typically exhibits life history traits including slow growth, late maturation, long life span, and sporadic recruitment which make them more susceptible to exploitation, and also slow to recover under effective protection (FSBI 2001). Less mobile species such as plaice and sole (de Veen 1970), are more likely to increase in size and abundance in an MPA of a given size than cod, which tends to be twice as mobile (Daan et al. 1994). Also sandeel could benefit from MPAs, since certain habitats are known to have a high export of larvae to other areas (due to oceanic patterns) and the management of such small but important areas could provide protection for sandeels across the North Sea (Christensen et al 2009).

Effects of fishing on ecosystems and biodiversity and the potential role of MPAs

Fishing activities have wider impacts on marine ecological systems and not just on target species. The interaction of fishing gears with the environment can either disturb the habitat directly (physical disturbance), or indirectly by removing competitors and predators from the system (biological disturbance). In a particular environment, a number of factors influence the impact of the disturbance, such as habitat stability, frequency of natural disturbance (related to depth, exposure, and current regimes), the type of fishing gear used, and the scale, intensity and frequency of fishing activities. The use of active fishing techniques such as towed trawls or dredges can lead to the turbulent resuspension of soft surface sediments. On hard substrata, boulders may be physically moved, while rock reef or biogenic structures may be completely destroyed (e.g. Tserpes et al 2006, Auster et al 1996). For living organisms, the severity of disturbance can range from damaging only the most sensitive organisms to the destruction of all multicellular life.

The extent of natural disturbances will also have implications for the severity of trawling effects and the utility of MPAs. For example, in areas of strong tidal flows, trawling resuspension of the sediments will be of short duration. Similarlyhe effects of sediment redeposition on biota which are adapted to storm events and sediment transport by currents will not be permanent. In such high energy areas, shifts in benthic community structure following trawling disturbance are typically much less noticeable (Kaiser and Spencer 1996; Thrush et al. 1995; Tuck et al. 1998). Thus, the impact of MPAs will vary according to the prevailing conditions (FSBI 2001).
In more stable sedimentary habitats (e.g. deeper waters or in more stable areas such as gravel, mud and biogenic habitats) the effects of fishing disturbance are more dramatic and longer-lasting (Collie et al. 2000; Tuck et al. 1998). In these places, MPAs can help reverse structural changes in habitats caused by fishing, and reduce sediment resuspension and nutrient release, leading to an increase in habitat complexity and increases in the number of species present (Auster et al. 1996; Collie et al. 1997).

Studies of the negative effects of fishing on benthic communities are numerous. Trawling and dredging can lead to instant high mortalities of animals, but can also infer longer-term effects and change in community structure, with a shift towards dominance by opportunistic, short-lived and smaller-bodied species, and a decrease in the number of long-lived sessile emergent, high-biomass organisms (e.g. Kaiser et al. 2000; Ramsay et al. 1999; Thrush et al. 1996). However, in terms of benthic productivity, the evidence is equivocal, with some studies measuring a decrease in overall productivity (Jennings et al. 2001), whilst others have indicated an increase in productivity as a result of trawling (Hiddink et al. 2008).

Interactions between non-target fish, seabirds and mammals and fisheries can also occur, if they compete for the same prey species in the same areas. In upwelling and coastal systems, seabirds can consume 5-30 % of fish production, and various studies show linkages between prey availability and reproductive success of seabirds (Tserpes et al 2006). In the North Sea, industrial fisheries forsandeel, coupled with oceanographic changes, seem to have influenced populations of kittiwakes (Frederiksen et al 2008). Also mammals can be affected by fishing activities, either through direct interactions or by decreased prey availability.

MPAs have, in many instancess been set aside specifically for the protection of benthic features (e.g. many of the current Natura 2000 designations) but MPAs established as part of a fisheries management system can have positive side-effects for benthos and benthic habitats too - in particular those set aside for demersal fish.
The establishment of MPAs provides site protection for a number of benthic plant and animals species, e.g. deep-water corals which in turn provides a habitat for other marine life such as crabs, sea cucumbers, sponges and sea spiders. MPAs can also promote the establishment of oyster beds, seagrass beds and,reefs formed by the calcareous tubeworm Sabellaria spinulosa. The re-establishment of such 'special communities' many of which have been lost since trawling began, is a particular attraction of MPAs (FSBI 2001).

MPA establishment is expected to restore habitat complexity and species composition, but any details of species compositions will be hard to predict. In the North Sea, where marine ecosystems have been exposed to intensive fishing for many decades and historical data are scarce, the studies available merely describevariations within a system continually subject to fishing pressure (FSBI 2001). In many of the MPAs established for demersal fish in the North Sea, the effect of the closure on benthic habitats has not been sufficiently monitored,evaluation of the closures typically concentrating on the target species for which the MPA was established . Also, some of the North Sea/Baltic Sea MPAs have only been closed on seasonal bases (e.g. during spawning seasons). Such seasonal closures will only have very limited positive effects on benthic biodiversity since they will still be trawled on a regular basis.
An example of how fishery MPAs can affect the diversity and productivity of benthic habitats and species is provided by the numerous studies conducted during the closures of the Georges Bank area in the western Atlantic. Compelling biological effects have been observed for sessile animals, and in particular for populations of sea scallop (Murawski et al., 2000, Murawski et al 2005) for which biomass had increased 14-fold by 2001. For microbenthic organisms, both colonial and noncolonial organisms were found to increase in abundance (Asch et al 2008) and the cover of hydroids, bushy bryozoans and sponges was generally higher at sites undisturbed by mobile fishing gear.

Size and design of MPAs

There is great variation in the levels of protection in different MPAs. Some MPAs are closed areas in which all activities are totally prohibited, while in others, no-take policies may be applied. In most MPAs, however, specific activities are allowed through a system of zoning, i.e., varying levels of protection are allocated to designated zones. MPAs established for fishery management purposes occur in a number of different forms, e.g., either as permanent or seasonal closures, or for specific types of fishing gear.

MPAs should include critical adult habitat, while juvenile habitat should be included for species that utilise different habitats as juveniles; especially when juveniles are vulnerable to fishing mortality (Bohnsack 1998). Much attention has been paid to the size of MPAs necessary to provide benefits. An important aspect of designing a MPA is its size, and also the scale of protection required in relation to the overall fishing grounds. The key to success is matching reserve size to the scales of movements of the organisms that they are designed to protect (Gell & Roberts 2003). For sedentary animals living on reefs, small sized reserves (1-5 km2) have proved sufficient to generate spillover to local fisheries, while for more mobile fish, reserves have been of more intermediate or large size – e.g. the Georges Bank closure which covers a total of 17.000 km2.

Modeling studies have predicted predicts that large MPAs will increase resilience to overexploitation by keeping the spawner biomass and recruitment success at higher levels than in non-protected areas (Guenette & Pitcher 1999). However, it is illustrated by recent studies by Christensen et al (2007; 2008; 2009) that to some species, certain habitats are more important than others due to interaction with oceanic parameters. Sandeel habitats in the North Sea are constituted by numerous adjacent, elongated sand banks, formed by tidal currents, and sandeel populations at these habitats are interconnected through patterns of larval dispersal. Some habitats have a high larval export (spill-over ranges of 100 km were modeled) and act as net "sources" to other "sink" habitats. The protection of these relatively small but important habitats could have implications for sandeel populations in other parts of the North Sea (Christensen et al. 2007; 2008; 2009).Other critical attributes in siting closures for the conservation of a particular species are depth distribution, degree of seasonal movement, and degree of density-driven dispersion relative to the proposed closed area boundaries (Murawski et al 2005).

Studies have addressed the question of how much of the sea should be protected from fishing, and depending on the fishery and conditions being considered, they conclude that fisheries benefits require closures of between 10 and 80% of fishing grounds, while most predict maximum benefits with closures of 20–40% (Gell and Roberts 2003). According to Sale et al (2005), however, efforts to prescribe the correct percentage of sea area to

protect in order to sustain a fishery have limited scientific support, and attempts to specify a universal proportion for protection seems rather naïve.
Hastings & Botsford (2003) compared the design of networks of MPAs for biodiversity conservation and for increasing fishery yields. They concluded that for biodiversity purposes, MPAs should be as large as possible while in contrast, the fisheries goal of maximising yield requires maximising fish larval transport outside of MPAs (i.e. "spillover"), which means that MPAs must be as small as practically possible. These conclusions, however, are based on several simplifications and assumptions that do not reflect the actual behaviour of marine ecosystems – for example that all larvae are mobile and all adults are sessile. In addition, MPA size and design must also consider aspects of administrative and social practicality.

Rotational fisheries closures have also been used. , In these areas fishing opportunities alternate so stocks can recover. However, these must be large enough for fish stocks to recover within them, and benefits may quickly disappear when areas are reopened (Bohnsack 1996). This was seen in thethe North Sea Cod box (ICES 2004) and Georges Bank area, where re-openings were associated with pulses of increased fishing pressure (Murawski et al 2005).
If closures are to be of any practical benefit at all, they need to be accompanied by measures for reducing fishing effort generally, and should not stand alone (e.g. Horwoood et al. 1998, FSBI 2001, Kraus et al. 2009).

The case of displacement

MPAs are used as a tool to control fishing pressure but since fishermen and fishing vessels are very mobile, the aggregate pressure from fisheries in the region can remain high if the vessels simply move outside the MPA border. And where MPAs cause spill over of the target fish species, or in cases of mobile fish, migrating in and out of the closed area, fishers will likely respond to this spillover by fishing on MPA boundaries (e.g. Murawski et al., 2000, 2005).
Displacement of fishing pressure can maintain fishing mortality at the same high level and potentially render the MPA ineffective, but displacement can also be related to the effects of fishing via bycatches or impacts on habitats. The effects of pressure outside an MPA could have greater or lesser effects, depending on the species and habitats present (Jennings 2009). It may reduce the footprint of fishing in a management region since patchy distributions of effort will have fewer total impacts than random or uniform effort distributions, (Kaiser et al., 2002, Jennings 2009). The concentration of fishing effort in smaller areas open to fishing can, however, lead to increased fishing mortality and habitat degradation in those areas (as it for example was the case in the North Sea Cod Box).

In the northeast USA, the implementation of year-round and rolling spatial closures at the Georges Bank has fundamentally restructured the spatial dynamics of the entire groundfish fishery. Effort displaced due to year-round closures was 31% of the total trawling effort, with the greatest portion of that directed towards groundfish stocks (Murawski et al. 2005). Coincident with the spatial closures, overall fishing effort was reduced to about 50% of the pre-1994 levels, meaning that the system did not simply reabsorb displaced effort into the open areas. There was however a difference between effort distribution around different closures: three of the year-round closures (CA-I, CA-II, and the Western Gulf of Maine area) attracted effort to the boundaries, while the Nantucket Light Ship, and the Cashes Ledge areas showed no such build-up at the boundaries. Together, about 10% of trawling effort now occurs at distances ≤1 km from the year-round closures, with about 25% of effort located within 5 km (Murawski et al. 2005).

Models have been developed to assess the effects of displaced fishing pressure on target populations (e.g. Horwood et al., 1998), but the science for predicting pressure displacement and assessing its effects - especially on non-target species and habitats - is not well developed (Jennings 2009). Assessment of such effects can be difficult and requires relatively fine spatial resolution, as they are location,and population specific. Effects of fishing pressure displacement on habitat can be assessed for a range of MPA configurations by combining information on habitat distribution, models to predict changes in the spatial distribution of effort following management action, and models of the impacts of fishing on habitat (Jennings 2009). This information has in a number of studies been used in different model approaches to examine the effects of different MPA designs (e.g., Duplisea et al. 2002; Hutton et al. 2004; Hiddink et al. 2006).
The consequences of effort displacement highlight the importance of embedding MPAs fully in regional management systems (Jennings, 2009).

Past and present use of MPAs in North Atlantic demersal fisheries

Several fishery closures in the North Atlantic aim at protecting demersal fish stocks. In European waters smaller closures over a range of temporal scales, have been targeted on demersal fisheries, such as the Plaice Box, the Baltic Cod Fishery Closure, the previous North Sea Cod Box, the Kattegat Cod closure, the Shetland Closure, and also ,although not classically 'demersal' , the Sandeel Closures in the North Sea. Around the United States and Canada, the Georges Bank and California Groundfish Closures are examples of demersal fishery closures. These closures are described in detail in our case study reviews, see below.

Many demersal fish such as cod and plaice have complex life histories, and various phases in their life cycles (juveniles, spawning females) can be particularly vulnerable to fishing. Area closures may aim to protect habitats and places of particular importance for these critical stages.The plaice box, for example, was originally intended to protect juvenile plaice, while the Baltic Cod Closure aimed to protect spawning cod.. If a nursery area is protected against destructive fishing practices that reduce recruitment, there could potentially be increased recruitment to a fishery. However, little is known about habitat limitation in North Sea stocks (FSBI 2001). For protection of adults, closure of part of the area inhabited by adults will not increase survivorship of animals outside of an MPA unless overall fishing effort is reduced (FSBI 2001) because effort previously targeted at the closed area will tend to be displaced from the closed area to the adjacent open areas. Spawning ground closure may, for example, be an ineffective conservation measure if animals migrating to and from the spawning ground are subject to the same overall fishing intensity (Shepherd 1993) and have sometimes proven counterproductive (Horwood et al. 1998). In the case of the Baltic cod, where spawning closures have been implemented, Kraus et al (2009) applied the ISIS-Fish model to the Baltic cod population ,for which a comprehensive amount of biological and ecological knowledge exists. It predicted that under unfavourable environmental conditions, none of the proposed or implemented closure scenarios were able to recover the stock, and further demonstrated that closed seasons of the entire fishing area had a much greater impact on recovery rates, final stock sizes, and yield compared with (the current) regionally restricted spawning area closures.
Kraus et al. also that MPAs were only effective for stock recovery when they reduced overall fishing effort, and also, that the performance of MPAs needed to be evaluated relative to environmental regimes, especially for stocks facing strong environmental variability.

Many of the existing North Sea MPAs (see case studies) have failed to meet their original management objectives. Often it is difficult (or impossible) to separate effects of management fromnatural variations that ocur throughout the lifespan of an MPA, However, an important point is that the existing North Sea MPAs are not protected per se (FSBI 2001). For example, smaller less powerful vessels (including beam trawlers), as well as vessels targeting other fish than the species being managed (e.g. very powerful Crangon shrimpers in the Plaice box), are still permitted to fish.

For the same reasons, the Royal Commission on Environmental Pollution (RCEP 2005) recommended that the UK government should review the activities and impact of smaller vessels that do not fall under the full set of fishing controls in marine areas. This was done because small vessels of sizeable capacity had been built to benefit from set cut-off points established in connection with MPAs/fisheries closures. Combined with a lack of recorded reference data prior to the closure, it can be difficult to determine whether or not the use of fisheries closures/MPAs has indeed been a successful strategy.

The Georges Bank closure has played a role in the increased cod spawning stock biomass and has also affected other fauna,. Commercial species such as scallop have increased together with the benthic epifaunal community (see fulldescriptin in the following Case Study section of this review). The reduction in fishing mortality that occurred, however, is also attributable to an increase in minimum mesh size, reduction of vessel days at sea, and imposition of quotas. Unless clear measures are taken to reduce the fishing mortality, especially on vulnerable post-spawning aggregations, any benefits of MPAs to spawning stock biomass (such as cod) and fisheries are expected to be negligible (Daan 1993; Guénette & Pitcher 1999; Murawski et al. 2000).

In addition to continued fishing, other human activities can also have impacts on fisheries resources and benthic community structure. Activities such as collecting, dredging, dumping, and discharge of pollutants may have important consequences for benthic habitat structure, and fish stocks may be adversely affected directly by hazardous chemicals, waste or indirectly by excessive nutrient inputs (FSBI 2001). Such activities are not addressed in the North Sea fishery closures.

CASE STUDY: The Baltic Cod Fishery Closure

History

In view of a rapid decline of the eastern Baltic cod stock in the early 1990's, two types of closures were enforced in mid 1990s by the International Baltic Sea Fishery Commission (IBSFC) to preserve the stock. These closures were:

- A summer ban on targeted cod fishing was introduced in 1995 and is presently enforced from 15th April to 31st August (the ban was shorter when established in 1995; since then the exact dates have been subject to some variation).
- A "spawning closure" for all fisheries from 15th May to 31st August in a relatively small area east of the island of Bornholm (in the Bornholm Basin).

It is relatively well documented that the drastic decline of the eastern Baltic cod stock in the most recent two decades has largely been caused by a combination of high fishing pressure and environmentally driven recruitment failure (MacKenzie et al. 2000; Köster et al. 2003). A drastically enlarged sprat stock in the Central Baltic Sea, caused by decreased predation pressure by the cod stock, high sprat reproductive success and relatively low fishing mortality, also influenced the recruitment of Baltic cod, since sprat predates on cod eggs (Köster and Möllmann 2000). Furthermore, the present sprat-dominated regime has had negative implications at lower trophic levels (e.g. Möllmann and Köster 2002). The re-establishment of a more abundant cod stock in the Central Baltic could lead to a more stable ecosystem structure and more sustainable, as well as economically sound fisheries.

Due to the lack of recovery of Baltic cod stocks and serious risk of stock collapse, new closures were enforced from 1.1.2005 by the EU (not binding for Russia). The following closures were enforced mainly to reduce the overall fishing mortality of Baltic cod, but were also aimed at protecting spawning cod.

- Extended summer ban: fishing for cod prohibited in Sub-divisions 25-32 (Central Baltic) from 1st May to 15th September;
- Spring ban (a new measure): fishing for cod prohibited in Sub-divisions 22-24 (Western Baltic) from 1st March to 30th April;
- All cod fishing prohibited within three historical spawning areas in the Central Baltic (Fig. 1) for the entire year (EU fleet).

New EU regulations relating to the three year-round closures were implemented on 1 January 2006. From the beginning of 2006 the areas are only closed during the spawning season of Baltic cod in the areas, i.e. from May 1 to October 31 2006. In 2005 the three areas were totally closed to all fisheries. In 2006, however, fishing for salmon with hooks or nets with mesh sizes larger than 157 mm is permitted year-round. In addition, vessels of lengths less than 12 meters using bottom nets with mesh sizes exceeding 110 mm are permitted to fish year-round, provided that bycatch of cod is less than 10% (Danmarks Fiskeriforening 2005).

Site selection and methodology

There is no published information on selection criteria, methodology and design principles for the Baltic Cod closures.

Effect of closures enforced in mid 1990s ("historical closures") on the Baltic Cod

ICES Baltic Fisheries Assessment Working Group (ICES 1999) assessed the effects of these closures and concluded that the introduction of the summer ban had no significant positive impacts on the Baltic cod stock; this is mainly because the main cod catches in the Baltic Sea are taken from September to April, with the trawl fishery in particular exploiting pre-spawning concentrations of cod in late winter and spring. Similarly, the Working Group concluded that the relatively small "spawning" closure area east of Bornholm, instigated to protect the spawning stock had had little effect (ICES 1999). The ICES Study Group on Closed Spawning Areas of Eastern Baltic Cod (ICES 2004) stated that the closed area in the Bornholm Deep enforced in 1995-2003 was not large enough to ensure adequate coverage of potential areas with favourable hydrographic conditions. The Group also stated that the extension of the closed area in the Bornholm Deep in 2004 was not likely to significantly increase egg production (i.e., eggs surviving) because the spatial extension covered mainly the eastern slopes where, under normal circumstances, hydrographic conditions are not favourable for egg survival and, furthermore, egg density is not particularly high.

Effect of the expanded (2005-2006) closures on Baltic Cod

There is not much information of the efficiency and potential stock implications of the expanded closures. The assessment made by the ICES Study Group on Closed Spawning Areas of Eastern Baltic Cod (ICES 2004) considered that an extended summer ban was an appropriate management measure; in particular in the situation when there are improved spawning conditions. In the context of the impact of closed areas on potential spawning, the Study Group stated that the Bornholm Deep had been an important spawning area in all years whereas the Gdansk Deep and, in particular, the Gotland Deep were only important in years where the salinity and oxygen conditions allowed successful spawning, egg fertilisation and egg development, and when the spatial distribution of cod stock had included these areas. A closure located, therefore, in the deep water areas of the Bornholm Deep may help to protect the spawning fish and ensure undisturbed spawning rather than closures located in the more eastern part of the Central Baltic.

The Study Groups concluded that any closed area implemented to secure undisturbed cod spawning should cover areas and times of high egg survival, and should be large enough to cover the natural spatial variability of hydrological conditions. The Group, however, also stressed that even favourable hydrographic conditions and high egg production do not guarantee successful reproduction as successful spawning depend on a number of factors and processes, e.g. egg and fry predation by clupeids, food availability, and cannibalism by adult cod (e.g. Tomkiewicz et al. 1998; Hinrichsen et al. 2002a, 2002b; Kraus et al. 2002). The spawning migrations undertaken by Baltic cod may also alter hydrographic conditions (Kraus et al 2009).

Changes in spawning time of cod in the central Baltic could also have implications for the effectiveness of the closure, e.g. a shift in spawning time from JuneAugust to earlier months of the year would have substantial implications for the design requirements of a closure. Prespawning concentrations of cod would start to gather earlier, increasing the catchability of cod in spring months in both the targeted fishery as well as in the pelagic fishery (as by-catch).

Kraus et al (2009) predicted that under unfavourable environmental conditions, none of the proposed or implemented closure scenarios could lead to stock recovery, and further demonstrated that closed seasons of the entire fishing area had a much greater impact on recovery rates, final stock sizes, and yield compared with regionally restricted spawning area closures. Kraus et al found that MPAs were only effective for stock recovery when they reduced overall fishing effort . Furthermore, they stressed that the performance of MPAs needed to be evaluated relative to environmental regimes, especially for stocks in areas with particularly pronounced environmental variability.

Recent monitoring does, however, indicate some increases in the Baltic Sea Cod Stock (M. Storr Paulsen, pers. comm. 2009).

Ecosystem and Socioeconomic effects of the closure

Wider ecosystem effects have not been assessed yet and neither have there been any studies of potential fisheries impacts (socio-economic effects) of these closures. No information exists about the level of enforcement.

Lessons learned

The poor status of the cod stock suggests that the present management regime is incapable of facilitating a recovery of the stock. Thus, there is a need for more effective management tools and closures (or MPAs) are one obvious candidate. To be effective in reducing the overall fishing mortality on cod, closure(s) should be designed after consideration of the distribution and migration patterns of cod, as well as the adaptive responses of fishing fleets. In Baltic cod pawning, larval development, juvenile and adult feeding all take place in different locations. Such complex life histories require a successful temporal and spatial linkage between these locations to integrate the whole life-cycle and produce abundant generations. Clearly, there are many open questions that the Baltic Case Study has to tackle and explore.

CASE STUDY: The Georges Bank closures

History

Until the mid-20th century,Georges Bank had abundant fin fisheries. Unfortunately in the last few decades poor fisheries management has led to steep declines in stocks (Fogarty & Murawski 2004). Changes in fish community structure also occurred, largely as a result of highly species-specific harvesting patterns driven by market considerations (Hall 2002).

As a consequence, in 1994 Federal regulations established a number of year-round fishery closures on Georges Bank and adjacent areas to help conserve and rebuild depleted stocks of flounders, gadoids and other species, with exclusions of all bottom contact fishing gear capable of catching demersal fish , i.e. the closures were not designated specifically for habitat protection (Lindholm et al. 2004). The closures were established under the USA Magnuson-Stevens Fishery Conservation and Management Act (Murawski et al. 2000).

Geography and closure system

Georges Bank is a shallow (3 to 150m depth) extension of the NE U.S. Atlantic continental shelf east of New England covering approximately 40 000 km2 (Collie et al. 1997). It is one of the largest closed area systems in effect (Fogarty & Murawski 2004) with a mosaic of closed areas consisting of approx. 22 000 km2 and has some of the most productive fishing grounds in the world (Murawski et al. 2005).

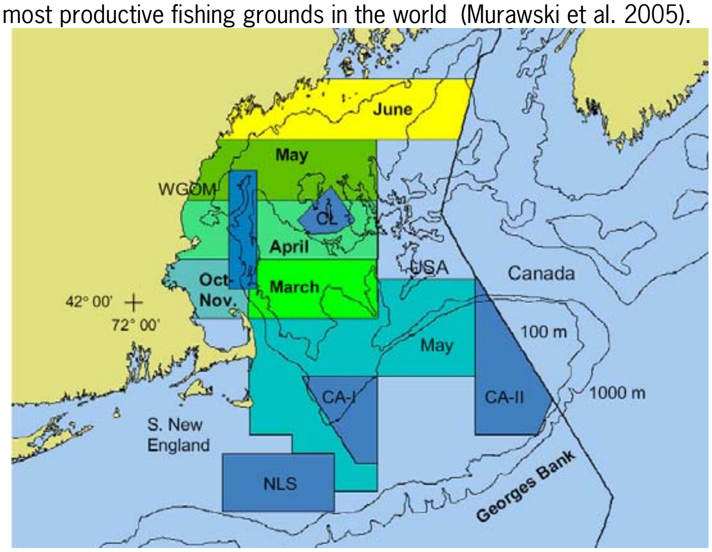


Figure 1.1 Year-round and seasonal closed areas for groundfish protection off the northeast USA. Coding is: CA-I=closed area I, CA-II=closed area II, NLS=Nantucket Lightship, WGOM=Western Gulf of Maine, CL=Cashes Ledge. Seasonal closure boundaries are partially obscured by various months (from Murawski et al 2005)

The closures in New England waters now consists of five year-round closures (Figure 1.1), sited with the aim of restoring overfished groundfish resources. The three southern areas (CA-I and CA-II and the Nantucket Lightship Area in Southern New England) were closed year-round to all fishing gears capable of retaining groundfish in December 1994. The Western Gulf of Maine closure (WGOM) was added in 1996, while an additional area was closed year-round in 1998 in the central part of the Gulf of Maine (Cashes Ledge). Since closure, the only gears that have been allowed in these reserves are lobster traps, midwater trawls (for Atlantic herring, Clupea harengus), and some limited dredge fishing for sea scallops. In 2004, some groundfishing was allowed in CA-II.

In addition, some nearshore seasonal or "rolling" closures (Figure 1.1) have been part of the groundfish management plan since the 1990s. These have been implemented with multiple objectives, but are primarily intended to limit exploitation on populations of Atlantic cod, Gadus morhua, and to protect harbour porpoise, Phocoena phocoena, from bycatch. Together with the establishment of closed areas, NOAA has also restricted numbers of days at sea (Fogarty & Murawski 2004).

Site selection methodology and design

The closed areas encompass areas of traditionally high CPUE, including part of the scallop grounds of the region and important spawning grounds for cod, haddock and yellowtail flounder. Sand/gravel areas that may be important for juvenile survivorship are also protected (Hall 2002).

Effects on the ecosystem and benthic community

The cessation of fishing following the closure has had a number of effects on habitat, and on benthic micro- and megafauna. Lindholm et al (2004) studied the effects of the closures on habitats, and seven common (i.e. featureless sand, rippled sand, sand with emergent fauna, bare gravelly sand, gravelly sand with attached-erect fauna, whole shell, shell fragment) and two rare (sponges, biogenic depressions) microhabitat types were compared separately. Results showed significant differences in the relative abundance of the shell fragment and sponge microhabitat types between fished and unfished areas, but with no differences for the remaining habitat types investigated. The lack of differences for the other microhabitats may indicate that the level of fishing activity in the area is matched by the system's ability to recover (Lindholm et al 2004).

For microbenthic organisms in the CA-II following the prohibition on bottom fishing, both colonial (i.e., sponges and bushy bryozoans) and noncolonial (i.e., P. magellanicus, S. droebachiensis, Pagurus spp., Asterias spp.) organisms increased in abundance (Asch et al 2008) and the cover of hydroids, bushy bryozoans, sponges, and F. implexa was generally higher at sites undisturbed by mobile fishing gear, although the magnitude and significance of this effect depended on water depth and differed between years. Colonial epifaunal community development was followed for a period of six years from disturbance but after six years recovery still didn't appear complete, indicating that even infrequent trawling can alter benthic communities for more years to come (Asch et al 2008)

The most compelling biological effects of the year-round closures on Georges Bank have been for sessile animals, and in particular for populations of sea scallop, Placopecten magellanicus (Murawski et al., 2000, Murawski et al 2005). Some non-commercial species such as sculpin increased in biomass., while scallop biomass increased 14-fold by 2001.
Stock effects following the closures can be difficult to attribute to the closures alone, since other management measures also took effect in the area in the same period. In the case of the scallops, however, the considerable increase stock-size is almost certainly a direct response to the closure (Hall 2002).
Production at a shallow disturbed site varied little over a sampling period of six years (32 to 57 kcal m–2 yr–1) and was markedly lower than production at a nearby recovering area (previously disturbed). At this recovering site, production increased from 17 kcal m–2 yr–1 in 1994 before the closure, to 215 kcal m–2 yr–1 in 2000 (Hermsen et al 2003). Atlantic sea scallops Placopecten magellanicus and green sea urchins Strongylocentrotus droebachiensis dominated production at the recovering site. At the deep sites, production remained significantly higher at undisturbed sites (174 to 256 kcal m–2 yr–1) than at disturbed sites (30 to 52 kcal m–2 yr–1). The soft-bodied tube-building polychaete Thelepus cincinnatus dominated production at the undisturbed site, while hard-shelled bivalve molluscs Astarte spp. and P. magellanicus were prevalent at the disturbed site. Mobile fishing gear disturbance has a conspicuous effect on benthic megafaunal production in this hard-bottom habitat. Cessation of mobile fishing has resulted in a marked increase in benthic megafaunal production (Hermsen et al 2003).

Effects on commercial groundfish stocks

It is not easy to separate the effects of the fishery closure from the reduction in days at sea. However, closures seem to play an important role in an overall increase in abundance of stocks within the closed areas (Fogarty & Murawski 2004; Murawski et al. 2005). The year-round closures have generated a build-up of some, but not most, of the groundfish stocks within the boundaries of the closed areas (Murawski et al. 2005).

- The biomass (total population weight) of a number of commercially important fish species has sharply increased, due to both an increase in the average size of individuals and, for some species, an increase in the number of young surviving to harvestable size.
- There is limited evidence for "spill-over" of biomass of harvestable sized animals from closed to open areas, for haddock, and yellowtail flounder, and a few other species (Murawski et al., 2004).
- Since 1993, haddock biomass has increased approximately eight-fold. 2005 stock assessments indicate that haddock will recover to near record levels in the next few years (Committee on Resources 2005).
- Yellowtail flounder populations have increased by over 800% since the establishment of the year-round closures.
- Georges Bank cod abundance is only 18 % more in 2005 than in 1994, while Gulf of Maine cod is about 50% more abundant than in 1994. Both stocks, however, declined in recent years (Committee on Resources 2005). However, the number of older fish in each stock has increased, and recent year classes of young fish are also increasing (Committee on Resources 2005).

Effects on fisheries effort

Apparent spill-over of animals outside of the year-round closures is driven by a few valuable species (e.g. haddock and yellowtail flounder), and this attracts some effort to the boundaries of three of the five closed areas (Murawski et al. 2005), i.e. large trawlers concentrate effort around the edges of closures (see Figure 1.2) (Fogarty & Murawski 2004; Murawski et al. 2005). Analyses confirm that large-scale year-round closed areas affect the spatial distribution and the allocation of trawling effort.

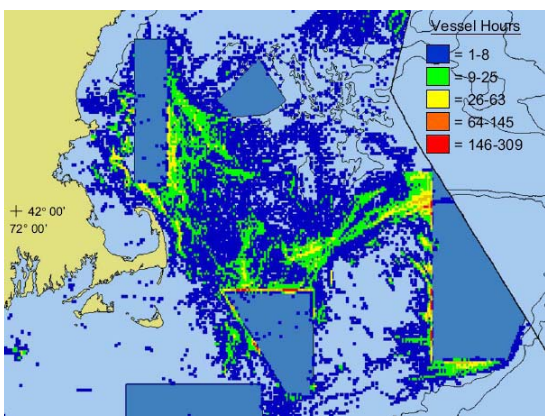


Figure 1.2. Otter trawl fishing vessel effort off the northeast USA, 2003. Data were obtained from vessels using VMS (vessel monitoring systems) using satellite tracking. Locations are plotted only for vessel speeds ≤ 3.5 kn. Data are aggregated to 1' square (Source: Murawski et al. 2005).

Based on the centre points of various 10' squares, Murawski et al. (2005) calculated that 31% of the total trawl-fishing days at sea expended in New England waters during 1991-1993 were located within the "footprints" of the five year-round closed areas.

In 2001-2003 about 10% of effort targeting groundfish was deployed within 1 km of the MPA boundaries, and about 25% within 5 km. In addition, average revenue per hour trawled was about twice as high within 4 km of the boundary, than for more distant catches, but the catch variability was greater nearer closed area boundaries (Murawski et al. 2005). The seasonal closed areas attracted more fishing effort after opening than prior to closure even while average CPUE was the same or lower (Murawski et al. 2005).

The increase in cod SSB in US part of Georges Bank, comes from the closure system, although it can also be contributed to increased mesh size, decreased vessel days at sea, quotas, etc. (FSBI 2001). In the case of Georges Bank cod, fishing mortality has been cut in half since 2001 (Committee on Resources 2005).

The scallop fishery continues to generate increasing economic benefits to the US, providing a larger supply of scallops for consumers and higher revenues for fishermen at lower costs (Committee on Resources 2005). In 1998 only 12 million pounds worth $87 million were landed, increasing steadily to over 60 million pounds worth $300 million in 2004. (NEFMC 2006; Committee on Resources 2005).

Lessons learned

Analyses confirm that large-scale year-round closed areas, in operation now for more than a decade, affect the abundance and spatial distribution of some target species, and the allocation of trawling effort (Murawski et al. 2005). Closed areas led to increased abundance of some species but not others. Spillover was observed for haddock, yellowtail and winter flounders (Fogarty & Murawski 2004). Large increases in sea scallop were an unintended side-effect. The effects of a closed area will depend on factors such as seasonal movement patterns of fish and locations relative to fishing ports that will almost certainly vary from one fishery to the next (Holland 2000).

CASE STUDY : The Shetland Box

History

The so-called Shetland Box was established in 1983 to protect "species of special importance which are biologically sensitive by reason of their exploitation characteristics." (NAFC 2004). The legal basis of the Shetland box is Council Regulation (EC) No. 2371/2002 of December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy (CFP). The Shetland box played an important role in attempts to achieve a balance between the different fleets and fishing communities.

The number and nationality of large demersal vessels fishing at any one time is restricted by a CFP licensing scheme (Council Regulation (EC) No. 2371/2002) (NAFC 2004). Vessels more than 26 m fishing for other than blue whiting and Norway pout are only allowed inside with a license from the European Commission. Allocations (below) are based on track records prior to partial closure (North Atlantic Fisheries College). Vessels without licenses may only enter if they are less than 26 m, unless they fish only for blue whiting and Norway Pout. There are 128 licenses: 62 to UK, 52 to France, 12 to Germany, and 2 to Belgium (NAFC 2004).
The exemption of blue whiting and Norway pout is to clarify what is covered by "fishing for demersal species". This is because these species are usually caught using techniques closer to those used in pelagic fisheries, and the species are covered by other regulations; among others the Norway Pout Box (COM 2002).

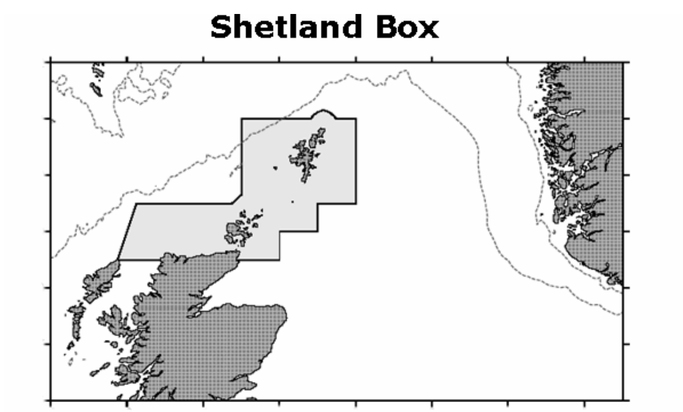


Figure 1.3. Area around the north of Scotland, Orkney and Shetland. Commercially important demersal species in the Box area are: cod, haddock, whiting, saithe, and anglerfish (Kunzlik 2001).

Site selection methodology and design

In principle the main criterion was to grant preference to local fishing vessels (Crean & Wisher 2000).

Effects on fish stocks

On the basis of fisheries sensitivity maps (Coull et al. 1998 in NAFC 2004) the Shetland Box is suggested to have relatively important, disproportionate concentrations of spawning and nursery grounds for 9 of 13 species for which maps were available. There appears to be a case for retaining (or strengthening) current management arrangements (NAFC 2004). Shetland box contains a disproportionate concentration of mature haddock and whiting, young anglerfish and, to a lesser extent, young haddock than neighbouring waters. It indicates that the area is important in the distribution of these fish at a time when the abundance of the principal gadoid fish stocks is known to be generally reduced (Kunzlik 2001). However, the vulnerability of stocks and importance of areas relies on a qualitative view of data. They reflect differing impacts on species, which also vary in age. Nevertheless, taken together, they support the argument that the region of the Shetland Box is of conservation importance to the species concerned (Kunzlik 2001).

Effects on fisheries effort/ benefits

For light trawlers, annual Landings Per Unit Effort (LPUE) when fishing in the Shetland Box are consistently higher than when fishing outside the box. Demersal fish stocks of importance to the region are shown to have declined generally in abundance since an initial EEC Regulation was adopted in 1983, especially for cod, whiting and haddock (Kunzlik 2001).

Socio-economic effects on fisheries and other stakeholders

There is a heavy economic dependency of the area's local communities on fishing. In 1998, 33% of Shetland economic turnover was from fisheries and approximately 20% of the active population is employed in the fishing industry (DEFRA 2002). The Box is a statement of the importance of fishing to the islands (Crean 2000). The general view amongfishers interviewed (NAFC 2004) is that the retention of the Shetland Box would be acceptable if a sufficiently compelling case was made for its conservation benefits. Discussions from representatives of fishing communities from Member States with and without access revealed support for non-discriminatory measures to conserve fish stocks. They were, however, unconvinced of the positive effects of the Shetland Box (NAFC 2004).
Shetlands fishermen that were interviewd have stated that the Box, as it is constructed, is viewed as relatively unimportant with regard to excluding outsiders and, therefore, its potential to lessen exploitation pressure upon fisheries resources (Crean 2000; Crean and Wisher 2000). A strong majority of Shetland fishermen believe that local fishermen do not have enough say in the management of coastal fisheries resources and that fishermen's knowledge is not used to help formulate fisheries management regulations (Crean & Wisher 2000). In addition, they believe that many of the uniform fisheries regulations in force do not suit local conditions.

Lessons learned

It seems unlikely that the management regime for the box has effectively restricted the level of fishing effort. Any decisions on the retention of the Boxmust be based on future potential and not on past record (NAFC 2004). Also, a management regime that is not overtly discriminatory should be developed (NAFC 2004).
Key interviewed informants of the Shetland Islands can be said to have the following points of view, among others (Crean & Wisher 2000):

- Diminished capacity of the centre to exert control;
- Marginalisation of local knowledge/views;
- Inadequate penalising of rule breakers.

No system has ever been established, either to monitor the Shetland Box, or to collect the data that would be needed to demonstrate its effectiveness (NAFC 2004).

CASE STUDY: The North Sea Cod Box

History

In November 2000, ICES indicated that the cod stock in North Sea area IV was outside of safe biological limits and in serious risk of collapse (ICES 2001). The Council met in December 2000, where the Commission and Council noted an urgent requirement to establish a recovery plan for the North Sea cod stock, termed the "North Sea Cod Recovery Plan" (ICES 2004a). An Agreed Record was signed on the 24th January,2001 by EU and Norway, indicating the management measures which should take place (ICES 2004a). It was decided that that a closed area be established. However, the North Sea Cod box took months to implement (ICES 2004a) but 7 February 2001 the Commission Regulation (EC)No 259/2001 of established measures for the recovery of the stock of cod in the North Sea (ICES sub-area IV).

The immediate requirement was to allow as many cod to spawn in the period mid-February to end April 2001 as possible (ICES 2004a). Therefore, the EU Council asked the Commission of the European Communities to establish a plan to protect the cod stock during its spawning season and to stop misreporting and discarding cod in all fisheries. The Cod Recovery Plan therefore included:

- Closed areas;
- Technical measures;
- Comprehensive proposals for longer-term measures.

The North Sea beam trawl fishery does not primarily target cod, but cod are taken as a significant and valuable by-catch. Beam trawlers are also know to fish in many cod spawning areas. Fishing for sandeel and pelagic species were allowed in the Cod box and observers placed on board vessels fishing for these species.

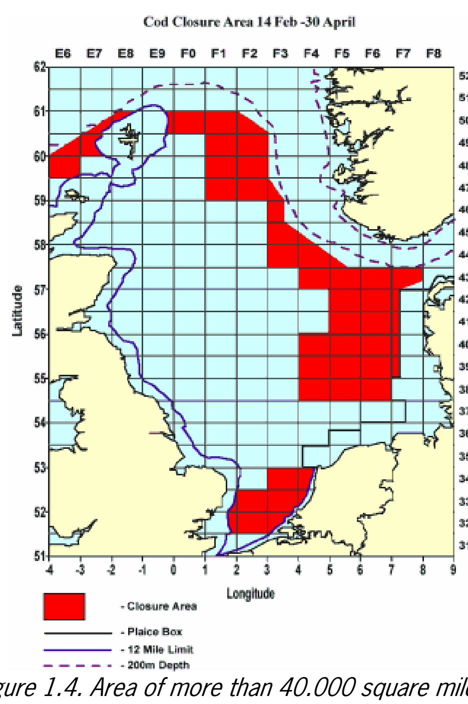


Figure 1.4. Area of more than 40.000 square miles, almost a fifth of the North Sea, that in 2001 was closed to fisheries likely to catch cod for 75 days (Dinmore et al. 2003).

Selection methodology and design

The closed area was part of the Cod Recovery Plan and was not designed as part of a larger network of closed areas (ICES 2004a).

Ecosystem effects

The closure probably had a negative impact on the rate of discarding of vulnerable components of the ecosystem (e.g. elasmobranchs or long-lived benthic species) due to an increase in trawling activities in areas that are not normally fished (ICES 2004a).

No data exist that allow an evaluation of changes outside the closure (ICES 2004a; Rijnsdorp et al. 2001). The closure may even have been counter-effective for cod, commercial species and benthic ecosystems (Rijnsdorp et al. 2001). In addition to overfishing, the North Sea cod stock is threatened by a decline in the production of young cod that has paralleled warming of the North Sea over the past ten years. Possible persistence of adverse warm conditions combined with a diminished stock endangers the long term sustainability of cod in the North Sea. To decrease risk of collapse, fishing pressure must be reduced (O'Brien et al. 2000).

Effects on fisheries effort/benefits

Fishing activities were monitored using Vessel Monitoring Systems (VMS) and the biota (demersal fish and benthos) during several bottom surveys (ICES 2004a). VMS was very effective in enforcement. During the period, target effort was reduced by (probably) 100% within the Cod box (ICES 2004a).

Beam trawl fisheries were affected. Beam trawlers in the area target sole, plaice, dab, turbot and brill, but they also catch roundfish such as cod as by-catch (Rijnsdorp et al. 2001). Eurocutters (beam trawlers up to 300 hp) were not directly affected by the area closure, since they may fish in the 12 nm-zone. These smaller vessels may even have benefited from reduced catches in the Cod box, since sole within the closure migrate to shallow coastal areas within the 12nm-zone to spawn in spring (Rijnsdorp et al. 2001).

Discard information shows that plaice discards were about 78% in the box area (ICES 2004a). Adjacent to the box area the discards were 31% before closure but 74% in the period 1999-2000 for focal species. For commercial species there was a minor increase in discards from 12% to 19% (ICES 2004a).

Displaced beam trawlers continued fishing throughout the closure, but in other fishing grounds (Rijnsdorp et al. 2001)beam trawl effort mainly moved to the area "Open North". Some of the beam trawling effort was displaced to areas that had never been beam trawled before (Rijnsdorp et al. 2001; ICES 2004a), and recovery of benthic communities in these areas is expected to take more than 10 years (ICES 2003). Environmental effects of trawling on diversity, biomass and production of benthic communities are expected to be greater in these previously untrawled and infrequently trawled areas than in the normal fishing grounds (ICES 2003; Frid et al. 2005). No data exist that permit an evaluation of changes outside the Cod box (ICES 2004a). Noo beneficial effects of the closure on cod, however, have been noted (Rijnsdorp et al. 2001; ICES 2004a). Catches of commercial species within the Cod box were higher for a short period after re-opening, but returned to normal after 2-3 weeks (ICES 2004a).

Lessons learned

Closed areas only partially overlapped with known spawning grounds (Rijnsdorp et al. 2001; ICES 2004a) and in the southern grounds, peak spawning takes place from weeks 4-7 and probably somewhat later further north. The Cod box was closed from week 8 to week17 so it probably only protected the second part of the spawning season (ICES 2004a; Rijnsdorp et al. 2001).

The aim of the emergency closure was to reduce fishing mortality on spawning cod, but the wider consequences of this closure were not considered at the outset (Frid et al. 2005), and the closure did not meet its objectives. Inappropriate timing and positioning of the area resulted in minimal positive effects (ICES 2004a). There was no overall effort reduction during closure, only displacement of fishing effort (Rijnsdorp et al. 2001). In summary, the closure of the Cod Box was poorly designed, did not consider side effects on the level of discarding in demersal stocks, and did not consider the wider ecosystem implications (Rijnsdorp et al. 2001).

CASE STUDY: The Firth of Forth Sandeel Fishery Closure

History

In the 1990s a sandeel fishery developed in the north-west North Sea, off the Firth of Forth. The landings from this fishery peaked at over 100 000 t in 1993 and fell subsequently. The Firth of Forth area is important for breeding seabirds and the removal of such large quantities of sandeels within their foraging range soon became a matter for concern. The UK called for a moratorium on sandeel fishing adjacent to seabird colonies along her entire coast. In response the EU requested advice from ICES, and an ICES Study Group was convened in 1999 in response (ICES 1999).

The study group noted that there was suggestion of a negative effect of the Firth of Forth fishery on the sandeel stock in 1993, which coincided with a particularly low breeding success of seabirds, especially kittiwakes. The study group concluded that there were reasons for continued concern about this area, and the EU agreed with ICES advice to close the fishery.
The regulation included a closely monitoredfishery where selected Danish sandeel vessels were allowed 10 fishing days in May, and 10 days in June for the collection of information relevant to monitor sandeel population development following the closure (ICES 2007). From 2003 the total number of fishing days was extended from 20 to 40.
Note: there has also been a proposal to close parts of the Dogger Bank area to protect declining sandeel stocks.

Geography and closure system

A zone along the east coast of Scotland and northern England (approximately 21 000 km2) including the Wee Bankie, was closed to the sandeel fishery from 2000 onward. The closure to the fishery is shown in Figure 1.5.

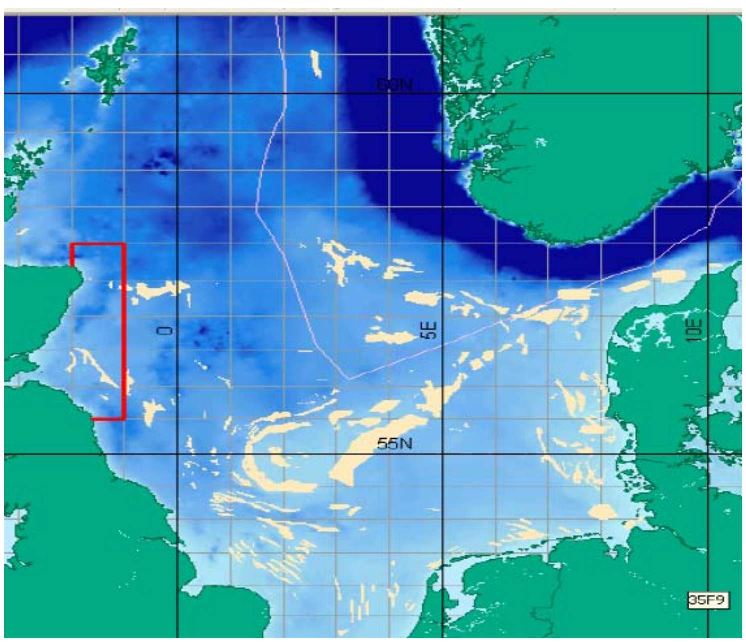


Figure 1.5. The closure to the sandeel fishery, marked in red.

Effects on the ecosystem

Studies have indicated that the closure has had a positive effect on the demographies of highly sensitive seabird species, although only one species, the surface feeding black legged Kittiwake was significantly affected by the closure of the Firth of Forth area (Frederiksen et al 2008). In a study by Wanless et al (2005) breeding success of black-legged kittiwake was related to abundance of both 1+ group (the age class targeted by the fishery) and 0 group sandeels. The proportion of 0 group consumed by kittiwakes and the proportion of the kittiwake population foraging in the area was linked to 0 group abundance. None of these parameters in other seabird species were associated with sandeel abundance.
Unrelated environmental changes, however, have since led to dramatic declines in prey quality and seabird breeding productivity , highlighting the complex and dynamic conditions found in this part of the North Sea (Wanless et al. 2005, Frederiksen et al 2008).

Effects on commercial sandeel stocks

Modeled data indicate that the biomass of 1+ year old sandeels increased sharply in the first year of the closure and remained higher in all four of the closure years than in any of the preceding three years when the fishery was operating. The biomass of 0-group sandeels in three of the four closure years exceeded the biomass present in the three years of commercial fishing. Whereas the response of 1+ sandeels may have been a direct consequence of the closure, this is not likely to have been the case in respect of 0-group sandeels. The closure appears to have coincided with a period of enhanced recruit production (Greenstreet et al 2006).

Effects on fisheries effort

Closure of the sandeel fishery reduced fishing effort in the area but the effect on catches has been less clear-cut. The catch in 1999, the last year that the commercial fishery was open, was very much on a level with catches by the scientific fishery during the four closure years. Only in 1997 and 1998 were catches substantially higher. The CPUE in 1999 was considerably lower than in the two preceding years, indicative of a much lower 1+ sandeel biomass in the area. It is possible that this low CPUE was not economically viable, forcing fishers to abandon fishing activity in the area in the last year before closure (Greenstreet et al 2006).

Lessons learned

The closure of the sandeel fishery at the Firth of Forth is an example of an ecosystem-based management measure, where fisheries were controleed in order to protect other parts of the ecosystem (seabirds). The closure has had some success, with one study indicating some positive effects on at least one seabird species, although it is not conclusive. The closure has coincided with environmental changes and fluctuations in sandeel recruitment, which has made separation of closure-effects difficult. This has, amongst others, indicated the importance of thorough knowledge of the fishery, fish stocks, and environmental factors before and after any closure.

CASE STUDY: The Kattegat Cod Closure

History

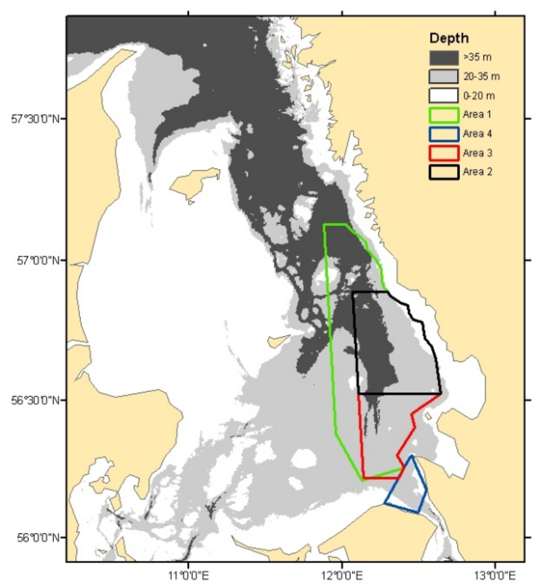
The Kattegat cod spawning stock biomass is now historically low, fishing mortality is very high, and clearly the management plan for the stock has not had the desired effect. The TAC for cod in the area has been gradually reduced from 6 200 tonnes in 2001 to 673 tonnes in 2008, but this reduction has not led to the decrease in fishing mortality required by the management plan. Some commentators have indicated that discarding of cod has been one of the contributors to the decline of the stock.

To ensure the rebuilding of the cod stock and reduce the catch of cod to the lowest possible level, in 2008 the Swedish authorities proposed closing a part of Kattegat to fisheries. The Kattegat cod stock is mainly fished by Swedish and Danish fishermen, and the authorities of the two countries reached an agreement for a closure located in the southeastern part of Kattegat and including a small part of Øresund,

The closure took effect on January 1st 2009 for a 3-year period, after which it will be evaluated.

Geography and closure system

The geographic extent of the closure is shown in Figure 1.1. It is divided into 4 zones of seasonal and permanent closures and with gear restrictions. One area is permanently closed to all fisheries.



Area 1: (Green) seasonally (1 January-31 March) closed area in the Kattegat, except for fishery with selective gear;
Area 2: (Black) closed all year around, except for fishery with selective gear;
Area 3: (Red) closed all year round for all fisheries;
Area 4: (Blue) seasonally (February-March) closed area in the Northern part of the Sound, except for fishery with selective gear

Figure 1.6: The Kattegat Cod closure, with different zones

Effects

Since the closure is only recent, no effects have yet been monitored. It is hoped that the closure will help increase the spawning stock biomass of cod and increase general abundance levels of fish in the area. The closure could also have wider ecosystem effects, through direct effects on species other than cod and through reduced disturbance of the sea bed, and indirectly through cascading effects on other species.

Concluding remarks

The use of MPAs in demersal fisheries management has received attention due to the continuous decline of several fish stocks, but despite some measured positive changes for fish stocks within MPAs (e.g. growth or sex ratios) the evidence of the ability for MPAs to rebuild stocks and benefit fisheries is not strong within North Europe. Cases in the USA do, however, provide records of stock increases and spill-overs following closures.
Many studies have emphasised that an MPA cannot stand alone as a management tool, and must be combined with overall effort reductions and gear restrictions (e.g. Horwood et al. 1998, Kraus et al. 2009) There should also be attention to fisheries by smaller vessels, and fisheries for species other than those being targeted which may have very high discard levels. After closure, attention should also be paid to effort reallocation, as the concentration of fishing effort in smaller areas open to fishing could lead to increased fishing mortality and habitat degradation in those areas (as it for example was the case in the North Sea Cod Box).

Recent studies discussing the design and siting of MPAS in the North Sea have emphasized prior requirements for detailed knowledge about species' habitat requirements, habitat selection strategies and feeding (e.g. Hiddink et al 2008, Christensen et al 2009); as well as the distribution of these habitats and their interaction with environmental parameters.. The same is the case for the need for more information pertaining to oceanic conditions, and larval transport patterns. This knowledge could be used for making MPAs more suited for specific life stages of a species instead of large-scale MPAs.

An important point which has emerged from the case studies is that careful monitoring and evaluation must be undertaken. This should include monitoring of the fishery, in addition to monitoring of the fish resources, the ecosystem itself and any changes in the environment. A problem with MPAs is that "success" criteria and methods of evaluation are often not set prior to the closure (e.g. Higgins et al 2008) making evaluation difficult or impossible.
Another important point is that of environmental variability, which also should be included in modelling and evaluation of MPA effects. Fish recruitment, growth and distribution are highly influenced by changes in environmental parameters, and the effects of an MPA willcertainly change according to the particular environmental regime (e.g. Kraus et al 2009).
There is reason to believe that MPAs established for fisheries management can hold several benefits for the wider ecosystem and its biodiversity, which has been clearly demonstrated in the case of the US (Georges Bank Case study) and some southern European MPAs. The sandeel fishery closure in the Firth of Forth has also been shown to benefit certain seabird species. The demersal fishery MPAs in the North Sea have, however, in most cases not been evaluated with respect to benthic habitats, theirspecies compositions and their top predators. With the increasing focus on ecosystem-based management across Europe and the protection of biodiversity it would seem appropriate to combine efforts and work towards a more integrated planning of objectives.

Chapter 2 Plaice Box (objectives, management regime, derogations).

Overview

In this Chapter we describe why the Plaice Box (PB) was originally instigated and its history ever since. An important component here is the section on the perceptions of the PB by stakeholders. Marieke Verweij, a social scientist from Wageningen University, has helped here, providing summaries from her interviews with fishermen and Conservation Organisations.

Review of how stakeholders (fisheries, NGOs) perceive the Plaice Box.

This section describes perceptions of fishermen and staff of environmental NGOs (ENGOs) about the plaice box and is derived from Verweij et al. in preparation (see references). Firstly, the context of the debate is described in which the perceptions arise. Secondly, the perceptions of fishermen and ENGO-staff are described. For this purpose, 15 fishermen were interviewed. They were all skippers of beamtrawlers of approximately 2000 hp (horsepower), hence, they were not allowed to fish inside the plaice box. Additionally, five employees working at three different ENGO-staff were interviewed.

Subject of the debate

The goal of the plaice box was to reduce the bycatch and discarding of undersized plaice (Pastoors et al. 2000). Inside the plaice box, this goal has been reached (Grift et al. 2004). Upon introduction, another expected effect of the plaice box was formulated as a 25% - 35% increase in spawning stock biomass (SSB) (Grift et al. 2004). The reasoning behind this was that thanks to the protection of the box, survival of young plaice would increase, eventually resulting in a higher SSB (Figure 2.1a). However, since 1990 the plaice SSB has declined (Figure 2.2). Therefore, the general feeling is that the plaice box 'has failed', or 'has not lived up to expectations'.

Measuring the effectiveness of the plaice box by looking at developments in SSB alone is difficult. This is because the SSB is influenced by many factors simultaneously; both natural (e.g. growth rates, recruitment levels, natural mortality) and human (fishing mortality throughout the whole of the North Sea). The isolated effect of the plaice box alone can therefore not be separated from such other factors unfluencing SSB. The same is true for measuring it's effect by looking at the number of recruits of age-1 fish (Figure 2.2), because recruitment is not only influenced by reduced discarding mortality in the plaice box, but also by other factors, such as larval influx and natural mortality (Pastoors et al. 2000). A more direct analysis of the effectiveness of the plaice box would include, for instance, measurements of the influx of larvae into the plaice box area, and their survival and growth. Unfortunately, measurement of these is technically and logistically too demanding. Concluding, the context of the current debate on the functioning of the plaice box focuses most often on developments in the stock size, but SSB is an ambiguous management indicator.

Perceptions of fishermen

In short, most fishermen perceive the plaice box as counter-productive and describe it as a 'disaster-story', or 'the biggest management-mistake ever made'. Their perceptions are formed in their experiental information-environment where they have noticed two events after introduction of the plaice box. Firstly, they say that only seastars (Asterias rubens) and crabs (Cancer pagurus) remain in the plaice box and perceive the area as a 'dead zone' for plaice. They gather this information from colleague eurocutter shippers, who are still allowed to fish inside the box. Secondly, fishermen have perceived a steep decline of the plaice stock in the early 1990s judging from the developments in their catch-per-unit-effort (which can be seen as a relative measure for stock size). They most often ascribe this decline to the plaice box and also to a decrease in the level of phosphates in the sea water, two processes which in their view have been detrimental to the food availability for plaice.

Fishermen say the plaice box has not led to expected effects mainly because bottom trawling diminished as a result of lowered fishing intensity (Figure 2.1b). They all firmly state that this has led to lower food availability for plaice (corresponding to working hypothesis 3 of this document). Most fishermen express their general idea that 'ploughing the seafloor' eventually is good for plaice, without mentioning the actual chain of processes. They say that bottom trawling ensures mixing of nutrients in the seabed, and often compared this to ploughing a farmland, which is needed to enhance productivity. Two of the interviewed fishermen added that they had heard a German scientist say that the sediment of the plaice box was covered by a layer of black slime; which they interpreted as an unhealthy, anoxic, and acidified situation. Additionally, some fishermen said that bottom trawling ensures the digging up of worms and shellfish, which are then eaten by plaice. In fact, in a recent scientific article, Hiddink et al. (2008) indeed suggest that certain levels of bottom trawling disturbance may enhance the production of food for plaice (small invertebrates).

Fishermen thus feel that they have become an important part of the ecosystem in that they enhance the productivity of the sea. They say that as a consequence of diminished fishing effort, young plaice have fled from the box ('fish follow the fishery'), because outside the box, where fishing intensity is higher, the seafloor is more productive and food availability is higher. Their belief is reinforced by their observation that the best fishing grounds, where lots of plaice can be caught, are located precisely at the border of the plaice box where many trawlers fish (see quote below). VMS data also suggest intensive trawling activity at the borders of the plaice box.

Illustrative quotes from fishermen:

- Fisherman 1: Beamtrawlers plough the sea. As a result, shells are cracked open and plaice feed on what's inside. Inside the box, plaice is gone. But at the border there still is plaice to be found. So, we conclude: after plaice are born near the Wadden Isles, that plaice has to cross the Sahara [plaice box] before they finally find some food [near the edge: where beamtrawlers fish].
- Fisherman 2: I wonder, why is plaice abundant precisely at the border of the box, and why does it no longer swim inside? The plaice obviously does not know that the border of the box is there; there is no fence or anything. So, we fishermen have only one conclusion: plaice swims towards food, the fish are attracted by fishing. If there is no fishing, there's no fish. Ploughing due to bottom trawling can be the only reason.

None of the fishermen attributed the change in spatial distribution of plaice to a rise of the water temperature. When the interviewer proposed this to have an effect as well, one fisherman answered that diminished bottom trawling had had the largest negative effect on the abundance of plaice in the box, and only 10% could be attributed to the rise in water temperature.

Perceptions of ENGO-staff

Staff of ENGOs perceive that the plaice box has performed poorly based partly upon what they hear from scientists. But the perception of ENGO-staff is also framed because they react to the perception of fishermen, and because ENGOs have a holistic view resulting from their ideology to preserve entire ecosystems. Some ENGO-staff do acknowledge that 'ploughing' may create advantageous conditions for plaice, but they added not to ambition a 'monoculture for plaice'. All ENGO-staff mentioned the negative overall effect of continuous bottom trawling in the plaice box on all benthic organisms. By doing so, they broaden the debate by not only talking about the effects of the plaice box on plaice, but its effects on the whole ecosystem.

- Quote from ENGO-coworker: The problem is that plaice is perceived like a potato. But you can not manage plaice without managing it's food, it's predators, everything is interlinked in an ecosystem.

ENGO-staff tend to emphasise the detrimental effect of remaining fishing pressure inside the box (Figure 2.1c) (Hugenholtz 2008). They mention that the plaice box has performed poorly because it has not been a fully closed area. Some of the ENGO-interviewees mentioned that the number of eurocutters increased after implementation of the box (also mentioned by Pastoors et al. 2000) and that many of these ships illegally have engine powers >300 hp, hence fishing intensity inside the box is underestimated. In their view, fishing intensity has not decreased sufficiently and discarding of young plaice went on (corresponding to working hypothesis 1 of this document). Most ENGO-staff also mentioned that warming of the sea water may have contributed to the shift in spatial distribution of young plaice towards areas further away from the coast (corresponding to working hypothesis 2 of this document). Hence, these young plaice enter waters outside the box, where they are discarded as by-catch in the 80 mm sole fishery. One ENGO-coworker mentioned that this shift may also have taken place due to high fishing pressure inside the box area before the box was implemented (see quote below).

- ENGO-coworker: Vessels with less than 300HP still discard undersized plaice and sole inside the box. And the plaice box does not account for the shifting patterns of young plaice. Here and there, I read that they move outside of the box. Why that happens, I'm not sure. Maybe the fish have gradually moved out of the plaice box because this area has been very heavily fished in the past.

Concluding remarks

Hence, when considering the plaice box, fishermen emphasise and express their view of the positive effect of fishing activity in the form of increased food availability, whereas ENGO-staff emphasise the negative effect of fishing activity in the form of fishing mortality. Because no area of the plaice box has been closed completely from all fishing activities, these two processes are impossibe to distinghuish in the current setting.

Neither fishermen, nor ENGO-staff mentioned the decline in recruitment of age-1 plaice (Figure 2.2) or diminished growth rates, two processes that occurred after introduction of the plaice box, as reasons for the decline in SSB in the early 90s. Up until now, scientists are not facilitating the multi-stakeholder debate by explaining and unravelling the factors that influenced the functioning of the plaice box. They are advised to fulfil this informing role more actively.

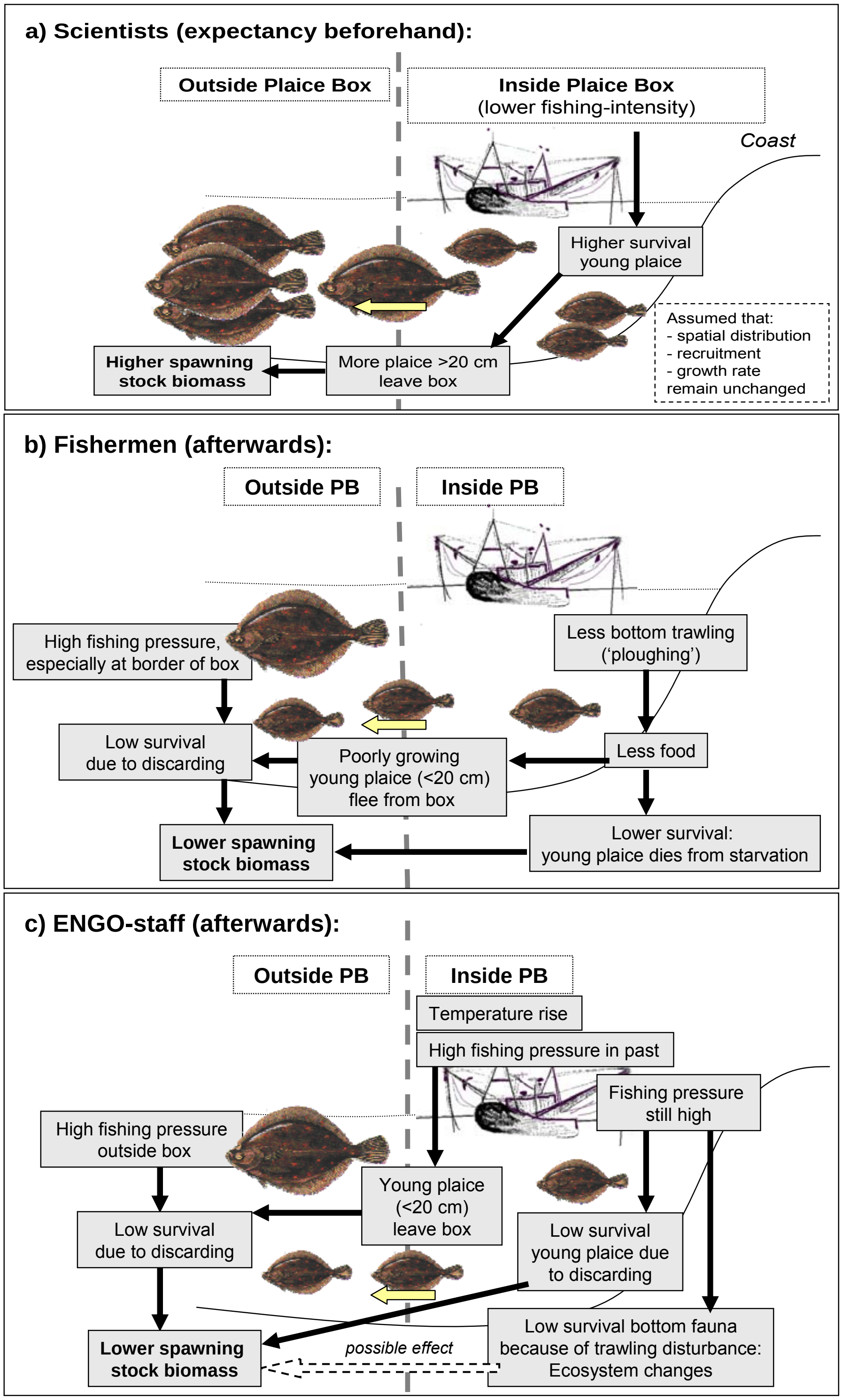


Figure 2.1. Different perceptions and causal reasoning about the plaice box. (a) The reasoning and communication by scientistst at the time the box was implemented; (b, c) the functioning of the plaice box in retrospect according to fishermen and ENGO-staff, respectively

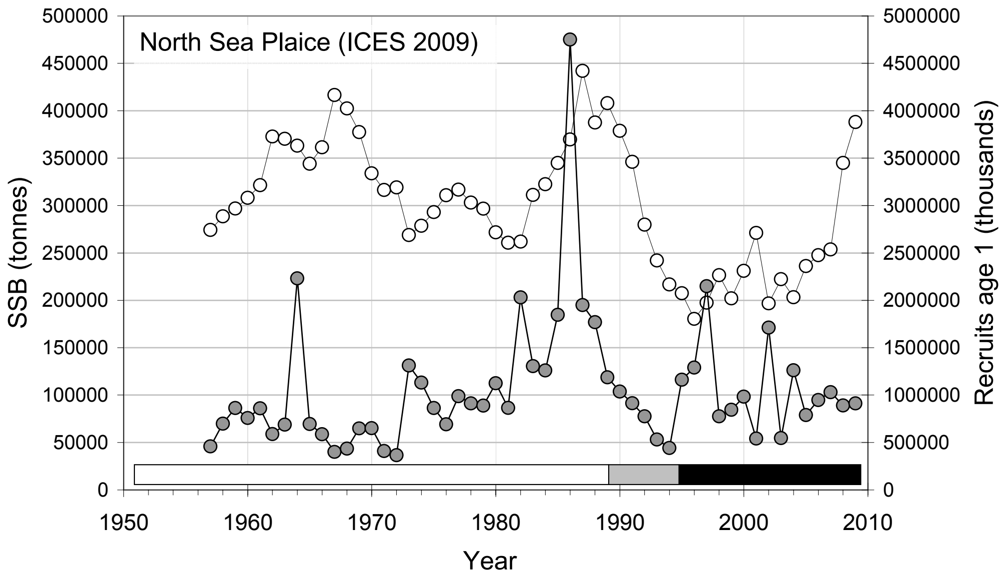


Figure 2.2 Spawning stock biomass (SSB) and recruitment of age-1 fish for North Sea plaice. The bars above the x-axis depict distinct implementation-phases of the plaice box: white bar = no plaice box; grey bar = plaice box closed to trawlers >300 hp for part of the year (since 1989); black bar = plaice box closed for these trawlers during the whole year (since 1995).

The role of the Plaice Box in management of plaice and the conservation of biodiversity

Plaice is exploited in the mixed flatfish fishery that is targeting for sole. Due to the small mesh sized used, large numbers of undersized plaice are caught and discarded (van Beek, 1989; ICES, xxxx). The survival of plaice discards is very low (van Beek et al., 1990).

The plaice stock is managed following the long term management plan. An ICES evaluation of the management plan for plaice is not yet conclusive with regards to consistency with the precautionary approach. The setting of last years' TAC, however, closely followed the lines of the plan. The plaice stock in the North Sea is assessed annually by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). The assessment forms the basis for the management advice each year and the latest (done in May 2009) is summarised below. Since plaice abundance within the Plaice Box is not assessed separately its direct role or impact in the management of plaice is small. The stock was estimated to be 388 kt in 2009 (above Bpa). The fishing mortality (including discards) for 2008 was estimated to be 0.25 (below Fpa and the target F in the long term management plan). Given the estimated fishing mortality in 2008 and the SSB in 2009, the stock is classified as being harvested sustainably and as having full reproductive capacity.

The assessment is, however, considered to be uncertain, because survey tuning series in different areas of the North Sea indicate different trends in the very recent development of the stock. In addition, discards form a substantial part of the total catch and are not well estimated from the sparse sampling trips available: especially for the UK. This uncertainty results in a strong retrospective pattern, with this years' assessment estimating much higher SSBs and lower fishing mortalities for the most recent years (Aarts and Poos 2009). Fishing mortality resulting from the landings has decreased considerably over the last 10 years while fishing mortalities resulting from the discards are fluctuating without trend. This is probably the result of the concentration of fishing effort in the Southern North Sea and a change in the spatial distribution of juvenile plaice.

The scientific basis underpinning the instigation of the PB was developed in the mid 1980s by the ICES North Sea Flatfish Working Group. This group noticed a change in the exploitation pattern towards the younger age groups of plaice, and expressed their concern that this could lead to an increase in the level of discarding. In response to this, the European Commission asked ICES to explore the possibilities to improve the exploitation pattern and reduce the discarding in the flatfish fisheries. ICES (1987) examined the possibilities of mesh size regulations and area closures and concluded that a closure of the fisheries in the coastal waters along the continental sea board of the North Sea, would be the most effective measure. The reason was that in these shallow waters the majority of undersized plaice were concentrated. The group demonstrated that if the Plaice Box was closed to all discarding fleets in the 2nd and 3rd quarters of each year then the survival by each cohort could increase by 25%; and by 35% if closed all year. Sole survival would also increase but the benefits would not be as pronounced (Rijnsdorp and Beek 1991).

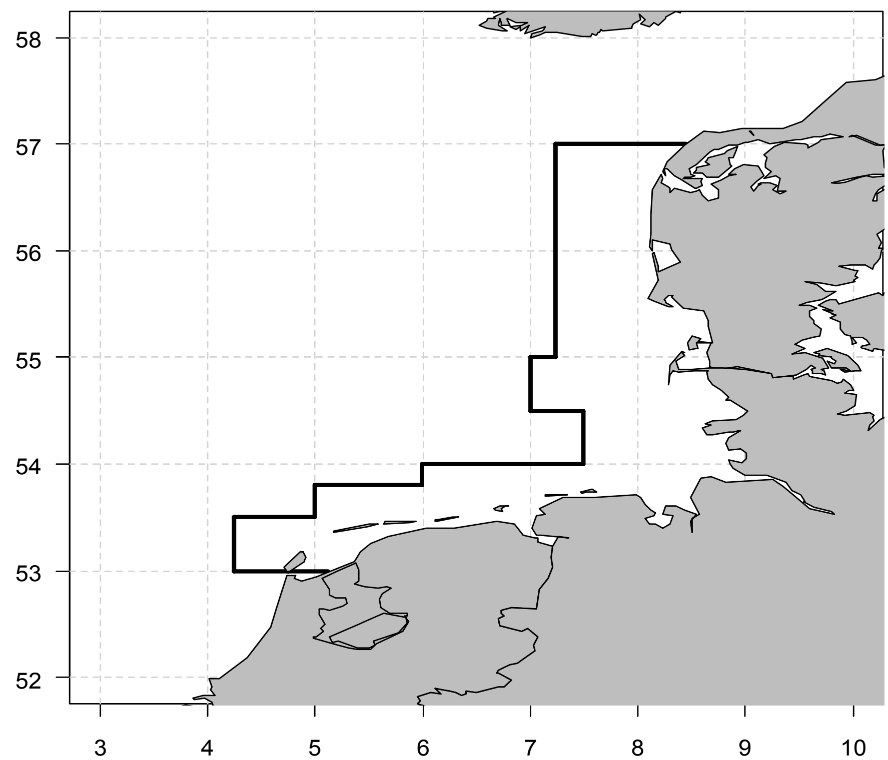


Figure 2.3. Location of the Plaice Box

Objectives

Based on the scientific advice of ICES, and with support of the major stakeholders, the EU established the Plaice Box in 1989 (EU Council Resolution 4193/88) with the objective "to establish seasonal limitations on certain fishing activities in the North Sea in order to limit fishing on juvenile plaice". The boundaries of the box are shown in Figure 2.3. The regulation is presented in Box 1 and summarised here. No fishing inside the Plaice Box was allowed by beam trawlers and otter trawlers exceeding 300 hp (221 kW). Fishing by other vessels was permitted provided that they were: – on an authorized list and then engine power did not exceed 300 hp, even if fishing with beam trawls – not on a list but fishing for shrimp – not on a list but fishing with other trawls using 100 mm mesh, even if engine power exceeds 300 hp, provided catches of plaice and sole which exceed 5% by weight of the total catch on board were discarded immediately. The Plaice Box regulations applied to the 2nd and 3rd quarter, only. In 1994 the Plaice Box regulation was extended to the 4th quarter, and since 1995, the Plaice Box has been closed year round.

Initially the instigation of the Plaice Box was considered as a "Technical Fisheries Management" initiative to reduce discarding and improve plaice yields and biomass. As such it was strongly supported by fishermen and their representatives. Non Governmental Organisations were not involved at all in the early stages. As the restrictions to the fisheries may fulfil other objectives such as nature conservation1 and socio-economic objectives2, the whole issue of the Plaice Box has become entangled with the conservation lobby and the worldwide debate (Laurel and Bradbury 2006) on Marine Protected Areas. A consequence is that in the societal debate the various stakeholders have suggested new objectives for the Plaice Box seem that far exceed its original remit. It should be stressed here that general conservation and protection of marine biota was never an original objective of the Plaice Box.

Box 1. Article 29 Restrictions on fishing for plaice

1. Vessels exceeding eight metres length overall shall be prohibited from using any demersal trawl, Danish seine or similar towed gear inside the following geographical areas:

(a) the area within 12 miles of the coasts of France, north of latitude 51° 00' N, Belgium, and the Netherlands up to latitude 53° 00' N, measured from the baselines;

(b) the area bounded by a line joining the following coordinates:

- a point on the west coast of Denmark at latitude 57° 00' N,
- latitude 57° 00' N, longitude 7° 15' E,
- latitude 55° 00' N, longitude 7° 15' E,
- latitude 55° 00' N, longitude 7° 00' E,
- latitude 54° 30' N, longitude 7° 00' E,
- latitude 54° 30' N, longitude 7° 30' E,
- latitude 54° 00' N, longitude 7° 30' E,
- latitude 54° 00' N, longitude 6° 00' E,
- latitude 53° 50' N, longitude 6° 00' E,
- latitude 53° 50' N, longitude 5° 00' E,
- latitude 53° 30' N, longitude 5° 00' E,
- latitude 53° 30' N, longitude 4° 15' E,
- latitude 53° 00' N, longitude 4° 15' E,
- a point on the coast of the Netherlands at latitude 53° 00' N;

(c) the area within 12 miles of the west coast of Denmark from latitude 57° 00' N as far north as the Hirtshals Lighthouse, measured from the baselines.

2. (a) However, vessels to which a special fishing permit has been issued in accordance with Article 7(3) of Regulation (EC) No 1627/94 shall be authorised to fish in the areas referred to in paragraph 1 using beam trawls. The use of any beam trawl of which the beam length, or of any beam trawls of which the aggregate beam length, measured as the sum of the length of each beam, is greater than nine metres, or can be extended to a length greater than nine metres, shall be prohibited, except when operating with gear having a mesh size between 16 and 31 millimetres. The length of a beam shall be measured between its extremities including all attachments thereto.

(b) Notwithstanding Article 1(2) of Regulation (EC) No 1627/94, special fishing permits for the purposes indicated in (a) may be issued for vessels exceeding eight metres length overall.

(c) Vessels to which a special fishing permit as referred to in (a) and (b) has been issued shall comply with the following criteria:

---

[1] Lindeboom H, Bäck S (2005) Establishing coastal and marine reserves — with the emphasis on fisheries. In: Allan R, Förstner U, Salomons W, Vermaat J, Salomons W, Bouwer L, Turner K (eds) Managing European Coasts Past, Present and Future Springer, Berlin, p 103-117

[2] European Parliament resolution on the review of certain access restrictions in the Common Fisheries Policy (Shetland Box and Plaice Box) (2005/2190(INI))

- they must be included in a list to be provided to the Commission by each Member State such that the total engine power of the vessels within each list does not exceed the total engine power in evidence for each Member State at 1 January 1998,

- their engine power does not exceed 221 kilowatts (kW) at any time and, in the case of derated engines did not exceed 300 kW before derating.

(d) Any individual vessel on the list may be replaced by another vessel or vessels, provided that:

- no replacement will lead to an increase for each Member State in its total engine power indicated in the first indent of (c),

- the engine power of any replacement vessel does not exceed 221 kW at any time,

- the engine of any replacement vessel is not derated, and

- the length overall of any replacement vessel does not exceed 24 metres.

(e) An engine of any individual vessel included in the list for any Member State may be replaced, provided that:

- the replacement of an engine does not lead to the vessel's engine power exceeding 221 kW at any time,

- the replacement engine is not derated, and

- the power of the replacement engine is not such that replacement will lead to an increase in the total engine power as indicated in the first indent of (c) for that Member State.

(f) Fishing vessels which do not comply with the criteria specified in this paragraph shall have their special fishing permit withdrawn.

3. Notwithstanding paragraph 2(a), vessels holding a special fishing permit and whose primary activity is fishing for common shrimp, shall be permitted to use beam trawls of which the aggregate beam length, measured as the sum of the length of each beam, is greater than nine metres when operating with gear having a mesh size between 80 and 99 millimetres, provided that an additional special fishing permit to this effect has been issued to these vessels. This additional special fishing permit shall be annually reviewed.

Any vessel or vessels to which such an additional special fishing permit has been issued may be replaced by another vessel, provided that:

- the replacement vessel does not exceed 70 GRT and does not exceed an overall length of 20 metres, or

- the capacity of the replacement vessel does not exceed 180 kW and that the replacement vessel does not exceed an overall length of 20 metres.

Fishing vessels which cease to comply with the criteria specified in this paragraph shall have their additional special fishing permit permanently withdrawn.

4. (a) By way of derogation from paragraph 1:

- vessels whose engine power does not exceed 221 kW at any time and, in the case of derated engines did not exceed 300 kW before derating, shall be authorised to fish in the areas referred to in that paragraph using demersal otter trawls,

- paired vessels whose combined engine power does not exceed 221 kW at any time and, in the case of derated engines did not exceed 300 kW before derating, shall be authorised to fish in said areas using demersal pair trawls.

(b) However, vessels whose engine power exceeds 221 kW shall be permitted to use demersal otter trawls, or paired vessels whose combined engine power exceeds 221 kW shall be permitted to use demersal pair trawls, provided that:

(i) - the catch of sand eel and/or sprat retained on board and caught in the said areas constitutes at least 90 % of the total live weight of the marine organisms on board and caught in the said areas, and

- the quantities of plaice and/or sole retained on board and caught in the said areas do not exceed 2 % of the total live weight of the marine organisms on board and caught in the said areas;

or

(ii) - the mesh size used is at least 100 millimetres, and

- the quantities of plaice and/or sole retained on board and caught in the said areas do not exceed 5 % of the total weight of the marine organisms on board and caught in the said areas;

or

(iii) - the mesh size used is at least 80 millimetres, and

- the use of such mesh sizes is restricted to an area within 12 miles of the coast of France north of latitude 51° 00' N, and

- the quantities of plaice and sole retained on board and caught in the said areas, do not exceed 5 % of the total live weight of the marine organisms on board and caught in the said areas.

5. Within areas where beam trawls, otter trawls or bottom pair trawls may not be used, the carrying on board of such nets shall be prohibited, unless they are lashed and stowed in accordance with the provisions laid down in Article 20(1) of Regulation (EEC) No 2847/93.

6. Detailed rules for the implementation of this Article shall be drawn up in accordance with the procedure laid down in Article 48.

Plaice Box evaluations

The efficacy of the Plaice Box has been evaluated several times. The 1st evaluation was in 1994 and noticed that the fishing effort in the box was substantially increased in October when the beam trawl fishery was allowed to fish inside the plaice Box. (ICES, 1994) . Based on this, the EU adapted the regulation and extended the Plaice Box to the 4th quarter in 1994 and the whole year from 1995 onwards. The 2nd evaluation was done in 1999 (ICES, 1999) which concluded that, in contrast to the expected positive effects, yield and spawning stock biomass have decreased. The effects of the plaice box were evaluated by analyzing the relevant factors and processes (natural and anthropogenic) that affect recruitment. It was shown that the Dutch beam trawl effort had decreased in two phases. During 1989–1993, when the plaice box was closed only during the second and third quarter, effort was reduced to around 40% of the original level. When the box was also closed in the fourth (1994) and first quarter (1995 onwards), effort decreased to around 6%. The effort reduction would imply a reduction in discard mortality if all other factors had remained constant. However, a reduced growth rate and possibly a higher rate of natural mortality may have counteracted the reduction in fishing effort. The apparent changes in growth and mortality coincided with changes in the North Sea ecosystem that occurred in the early 1990s but may also be related to a response to the change in beam trawl effort.

The 3rd evaluation was done in 2004 (Grift et al., 2004). In this evaluation it was stressed that it was difficult to separate the important competing effects from one another. No 'designed experiment' was done and only observational data were available. The team examined trends in time-series of various parameters (landings, effort, discards, growth rates, spatial distributions of juveniles and environmental parameters such as water temperature and nutrient concentrations). The hypothesis that food availability in the plaice box had decreased because of a fall in disturbance of the benthos by trawling activity was also investigated by quantifying growth rates. At that time the plaice stock was estimated to be around 200,000 tonnes which is less than Blim. A general reduction in plaice recruitment was noted It was concluded that fishing effort had decreased overall (69% of pre-closure levels followed by a further 23% when the plaice box was completely closed) but there was still intensive trawling by small beamers (<300HP). In 2003 7% of the total North Sea landings came from the plaice box. Together with the reduction in effort, landings of plaice also fell but discards increased. The spatial distribution of juvenile plaice also changed after the instigation of the plaice box with more young fish being seen off shore in deeper water. Growth rates of plaice decreased while sea temperatures in the southern North Sea increased and nutrient loads fell. In conclusion, the study provided no direct evidence that the abundanc of plaice had increased either in terms of recruitment, spawning stock biomass or yield. Since 1989 recruitment had fallen while yield fell by 60%.

Article 19 of Council Regulation (EC) No 2371/2002 which controls access to waters outside the 12 mile zone was reviewed in May 2004. At that meeting the EU, also mainly using the report of Grift et al. (2004), evaluated the efficacy of both the Plaice and Shetland Boxes and suggested that there should be a wide consultation of the fishing industry and Member States before an opinion on the future of the boxes was formed. Hence a non-paper was circulated to all interested parties including the North Sea Regional Advisory Council (NSRAC) which made the following observations:

1. Access restrictions only apply to beam trawlers of more that 300hp and do not apply to other types of fisheries targeting plaice, some of which have intensified in the area. The enforcement of the current access restriction and, in particular, the acknowledged deficiencies in enforcing engine power limitations, gives cause for concern. As a result of poor enforcement, the beam trawl effort is estimated to be significantly higher than assumed in the report. Its possible effects on the effectiveness of the Plaice Box have not been considered in the scientific evaluation. The NSRAC reaffirms its position that the licensed engine capacity should be subject to tighter and strict control and enforcement measures.

2. There was a lack of clear objectives when the plaice box was established, which hinders the ecological assessment. The evaluation report suggests that objectives should now be set, and clear criteria defined for evaluating its success. The NSRAC notes that the Plaice Box is yet another example of a measure that has been introduced without clearly stated criteria for judging its success.

3. The evaluation provided no direct evidence that the Plaice Box has enhanced recruitment, spawning stock biomass and yield. Since its establishment, recruitment has shown a negative overall trend, and spawning stock and total yield have decreased by 60%. From the trends observed it was inferred that the Box has likely had a positive effect upon recruitment, but that this overall effect has decreased with time. The box does not seem to have had any negative effects upon growth or spatial distribution.

4. The spatial distribution of juvenile plaice has changed. Juveniles tend to move towards deeper waters further offshore. At present approximately 70% of undersized plaice are found in the Box and Wadden Sea area. Densities of juvenile plaice inside the Box are higher than outside. This is one reason to assume that the Plaice Box has a positive effect on recruitment.

5. Scientific information on discard levels within the Plaice Box is generally poor, particularly for the twin-rig fishery. There is evidence that discard percentages are now higher in the waters adjacent to the Plaice Xox. The new plaice discard monitoring scheme by the Dutch fleet, which covers the whole North Sea, will provide valuable information on discard levels and is welcomed.

6. The effects of observed changes in water temperature and primary production in the coastal zone on the functioning of the Plaice Box are unclear.

7. No clear conclusions could be drawn on the question of whether increased levels of beam trawling in the area would increase food availability for plaice as some fishers have suggested.

8. Through experimental research, using a checkerboard pattern of opened and closed areas, some mechanisms within the Plaice Box could be measured. Both potential negative effects of the closed area (i.e., a lower benthic productivity due to the lack of trawling disturbance) and potential positive effects (better survival of undersized plaice) need to be assessed.

9. The evaluation of the Plaice Box cannot be seen in isolation from a wider discussion on protected areas as a management instrument for fisheries and ecosystems. The NSRAC Spatial Planning WG is considering the criteria to be applied in evaluating proposals for specially protected areas.

11. It is noted that the Plaice Box is also valuable for the socio-economic welfare of the small-scale coastal fishery and the coastal region. Against this background, the Flatfish Working Group concludes that the Plaice Box should be subject to a thorough evaluation. Changes to the Plaice Box should not lead to increased fishing pressure on juvenile plaice. In this context, the NSRAC notes that the target effort reductions in its proposed medium term management strategy will also apply to the Plaice Box. It is also noted that the German industry want to keep the current access regime within its national waters, including the German EEZ, in place in the event that research is carried out.

NSRAC Advice

The NSRAC advises that a thorough scientific evaluation of the Plaice Box should be carried out (see Appendix to Chapter 2). To this end, the Plaice Box could be modified on an experimental basis. Through this evaluation, the potential positive and negative effects of the Plaice Box Box should be investigated while respecting the wishes of various stakeholders. This experimental research will provide decision-makers and stakeholders with valuable information on the impact of protected area measures for plaice, assisting the development of a long-term management strategy for North Sea flatfish as well as assisting with the wider discussion on Marine Protected Areas.The NSRAC stresses that the experimental modification must be designed in close cooperation with fisheries scientists, economists, fishers and conservation organisations. Industry involvement is of particular importance in view of the need for compliance with the scheme. The NSRAC has already set up a focus group to identify a broad range of questions that should be answered by the experiment as well as the criteria for evaluation of its results and a design for the scheme. The NSRAC would welcome the participation of the Commission and Member States in these discussions, with the aim of devising, seeking funding and recruiting participants for the planned experimental studies.

As far as governments were concerned, comments on the non-paper were only received from two: The United Kingdom and Germany (Commission of the European Communities 2005). The UK had no firm position on the future of the Plaice Box while Germany was strongly in favour of retaining the Box and of possibly even extending its coverage further west in order to protect juvenile plaice now found there. Germany also advocated better enforcement of the 300hp limit on vessel power and an investigation on the impact of twin trawling in the area. In response the Commission stated that, although the NSRAC would like to modify the Plaice Box on an experimental basis, the consultations necessary to establish the objectives of the Box, design the experimental studies to evaluate its effectiveness and the to implement the new measures would take time. The objection of the German fishing industry to changes in access demonstrated the potential difficulties. The Commission, therefore, accepted in principal the proposal to study the issue further but that in the meantime stated that the status quo regarding access should be maintained. It was stressed that the proper access restrictions be properly and rigorously enforced, particularly with respect to engine power.

The Dutch Ministry of Agriculture, Nature Conservation and Food Quality also commissioned a study in 2006 to investigate the interactions between commercial fisheries and protected areas (Deerenberg et al. 2006). During this study fishing effort was quantified within and without the Plaice Box using log book and VMS data. A potentially useful model summarising migration patterns of plaice was also described.

Conclusions

This Chapter shows that the Plaice Box, initiated to reduce the bycatch and discarding of undersized plaice and improve the exploitation, has not led to the expected increase in Yield and Spawning Stock Biomass. Previous scientific evaluations of the efficacy have been unable to explain the causal processes behind the observed changes in distribution and growth rate of undersized plaice. This has resulted in a situation where the different stakeholders have opposing views on the efficacy of the Plaice Box and on the need for possible amendments.

It should be noted that no representatives of the coastal fisheries participated, and it may be expected that these groups have different views as they may have benefited as the plaice box became an exclusive fishing areas of vessels below 221 kW.

Chapter 3. Theoretical framework

The Plaice Box (PB) was established as a technical fisheries management measure to reduce the discarding of undersized plaice and improve recruitment and increase the spawning stock (ICES, 1987). Because the population dynamics is also affected by a multitude of processes acting both inside and outside the PB, its effectiveness cannot be assessed from the observed trends in recruitment or spawning stock biomass.

For a scientific assessment of the effectiveness, a quantitative study of the key processes affecting plaice recruitment is required (see Figure 3.1). In previous evaluations, changes in growth and distribution were reported to have influenced the effectiveness of the PB (Grift et al. 2004; Pastoors, A. D. Rijnsdorp, and van Beek 2000). Changes in growth and distribution will affect the protection offered by the PB. A decrease in growth rate will prolong the period during which plaice are exposed to discard mortality, while a decrease in the proportion of undersized plaice residing in the PB will reduce the protection. The key question to address is whether the observed change in growth and distribution area were (i) caused by the establishment of the PB or (ii) caused by changes in the environment.

The establishment of the PB may have triggered density-dependent feed back mechanisms (Hixon and Jones 2005; Beverton and Holt 1957) that may have reduced its effectiveness. If the establishment of the PB led to an increase in fish density this in turn may have given rise to density-dependent reductions in growth rate (Lorenzen and Enberg 2002), density-dependent increases in natural mortality (Modin and Pihl 1994) or density-dependent changes in distribution (Shepherd and Litvak 2004). Density-dependent reductions in growth rate may occur at the level of plaice, but may also occur at the ecosystem level. All of these factors may reduce the effect of the reduction in discard mortality.

Another process that may influence the effectiveness of the PB is the potential impact of bottom trawling on the food of plaice. Such a mechanism has been suggested by fishers as the most important reason for the perceived failure of the PB management measure. They maintain that the seabed must be ploughed in order to speed up the growth of benthos edible to plaice. Recent simulations with a complex model (Hiddink et al. 2008) have suggested that such an effect is not impossible. The observed increase in growth rate of sole and plaice in the 1960s and 1970s has bee.n suggested to be partly related to an increase in beam trawling (De Veen 1978; Rijnsdorp and Beek 1991). Bottom trawling imposes an additional mortality on benthos, and impacts the biomass and species composition as well as competition among invertebrates (Jennings and Kaiser 1998). Based on general ecological theory one would expect that larger long-lived species would be negatively affected by bottom trawling, while small opportunistic species would benefit due to a reduction of competition or predation by larger benthic organisms. Since plaice feed on small opportunistic species, a reduction in bottom trawling within the PB may reduce the food for plaice relative to areas outside the PB (Hiddink, A. D. Rijnsdorp, and Piet 2008) and may explain the offshore movement of undersized plaice to habitats outside the PB (Van Keeken et al. 2007.).

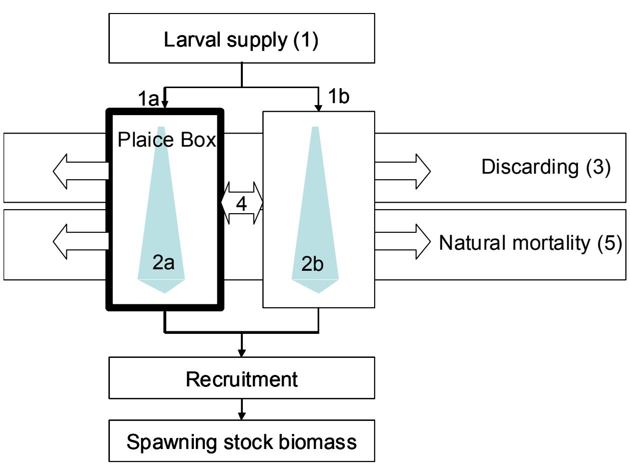


Figure 3.1. Processes affecting the number of plaice that recruit to the spawning stock (modified from Pastoors et al., 2000). A cohort starts with the larval supply of number of individuals that survive the pelagic egg and larval phase and settle on the nursery grounds inside (1a) and outside the Plaice Box (1b). The duration of their discard phase is affected by the growth rate (2), which may be affected by density-dependent processes and differ inside (2a) and outside (2b) the PB. The discard mortality rate will depend on the fishing effort (3) inside and outside the

PB and will be affected by the relative larval supply to the two areas (1a, 1b) and the movement of undersized plaice between the PB and the areas outside the PB (4). Finally, recruitment will be affected by natural mortality processes (5). In the assessment of the effectiveness of the PB, the key question to address is whether the establishment of the PB has resulted in a change in growth or distribution, influencing the effectiveness, or whether changes in growth or distribution are caused by changes in the environment which are unrelated to the establishment of the PB.

THEORETICAL BENTHIC PRODUCTION MODEL

The theoretical consequences of a positive feedback of trawling intensity on the productivity of the benthic resource was explored using the simple model outlined below (see Figure 3.1) which distinguishes between two types of benthos of which one is preferred while the other is avoided by fish, and shows that such an effect is possible when the avoided benthos type is more sensitive to trawling (Figure 3.2). In the subsequent plaice box model this will be implemented as a relation between trawling mortality and the productivity of the benthic resource. The model suggests that the trawling disturbance hypothesis advocated by the fishers is at least possible.

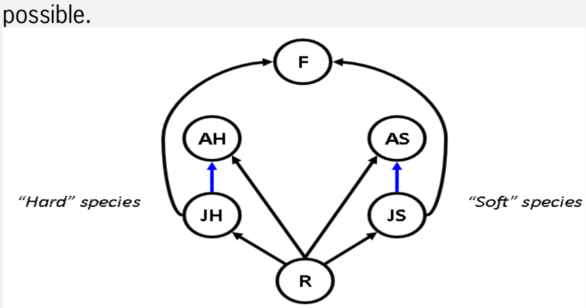


Figure 3.2: Schematic representation of benthos model. Blue arrows indicate ontogenetic processes, black arrows indicate feeding relationships. F=fish, AH and AS are adult hard and soft benthos respectively, JH and JS are hard and soft juvenile benthos. R is the shared resource for the benthos. Fish preferentially feeds on juvenile individuals of the soft benthos species (JS). All benthos groups suffer the same background mortality, except adults of the hard benthos species (AH), which always suffer 20% more mortality, representing their increased sensitivity to trawling.

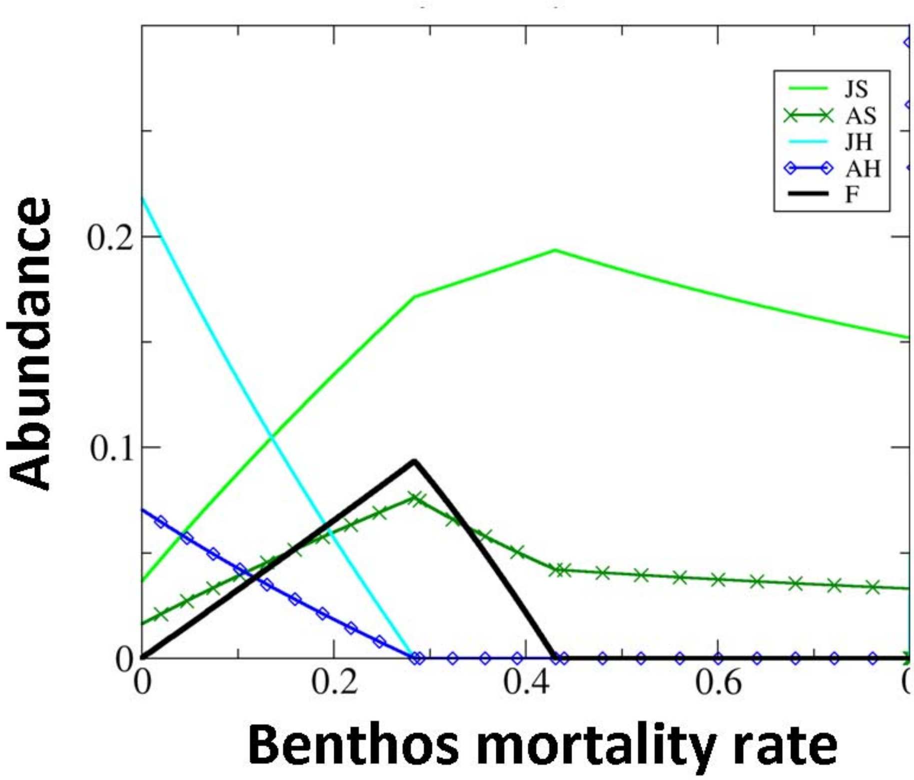


Figure 3.3: Results of the benthos model. Plotted are the equilibrium biomass abundances of the four benthos stages and fish. As benthos mortality increases from low values, so does the abundance of soft benthos species and fish abundance. This increase is due to that more food is available for the soft species, because the hard species decreases strongly in abundance. At high mortality, the hard species is lost from the system and the release from competition mechanism ceases to work. At this value, the increase in fish abundance with benthos mortality is also reversed, leading eventually to the loss of fish from the system. Eventually at very high mortality (not shown in figure), the soft species also goes extinct.

Table 3.1: Equations of the benthos model.

$\frac{dR}{dt} = \delta(R_{\max} - R) - I_{\max}(JS + AS + JH + AH)\frac{R}{H + R}$	(1)
$\frac{dJS}{dt} = \nu(R)^{+} AS + \nu(R)\, JS - \nu(R)^{+}\gamma(R)\, JS - \mu_{JS}\, JS - I_{\max F} F \frac{psJS}{H_F + psJS + (1-ps)JH}$	(2)
$\frac{dAS}{dt} = \nu(R)AS - \nu(R)^{+} AS + \nu(R)^{+}\gamma(R)\, JS - \mu AS$	(3)
$\frac{dJH}{dt} = \nu(R)^{+} AH + \nu(R)\, JH - \nu(R)^{+}\gamma(R)\, JH - \mu_{JH}\, JH - I_{\max F} F \frac{(1-ps)JH}{H_F + psJS + (1-ps)JH}$	(4)
$\frac{dAH}{dt} = \nu(R)AH - \nu(R)^{+} AH + \nu(R)^{+}\gamma(R)\, JH - \mu AH$	(5)
$\frac{dF}{dt} = eI_{\max F} F \frac{(psJS + (1-ps)JH)}{H_F + psJS + (1-ps)JH} - \mu_F F$	(6)
$\nu(R) = \sigma I_{\max} \frac{R}{1+R} - T$ and $\nu^{+}(R) = \max[\nu(R), 0]$	(7)
$\gamma_i(R) = \frac{1 - \frac{\mu_i}{\nu(R)}}{1 - z^{1 - \frac{\mu_i}{\nu(R)}}}$ Where $i \in \{JS, JH\}$ and μJH=tf μ.	(8)

Table 3.2: Parameter values used in the model in Figure 8 to obtain results shown in Figure 9.

Description	Symbol	Default value
Resource growth rate	δ	0.1
Resource carrying capacity	Rmax	5
Ratio biomass at birth/biomass at maturation	z	0.01
Biomass-specific maximum intake rate benthos	Imax	13
Handling time of Benthic species	H	1
Biomass-specific respiration rate	T	1
Mortality of JS, AS, and AH	μ	0.1
Trawling mortality scaling factor for JH	tf	1.2
Fish preference for JS	ps	0.7
Biomass-specific maximum intake rate fish	ImaxF	2
Fish assimilation fraction	e	0.6
Fish background mortality	μB	0.1
Trawling mortality scaling factor fish	g	0.1
Static fish density in case of small MPA	F	0.1

The challenge for the assessment of the effectiveness of the PB is to quantitatively disentangle the effects of the establishment of the PB on the feed-back mechanisms from the changes due to the changes in the environment which are unrelated to the establishment of the PB. Factors that may influence the population dynamics and distribution of plaice, but are not directly related to the establishment of the PB, are the larval supply (survival of pelagic egg and larval stages and transport success between offshore spawning grounds and coastal nursery grounds: (R. J. H. Beverton and Iles 1992; H. W van der Veer et al. 2009; Henk W. van der Veer et al. 2000), abundance and distribution of food (eutrophication, ocean climate) and predators. Particular attention will be given to the influence of the increase in sea surface temperature observed since the late 1980s, and the decrease in eutrophication. Although the lack of reference areas has been recognised as a major impediment of the assessment (Pastoors et al. 2000; Grift et al. 2004), a comparison of changes among areas in the southeastern North Sea may be used as a proxy. Because the establishment of the PB did not change the management within the 12 nautical mile zone, any changes observed within the 12 nm zone cannot be directly caused by the establishment of the PB.

Conclusion

The scientific assessment of the efficiency of the PB is focused on a study of key processes that are affected by the establishment of the PB (Figure 1) with particular emphasis on the feed-back mechanisms related to the PB establishment. The two hypothesis investigated are:

- Trawling increases either the availability of food or the general productivity of the entire benthos. (This theory is popular with the fishing industry).
- Changes in climate. Water temperature has increased forcing the younger plaice further offshore. There may have been other changes. Perhaps the input of nutrients (nitrates and phosphates) have changed substantially which can affect the primary production in the area.

To summarise, the critical question is: "Are changes in the distribution of undersize plaice due to changes in commercial fishing or the environment ? In the proposal we promised to examine biological (density-dependence, fishing effects on benthos, response of fish to fishing) and fisheries (investment in coastal fleets). We have now compiled data on all these factors and we analyse them in various ways in the remainder of the current report. Data-based, regression approaches described allow us to potentially split and quantify (simultaneously) the effects of trawling, food availability, abundance of plaice the year before, environmental factors such as temperature, and the abundance of conspecific competitors (density dependence). This is done in the context of growth of plaice in Chapter 6 and in the context of numbers of plaice in Chapter 9. The lack of any clear 'experimental design hampers our ability to derive truly 'confirmatory statistics' but detailed qualitative observations of this sort do enable various hypotheses to be favoured over other ones. Mathematical models developed by Tobias Kooten (see Chapters 3 and 9) also help us to crystallize our thinking and enable us to deduce mechanisms that may or may not be possible.

Chapter 4 Fishing effort and discards

Effort and landings from logbooks.

Introduction

In 1994, an assessment report on the ecological effects of the Plaice Box was published (Grift et al., 2004). Fully logbook based effort estimates are only available since 1995. For the time period until 1989, effort estimates were reconstructed in previous assessment reports. For the period 1990 to 1995, figures were provided including estimates for German beam trawlers, for which logbooks became mandatory after 1995 were included.
·Beam trawl fishing effort (kW days at sea) in the plaice box area has decreased stepwise since the establishment of the box in 1989 and the full closure since 1994 to ca 35 % and ca 10%, respectively of the estimated pre-closure level.

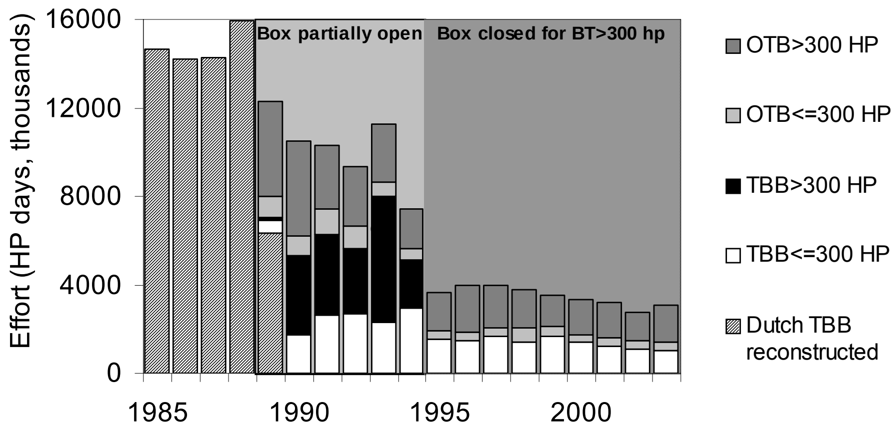


Figure 4.1.1 *Total effort (HP days, thousands) of beam trawlers (TBB) and otter trawlers (OTB) in the Plaice Box. Data from Germany, Denmark, England and the Netherlands combined. The effort in the years 1985-1989 represent data of the Dutch beam trawl fleet only, that was reconstructed. Total effort before 1989 was thus higher then presented here because data from beam trawlers of other countries and otter trawlers of all countries are lacking from that period. (From Grift et al. 2004)*

Methodological limitations

Partners submitted EU logbook data for Denmark, Germany and The Netherlands. These data consist of skipper's logbook reports and detail the landings by species together with an approximation of the fishing effort made on each trip in each ICES statistical rectangle. Log book data are not available at a finer spatial resolution. Some statistical rectangles are cut by plaice box borders and Table 4.1.1 below shows the protocol we used for partitioning the data. If, for example, we have effort or landings data for 35F4 (plaice box border runs through it) for a boat under 300hp we assume that 75% of the data were collected inside the plaice box and 25% outside. For > 300hp vessels we assume that the data apply to outside the PB. The VMS data lends support to this protocol.
However, in some situations these approximationsdue to unexplained catches are incorrect. It appeared already in the previous evaluation (Grift et a. 2004) that

(a) landings and effort are reported from inside the PB for vessels >221 kW not applying to the derogations from EC 850/98 if logbooks are taken as source of information. One source of error might be misreporting of ICES statistical rectangles.
(b) Under certain conditions EC 850/98 allows for derogations from the exclusion of larger vessels. However, it is not mandatory to report these derogations in the logbooks.

In these cases, the respective figures are highlighted and interpreted with respect to EC 850/98. It appears from the analysis in this chapter, that unexplained ctaches account for ca. 5 % of catches (Figures for effort might differ, but are likely subject to calculation of effort, see example for Dutch fleet). With this error margin regarded acceptable, it was decided not to discard or reassign these figures.

Table 4.1.1. ICES statistical rectangles with at least some part inside the plaice box.

Statistical Rectangle	Proportion inside	Proportion outside
35F4	0.75	0.25
35F5	1.00	0.00
36F5	0.60	0.40
35F6	1.00	0.00
36F6	1.00	0.00
35F7	1.00	0.00
36F7	1.00	0.00
37F7	0.50	0.50
38F7	1.00	0.00
39F7	0.75	0.25
40F7	0.75	0.25
41F7	0.75	0.25
42F7	0.75	0.25
35F8	1.00	0.00
36F8	1.00	0.00
37F8	1.00	0.00
38F8	1.00	0.00
39F8	1.00	0.00
40F8	0.75	0.25
41F8	0.75	0.25
42F8	1.00	0.00

Time series of the fishing effort and landings in and outside the PB by fishing gear and country

Initially we opted for a complex set of métier descriptions (see Interim Report) but after discussions at the mid-term workshop in October we realized that there were simply too many for sensible summaries to be made. The original metiers were, therefore, simplified to the following:

- Beam trawlers working 16-31mm meshes;
- Beam trawlers working 80-99mm mesh;
- Beam trawlers working > 99mm mesh;
- Otter trawlers working 80-99mm mesh;
- Otter trawlers working > 99mm mesh;
- Gill or trammel netters and 'Others'.

These categories were further split into those boats with engine powers <= 300hp (<=221 kW) and those > 300hp (> 221 kW).

Denmark

Table 4.1.2. Fishing effort (kwhours) by Danish vessels in the PB in 2008. P= percentage of small power category on total effort.

	<=221kW	>221kW	P
BEAM.>100	24653	0.00	100
BEAM.16-31	15414689	0.00	100
GILL-TRAMMEL	4777740	599085	89
OTHER	3833342	3785576	50

OTTER.>100	2510191	19653	99
OTTER.80-99	12040	0.00	100

Of the Danish fleets, the shrimpers (BEAM.16-31) with <=221kW engine capacity were by far the most important category (15414689 kwhours in 2008) impacting the PB. The gill and trammel netters were the next most important (Table 4.12). Large changes have taken place in the effort by this fleet with 3.6 million kWhrs in 1987, peaking at nearly 25 million kWhours in 1994, followed by a steady reduction to 4.8 million kWh in 2008.
There was also some fishing effort by vessels > 221kW although these were not landing plaice (see Table 4.1.2). Plaice landings by Danish boats were negligible inside the PB, at 1245t in total for 2008 (Table 4.1.3).

Table 4.1.3. Plaice landings (tons) by Danish vessels in the PB in 2008. P= percentage of small power category on total landings.

	<=221kW	>221kW	P
BEAM.>100	0.00	0.00	NA
GILL-TRAMMEL	498	0.00	100
OTHER	81	0.00	100
OTTER.>100	668	0.00	100
OTTER.80-99	0.10	0.00	100

Table 4.1.4. Fishing effort (kwhours) by Danish vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	0.00	9605105	0.00
BEAM.16-31	2094299	NA	NA
GILL-TRAMMEL	7833164	6733963	0.54
OTHER	6571537	111971277	0.06
OTTER.>100	5968545	75157548	0.07
OTTER.80-99	1139965	20902054	0.05

Outside the PB Danish fleets <= 221kW also exerted some fishing effort, the most important of these being the 'GILL-TRAMMEL' category. In terms of plaice landings by Denmark outside the PB both power categories were similar when summed over all métiers with 5039t landed by the smaller vessels and 5537t by the larger ones (Tables 4.1.4; 4.1.5) .

Table 4.1.5. Plaice landings (tonnes) by Danish vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	NA	1050	NA
GILL-TRAMMEL	1193	241	0.83
OTHER	2078	695	0.75
OTTER.>100	1702	2699	0.39
OTTER.80-99	66	852	0.07

Figure 4.1.2: Trends in Danish landings (tonnes) of plaice by static netters and otter trawlers (>100) in and out of the PB 1987-2008. Both kW categories are designated.

In Figure 4.1.2 we have plotted the landings of plaice by the most important métiers (GILL.TRAMMEL and OTTER > 100) recorded in the Danish logbook data between 1987 and 2008. Overall the trends are rather similar both in and outside the PB for both métiers. Inside the PB there was a large increase in plaice landings between 1987 which peaked in 1994. After the PB was completely closed to large beam trawlers, landings of plaice declined rose again in the early 2000s and have since fallen. Interestingly these trends are seen both inside and outside the PB and in the two most important Danish métiers in terms of plaice landings (gill.trammel and otter > 100).

Germany

The effort and landings for beam and otter trawlers > 221 kW is likely due to misreporting. For otter trawlers, likely 1 day of fishing is misreported, for beam trawlers ca 5 days.

Table 4.1.6. Fishing effort (kwhours) by German vessels in the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	217585	NA	NA
BEAM.16-31	81593062	4480	1.00
BEAM.80-99	1007000	135304	0.88
GILL-TRAMMEL	815555	0	1.00
OTHER	1096690	2792313	0.28
OTTER.>100	441012	0.00	1.00
OTTER.80-99	201941	10720	0.95

Although fishing effort by German vessels was considerable in the PB (85372846 kW hours in 2008 versus 26572656 kwhours by the combined Danish fleet) the corresponding landings of plaice were very low (Tables 4.1.6 and 4.1.7) with only 202t landed in total.

Table 4.1.7. Plaice landings (tonnes) by German vessels in the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	38	NA	NA
BEAM.16-31	0.30	NA	NA
BEAM.80-99	14	0.00	1.00
GILL-TRAMMEL	2	NA	NA
OTHER	70	0.00	1.00
OTTER.>100	64	0.00	1.00
OTTER.80-99	14	0.00	1.00

Table 4.1.8. Fishing effort (kwhours) by German vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	111695	0.00	1.00
BEAM.16-31	3668541	0.00	1.00
BEAM.80-99	743751	25608313	0.03
GILL-TRAMMEL	1630975	0.00	1.00
OTHER	760498	6227809	0.11
OTTER.>100	3020461	18169835	0.14
OTTER.80-99	3908907	4927859	0.44

Table 4.1.9. Plaice landings (tonnes) by German vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	18	NA	NA
BEAM.16-31	0.51	NA	NA
BEAM.80-99	29	761	0.04
GILL-TRAMMEL	7	NA	NA
OTHER	37	175	0.17
OTTER.>100	775	254	0.75
OTTER.80-99	464	339	0.58

Outside the PB the most important German fleet in terms of plaice landings were the OTTER > 100mm <= 221kW and BEAM 80-99mm > 221kW (Table 4.1.9). Nevertheless plaice landings were still low, being only 2867t in 2008.

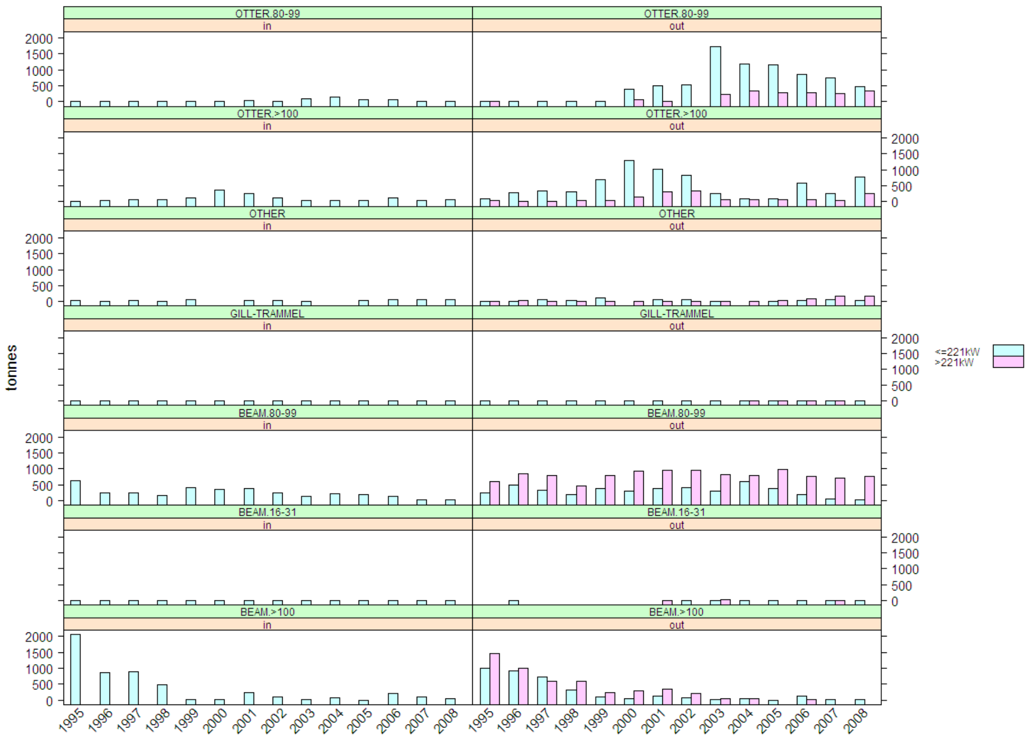


Figure 4.1.3: German plaice landings 1995-2008.

We were only able to follow trends in plaice landings between 1995 and 2008. As was observed above in the Danish data the time trends for all métiers examined were rather similar both inside and outside the PB (see Figure 4.1.3).

The Netherlands

The most important Dutch fleet inside the PB are the small shrimpers (80.1million kWhrs). The PB is currently almost irrelevant to the Dutch fisheries as far as plaice landings are concerned: in 2008 circa 20 000 t of plaice were landed outside the PB next to only *circa* 150t inside (Figure 4.1.4, Tables 4.1.10 to 4.1.13). Recent sole landings inside the PB are also a fraction of those taken outside (see Figure 4.1.5 for <=221kW vessels). Trends in landings of plaice and sole by the most important Dutch exemption (<=221kW) fleets are displayed in Figs. 4.14 and 4.15. These data show that the <=221kW vessels landed proportionally more plaice and sole inside the PB in the past (ie. 1990-1994). Since 1995 when the PB was completely closed to large beam trawlers, landings by the smaller vessels (<=221kW) have fallen steadily in importance relative to landings made outside the PB.

Table 4.1.10. Fishing effort (kwhours) by Dutch vessels in the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	346012	0.00	1.00
BEAM.16-31	80159226	0.00	1.00
BEAM.80-99	1932636	3336167	0.37
GILL-TRAMMEL	300145	0.00	1.00
OTHER	101346	1991494	0.05
OTTER.>100	152354	412729	0.27
OTTER.80-99	90437	13997	0.87

Table 4.1.11. Plaice landings (tonnes) by Dutch vessels in the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	58	0.00	1.00
BEAM.16-31	0.00	NA	NA
BEAM.80-99	55	75	0.43
GILL-TRAMMEL	0.22	NA	NA
OTHER	23	28	0.45
OTTER.>100	7	7	0.50
OTTER.80-99	3	1	0.79

Table 4.1.12. Fishing effort (kwhours) by Dutch vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	699359	18442867	0.04
BEAM.16-31	5056091	423648	0.92
BEAM.80-99	14693578	501262182	0.03
GILL-TRAMMEL	3994903	2765760	0.59
OTHER	1713537	41489848	0.04
OTTER.>100	2608720	16614707	0.14
OTTER.80-99	8311488	22468581	0.27

Table 4.1.13. Plaice landings (tonnes) by Dutch vessels outside the PB in 2008.

	<=221kW	>221kW	P
BEAM.>100	83	1317	0.06
BEAM.16-31	0.27	NA	NA
BEAM.80-99	497	15007	0.03
GILL-TRAMMEL	1	NA	NA
OTHER	0.01	255	0.00
OTTER.>100	212	940	0.18
OTTER.80-99	695	794	0.47

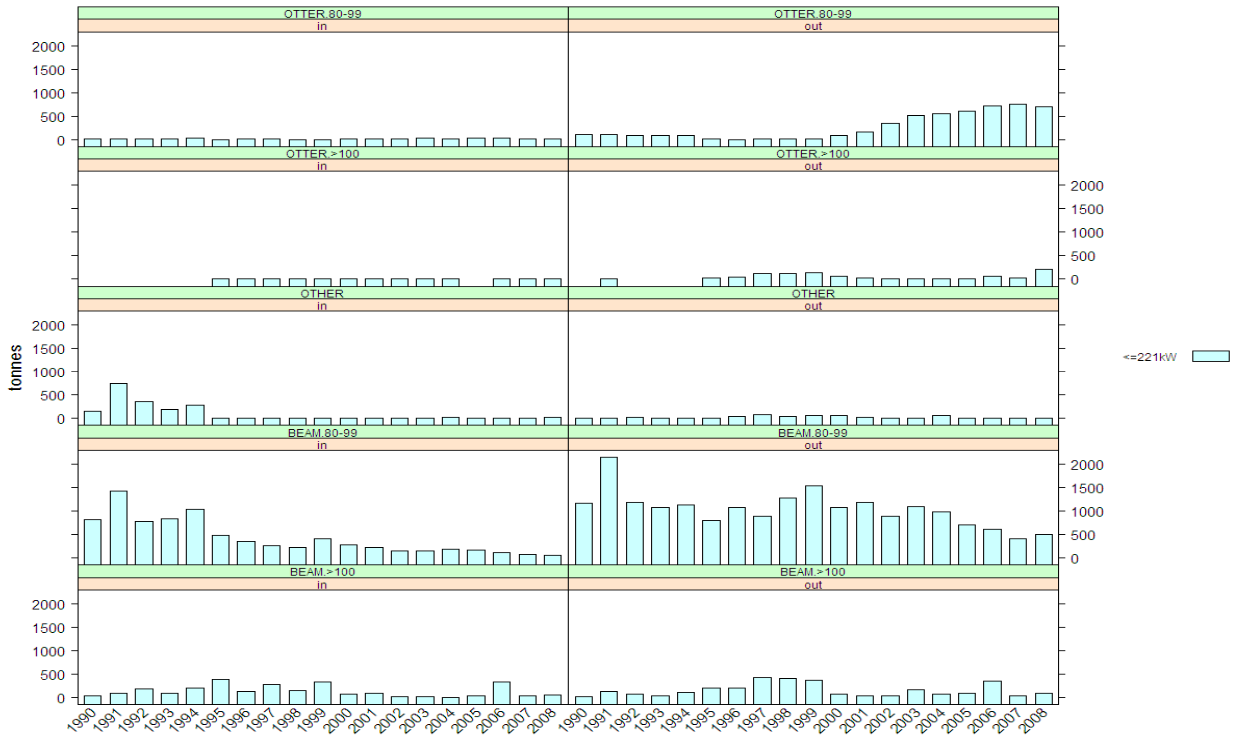


Figure 4.1.4. Dutch plaice landings inside and outside the PB by vessels <= 221kW between 1990-2008.

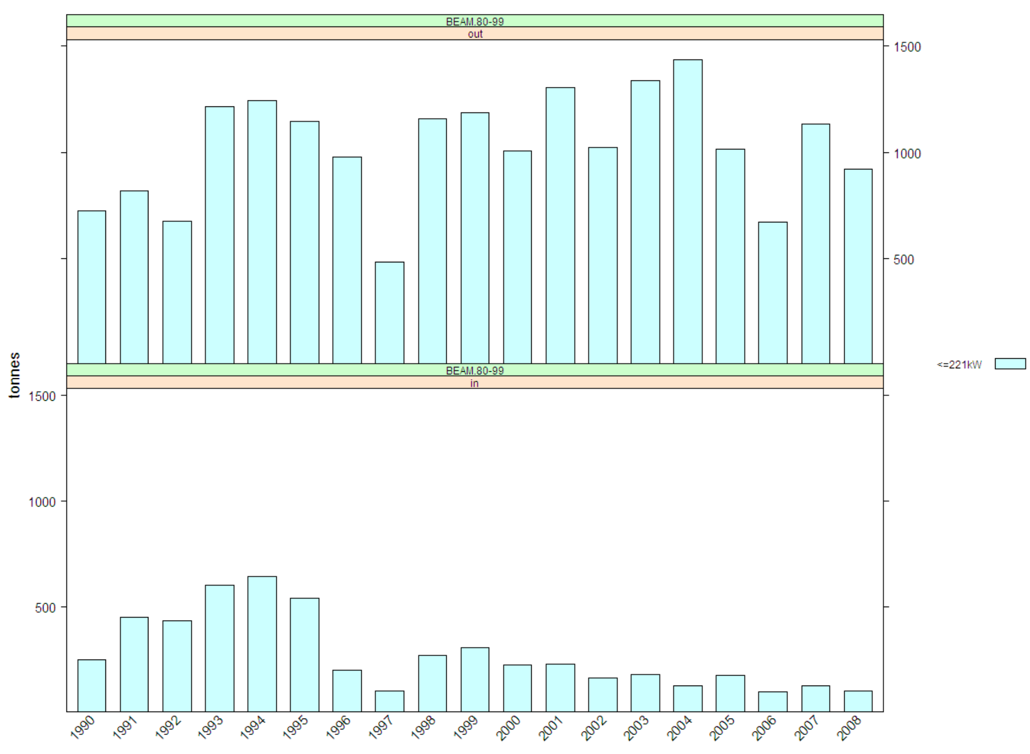


Figure 4.1.5. Dutch sole landings inside and outside the PB by <=221kW beam trawlers with 80-99m mesh between 1990 and 2008.

Combined fishing effort and landings

Fishing effort

We have presented the countries separately above. Danish landings data were available for 1987-2008, German for the period 1995-2008, and Dutch for 1990-2008. Here, we now consider the period 1995 – 2008 for all countries combined. For most métiers both fishing effort and plaice landings decreased between 1995 and 2008 (Figure 4.1.6a,b) for both engine size categories, and both in and outside the PB. The exceptions are BEAM 16-31mm inside the PB which has increased (see shrimp landings in Fig. 4.10), BEAM 80-99mm outside the PB which has been fairly stable and the OTTER 80-99m fleet; the effort and plaice landings by which have increased although its total landings are comparatively low (Figures 4.1.6a,b; 4.18a,b).

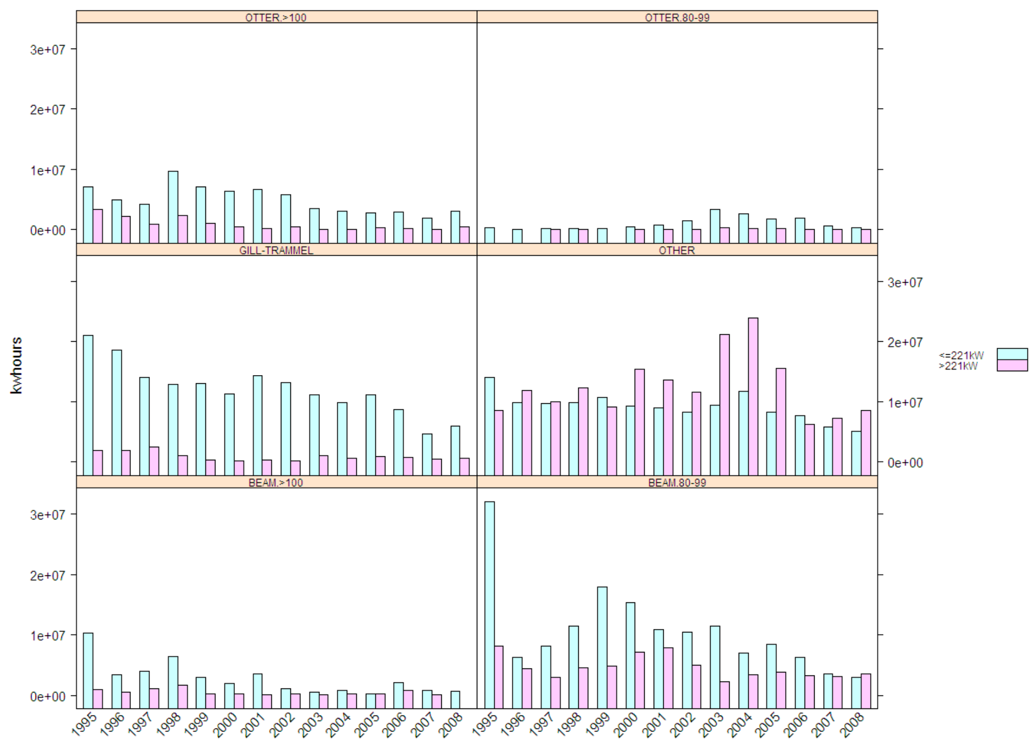


Figure 4.1.6a. Total fishing effort (kWhours) inside the PB by metier between 1995 and 2008. Note: the shrimp fleet is excluded.

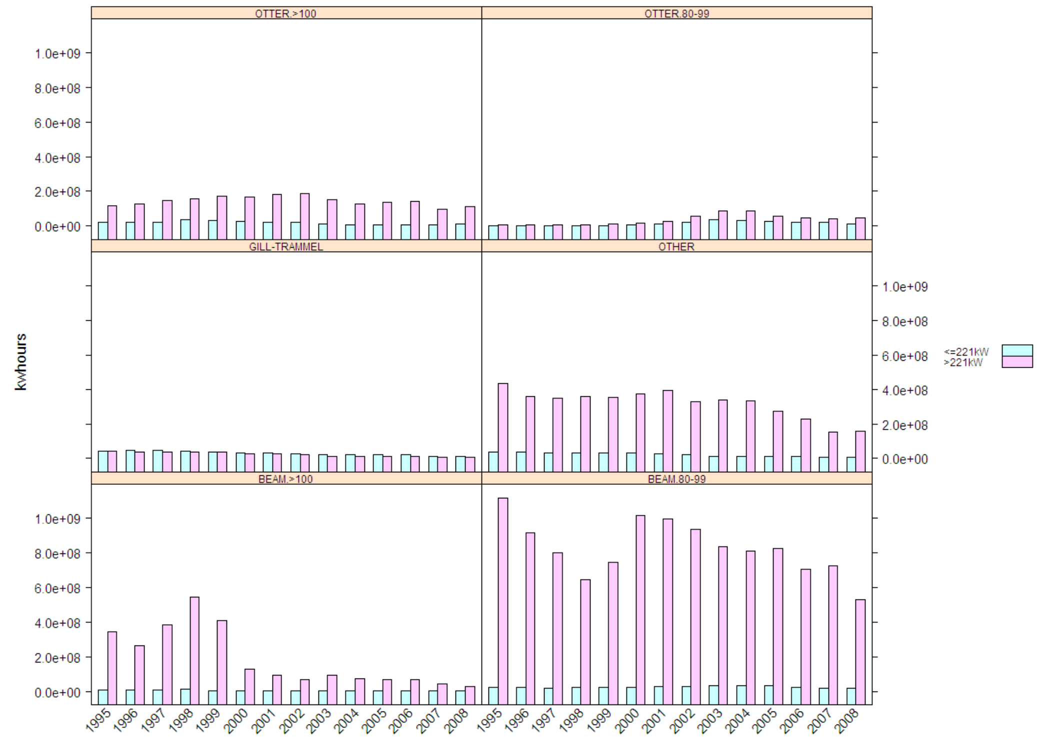


Figure 4.1.6b. Total fishing effort (kWhours) outside the PB by metier between 1995 and 2008. Note: the shrimp fleet is excluded.

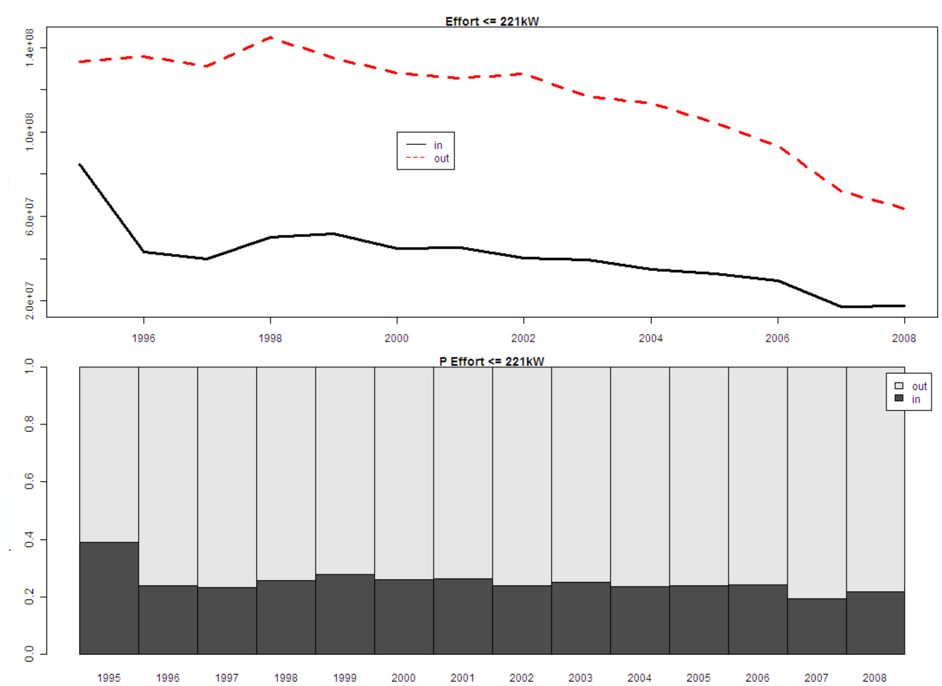


Figure 4.1.7. Top: total effort by all <=221kW vessels except BEAM.16-31 in and out of the plaice box between 1995 and 2008. Bottom: proportion of the effort in and out of the PB.

In Figure 4.1.7 we show how the total fishing effort by the small <=221kW targeting finfish in the PB has decreased relative to the North Sea from ca 30% in the mid 1990s to ca 20% in 2008. Note: effort by the <=221kW fleet targeting shrimps has increased so the overall trend in fishing effort by these smaller boats is strongly positive since the mid 1990s.

Landings

For plaice and sole landings, by far the most important fleets are the large >221kW beam trawlers. Outside the PB, landings of plaice and sole by large beam trawlers (BEAM 80-99, >221kW) were high in 1995 fell to a trough in 1998, increased again to a peak in 2000 and have since declined (Figs. 4.1.8a,b; 4.1.9). For the beam trawlers fishing larger meshes, the temporal patterns are also rather similar with an almost step change in the landings by both species falling from relatively high levels in the period 1995-1999 to lower levels between 2000 and 2008.

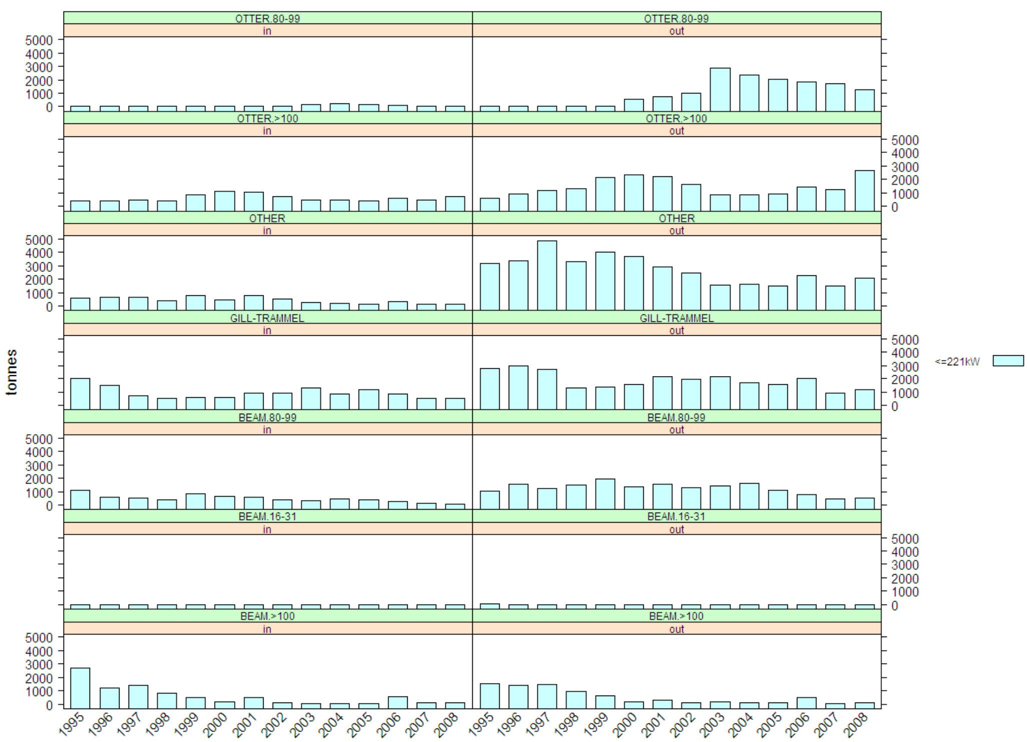


Figure 4.1.8a. Total plaice landings by <=221kW vessels 1995-2008 inside and outside the PB. Note: BEAM.16-31 is not included.

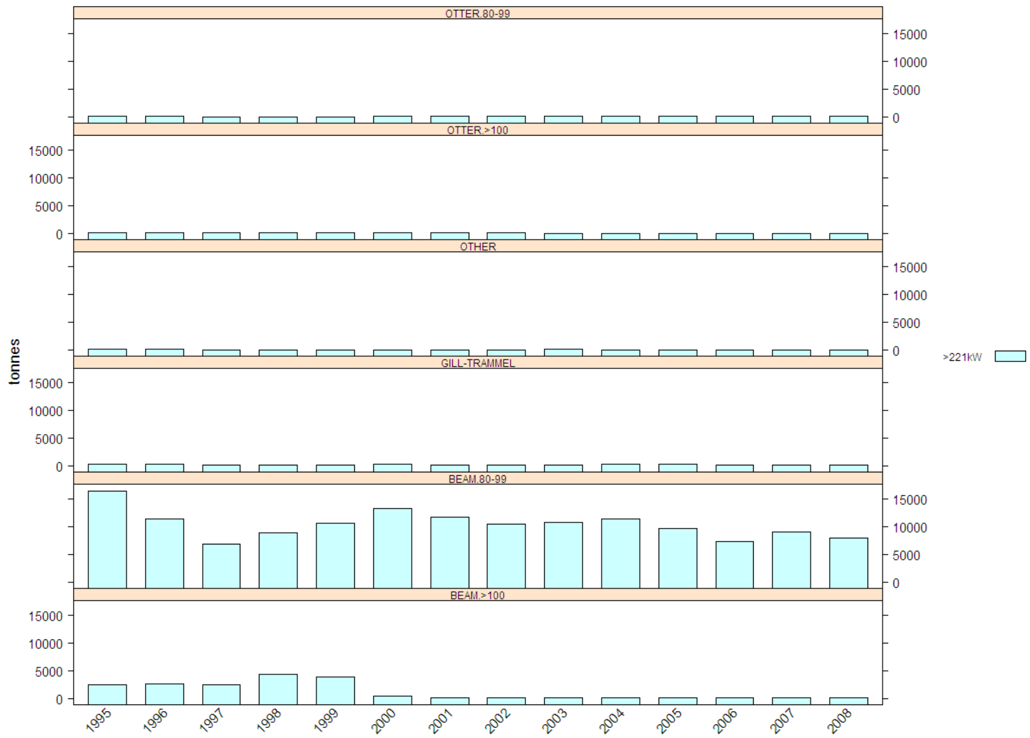


Figure 4.1.8b. Total plaice landings by >221kW vessels 1995-2008 outside the PB. Note: BEAM.16-31 is not included.

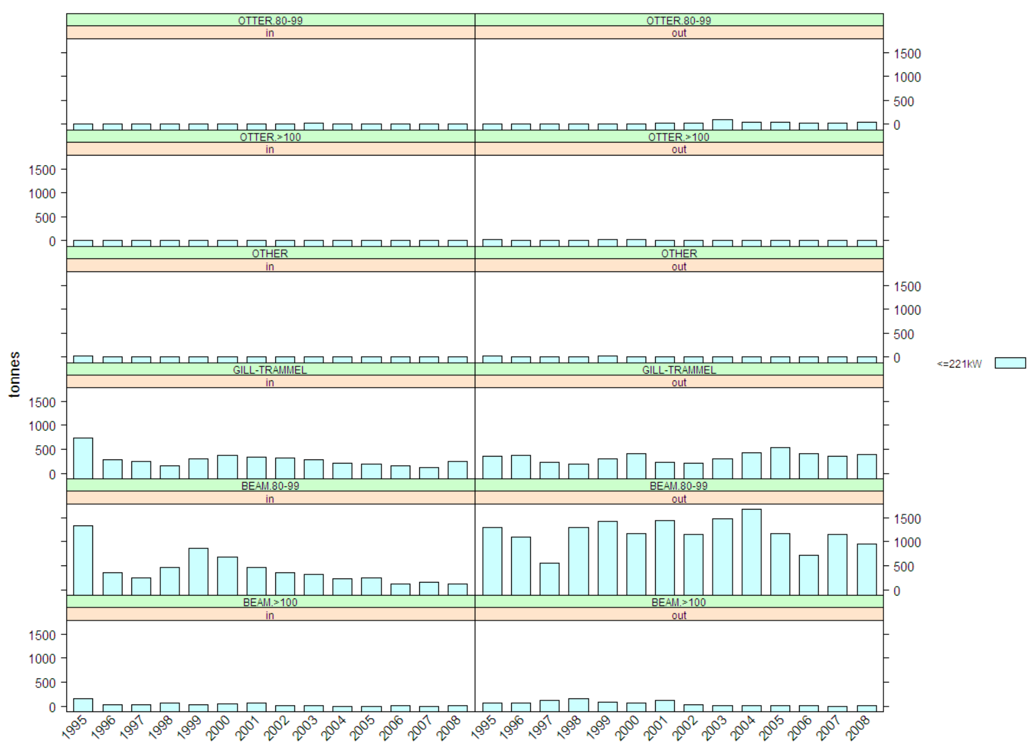


Figure 4.1.9: Total sole landings 1995-2008 by vessels <=221kW inside and outside the PB.

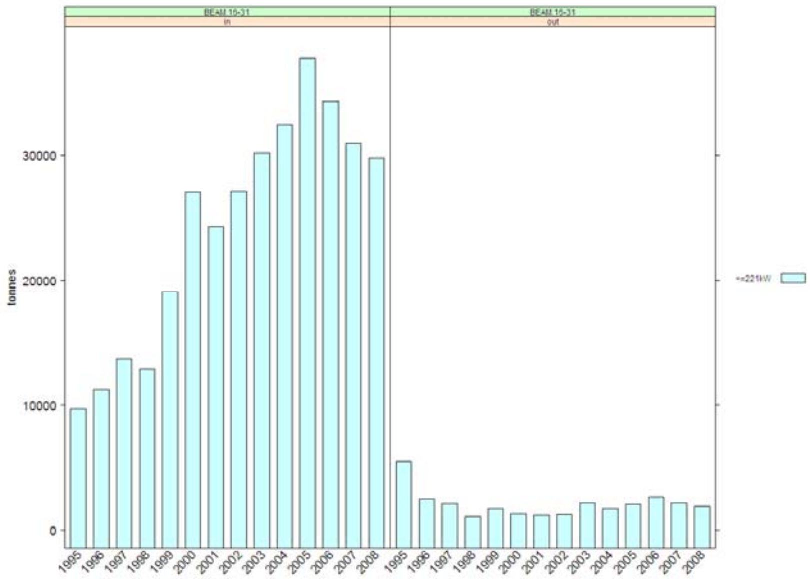


Figure 4.1.10: Total common shrimp landings 1995-2008 by <=221kW inside and outside the PB.

Landings of the common shrimp by small beam trawlers (BEAM.16-31, <=221kW) were much higher inside the PB than outside although the temporal trends were different (4.1.10). Inside the PB shrimp landings rose steadily from about 10 000t in 1995 to ca 35 000t in 2005 since when they have declined to slightly less than 30 000t in 2008. Outside the PB, shrimp landings peaked (5 700 t) in 1995 and have since declined overall: in 2008 they were only 1 934t recorded from outside the PB. Note: recording shrimp landings in logbook data only became mandatory in 2000 and there may, therefore, be inaccuracies and biases in the data we have available prior to that period.

In Table 4.1.14 we show the ratio [landings inside PB/landings outside PB] of landings of plaice, sole and common shrimp by <=221kW vessels for all gears and all countries combined, inside and outside the PB. In 1995 42% of plaice, 56% of sole and 63% of common shrimp were taken inside the PB, but by 2008, only 17% of plaice 21% of sole were being taken there by the small vessels. The relative importance of the PB for catches of plaice and sole by the <=221kW fleet has therefore declined markedly between 1995 and 2008. In common shrimp, however, the relative importance of the PB has increased overall from only 63% in 1995, 81% in 1996 to 94% in 2008.

Table 4.1.14. Proportions of plaice, sole and common shrimp caught inside and outside the PB between 1995 and 2008 by vessels <=221kW.

	Plaice		Sole		Shrimp	
	in	out	in	out	in	out
1995	0.42	0.58	0.56	0.44	0.64	0.36
1996	0.30	0.70	0.29	0.71	0.82	0.18
1997	0.25	0.75	0.36	0.64	0.87	0.13
1998	0.23	0.77	0.29	0.71	0.92	0.08
1999	0.26	0.74	0.39	0.61	0.92	0.08
2000	0.24	0.76	0.40	0.60	0.95	0.05

2001	0.28	0.72	0.33	0.67	0.95	0.05
2002	0.24	0.76	0.33	0.67	0.95	0.05
2003	0.22	0.78	0.25	0.75	0.93	0.07
2004	0.21	0.79	0.18	0.82	0.95	0.05
2005	0.23	0.77	0.20	0.80	0.95	0.05
2006	0.24	0.76	0.20	0.80	0.93	0.07
2007	0.19	0.81	0.16	0.84	0.93	0.07
2008	0.17	0.83	0.21	0.79	0.94	0.06

Spatial patterns of effort, landings and catch based on VMS and logbooks by métier

We also examined maps of fishing effort and landings according to the logbook data. Selected fleets are plotted as an Appendix.

Methods of VMS analysis

Partners submitted EU VMS (vessel monitoring system) data for Denmark, Germany and The Netherlands. Original VMS data consist of the vessel identification number, position, speed and heading. For each position a flag indicating "fishing" or "not fishing" was computed from the speed of each vessel, i.e., a certain range of low speed was labeled "fishing" whereas higher speed and standing still were labeled "not fishing". The position of the boat was then allocated to a 3 times 3 nm miles rectangle (i.e. 100 fine rectangles per ICES rectangle) and the time interval between two positions was summed up to the amount of fishing effort spent in a specific 3 by 3 nm rectangle (hours fishing). Since the time interval between each position can be up to two hours there is a considerable portion of 'unseen' activity by each vessel. The method applied, here, for VMS data analysis takes account of this uncertainty by substituting each registration with a discrete sets of positions with high probability of vessel presence (Fock 2008). This assumption, however, leads to inaccuracies when specific borders are met which may not be passed so that the probability assumption does not hold. For the PB, this may lead to indications of fishing inside the box when actually no fishing inside has taken place, e.g. for vessels > 221 kW. Further, positions with low steaming speed indicating "fishing" action are generated while slowly moving through tidal gullies etc. which is a further inaccuracy of the method. Error for this method to analyse VMS was assessed to be ca 5 % (Fock 2008).

The data were aggregated by year, month, métier (see above) and power class (<=221 kW and >221 kW) so that no individual boat or fisherman may be identified.

Since only part of the VMS data of the Dutch fleet were available for the current study, the Dutch effort per métier and power class data were corrected by the proportion of effort in terms of kWhours covered in the VMS data with the kWhours-effort covered by logbook data (Table 4.2.1). To check the VMS model applied in this analysis, an alternative approach was run by IMARES and results for the Dutch fleet were plotted (AppChpt4.Figures5-7). Results are fully consistent with the model applied (Fig. 4.2.1 ff) and corresponding logbook effort (AppChpt4.Figures 1-4).

Metiers with a catch less than 100 t in 2008 for either target species (plaice, sole or shrimp) were excluded. The métiers with comparably low landings demersal seine fisheries, pelagic trawlers, potters and dredges were all combined into one métier 'OTHER'.

Table 4.2.1.: Proportion of kWhours covered in the dutch VMS data on the kWhours covered by logbook data.

Metier	Power	Year	Ratio vms-logbook
BEAM.>100	>221kW	2005	0.10
BEAM.>100	<=221kW	2005	0.18
BEAM.16-31	<=221kW	2005	0.16
BEAM.80-99	>221kW	2005	0.22
BEAM.80-99	<=221kW	2005	0.39
GILL-TRAMMEL	<=221kW	2005	0.06
OTTER.>100	>221kW	2005	0.57
OTTER.>100	<=221kW	2005	0.28
OTTER.80-99	<=221kW	2005	0.28
OTTER.80-99	>221kW	2005	0.39
BEAM.>100	>221kW	2006	0.37
BEAM.>100	<=221kW	2006	0.30
BEAM.16-31	<=221kW	2006	0.20
BEAM.80-99	>221kW	2006	0.46
BEAM.80-99	<=221kW	2006	0.51
GILL-TRAMMEL	<=221kW	2006	0.16
OTTER.>100	>221kW	2006	0.29
OTTER.>100	<=221kW	2006	0.30
OTTER.80-99	<=221kW	2006	0.34
OTTER.80-99	>221kW	2006	0.38
BEAM.>100	>221kW	2007	0.36
BEAM.>100	<=221kW	2007	0.22
BEAM.16-31	<=221kW	2007	0.22
BEAM.80-99	>221kW	2007	0.50
BEAM.80-99	<=221kW	2007	0.51
GILL-TRAMMEL	<=221kW	2007	0.13
OTTER.>100	>221kW	2007	0.73
OTTER.>100	<=221kW	2007	0.34
OTTER.80-99	<=221kW	2007	0.42
OTTER.80-99	>221kW	2007	0.54
BEAM.>100	>221kW	2008	0.48
BEAM.>100	<=221kW	2008	0.43
BEAM.16-31	<=221kW	2008	0.25
BEAM.16-31	>221kW	2008*	0.06
BEAM.80-99	>221kW	2008	0.54
BEAM.80-99	<=221kW	2008	0.59
GILL-TRAMMEL	<=221kW	2008	0.05
OTTER.>100	>221kW	2008	0.57
OTTER.>100	<=221kW	2008	0.42
OTTER.80-99	<=221kW	2008	0.49
OTTER.80-99	>221kW	2008	0.61

Results of VMS analysis

The fishing effort (hours per year) in the year 2008 per 3 by 3 nm rectangle of the main métiers for each fleet is displayed in Fig 4.2.1. The plots show clearly that some metiers with engine power <=221kW are intensively fishing inside the box (e.g. beam trawls of all countries fishing for shrimps, i.e. Beam 16-31mm <=221kW).

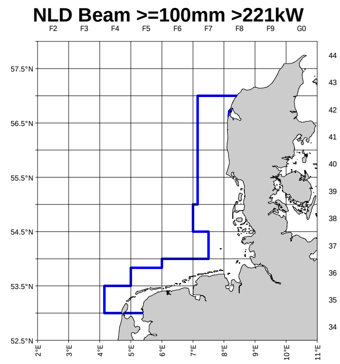
Large vessels (>221kW) affected by EC 850/98 are fishing mainly outside the PB (e.g. beam trawlers and ottertrawlers fishing for plaice and sole, mesh size 80-99mm). Apparent VMS effort for this size class inside the PB is likely due to methodological constraints (see above) and derogations from the regulation for single vessels by means of derating engine power etc. not reported in available data.

Otter boards fishing for sole, plaice and *Nephrops norvegicus* , both <=221kW and >221kW (e.g. Otter80-99mm<=221kW, >221kW) mainly operate outside the PB. A particular focus is on the Nephrops-grounds North of the 'White Bank' (Weiße Bank). Otter trawlers > 100 mm are not regulated by EC 850/98. Utilization patterns for this metier show that only Danish trawlers targeting plaice use the PB to some extent, mainly in the northern part of the investigation area.

Dutch large shrimpers (BEAM.16-31.> 221kW) appeared outside of the PB in southwestern direction. This area outside the PB was also operated by small dutch shrimpers. Accordingly, small Dutch shrimpers spent only a fraction of their effort inside the PB, whereas German and danish shrimpers spend almost their entire effort inside the PB (Fig. 4.2.2+3).

The fishing effort in all years analysed (2005 to 2008) is shown in Fig 4.2.2 to Fig 4.2.4 for the Dutch, German and Danish fleet. Apparent effort for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

Concerning overlap between small and large vessels it appears that there is little overlap between German and Danish shrimpers with large vessels (>221kW). However, small Dutch, German and Danish vessels using otterboards and fishing for sole and plaice are fishing together with large vessels mostly outside the PB and do not seem to be deprived in this area. Also, off the Belgian coast, small Dutch shrimpers (<=221 kW) are fishing in the same coastal areas as large vessels (>221 kW).



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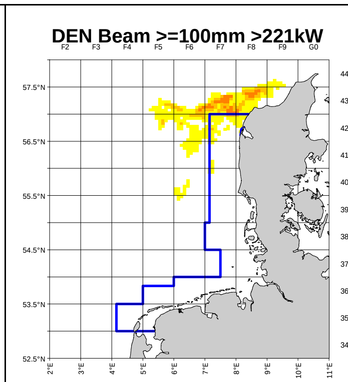

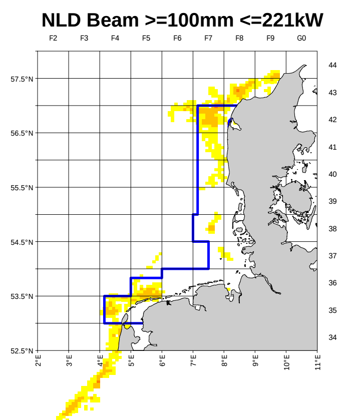

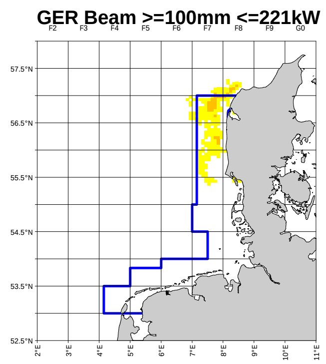

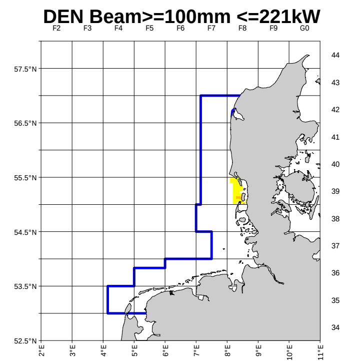

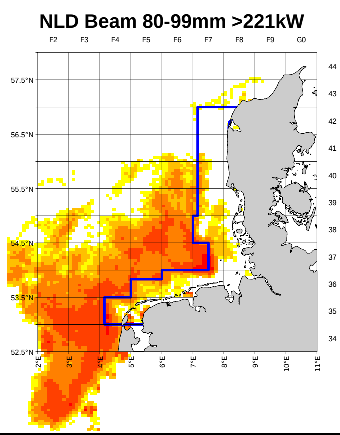

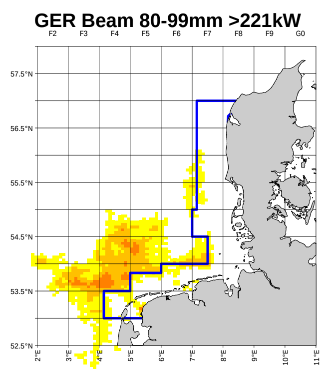

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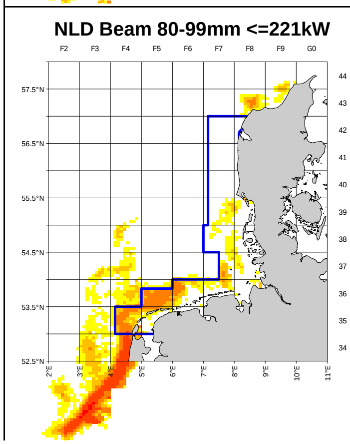

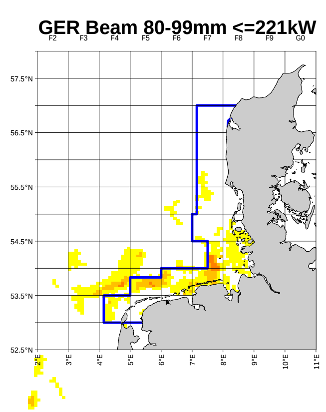

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hours fishing per year

- 0 - 10
- 10 - 50
- 50 - 250
- 250 - 1000
- 1000 - 5000

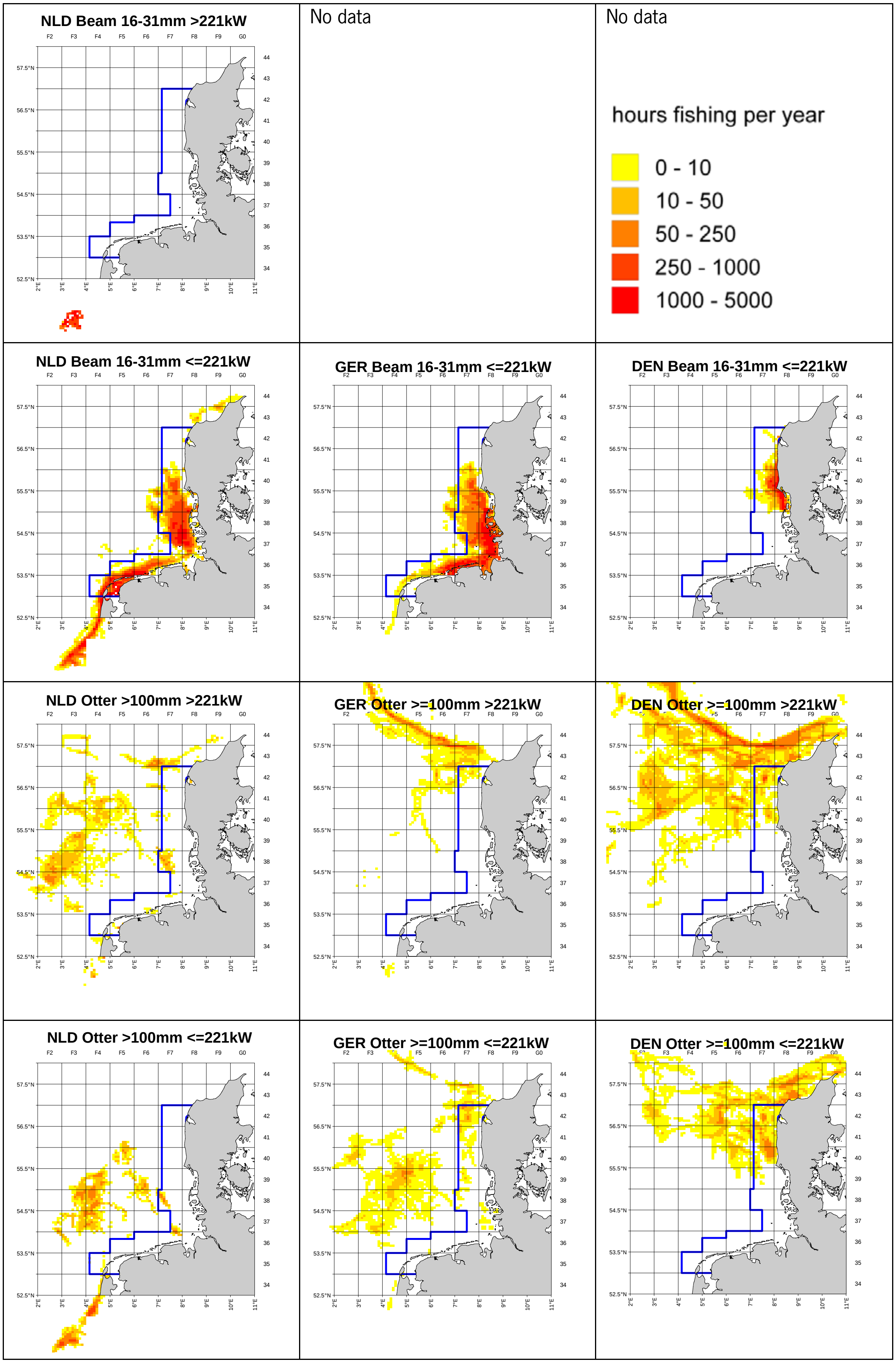


Fig 4.2.1: Fishing effort 2008. Continued.

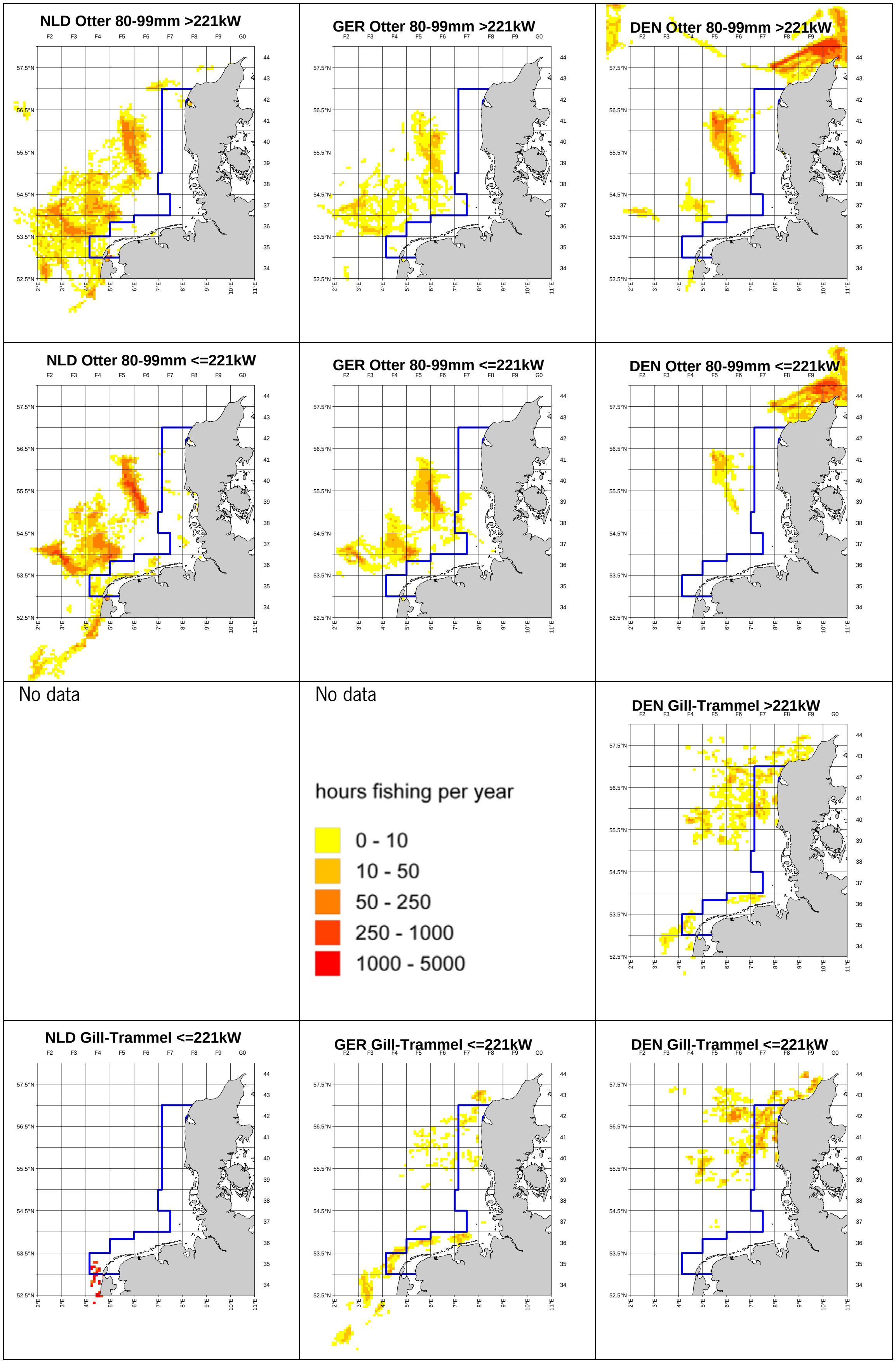


Fig 4.2.1: Fishing effort 2008. Continued.

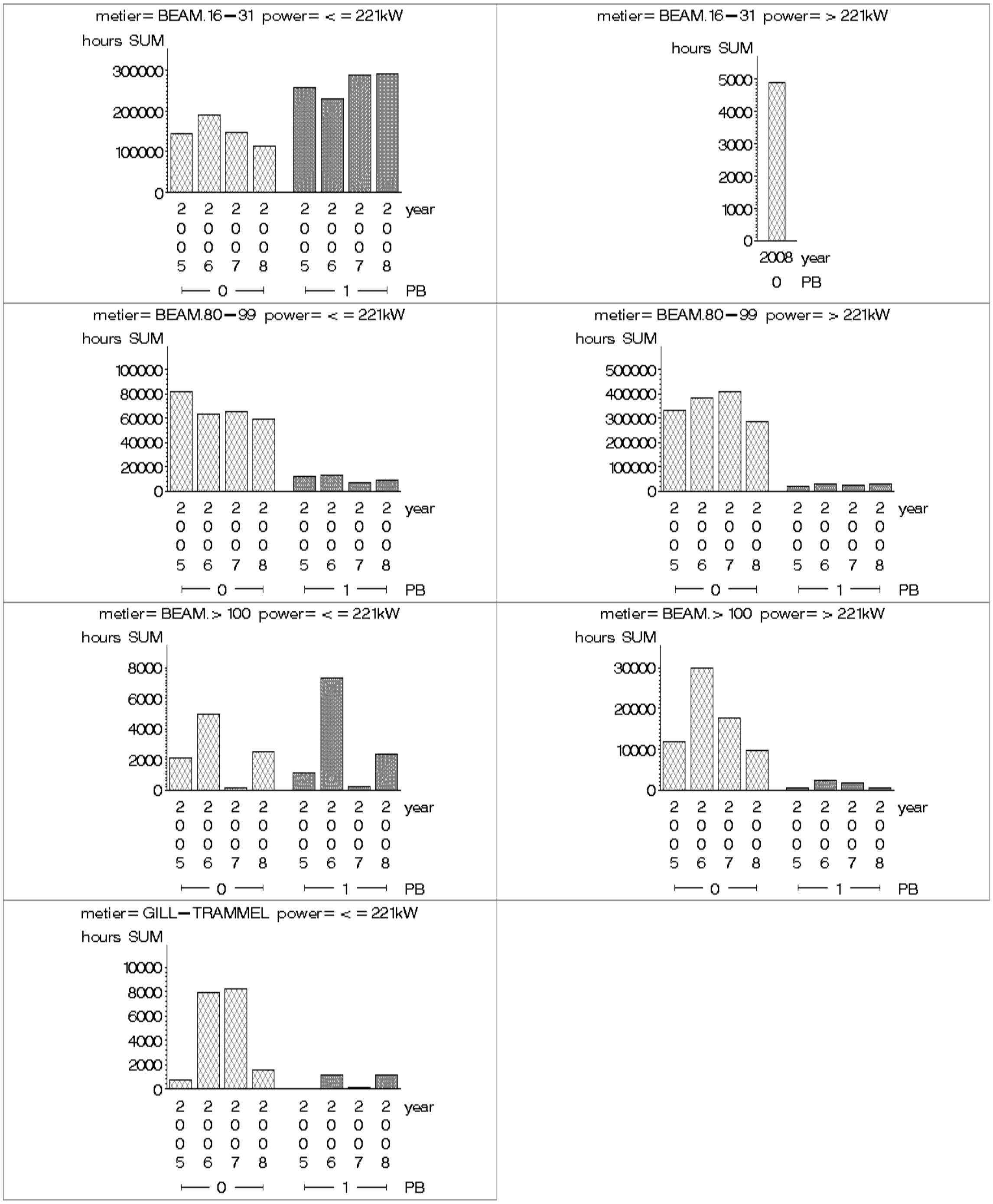


Fig 4.2.2: Dutch effort (hours fishing) by metier and power class for the year 2005 to 2008 outside (bright columns, PB=0) and inside (dark columns, PB=1) the PB calculated from VMS data. Apparent effort for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

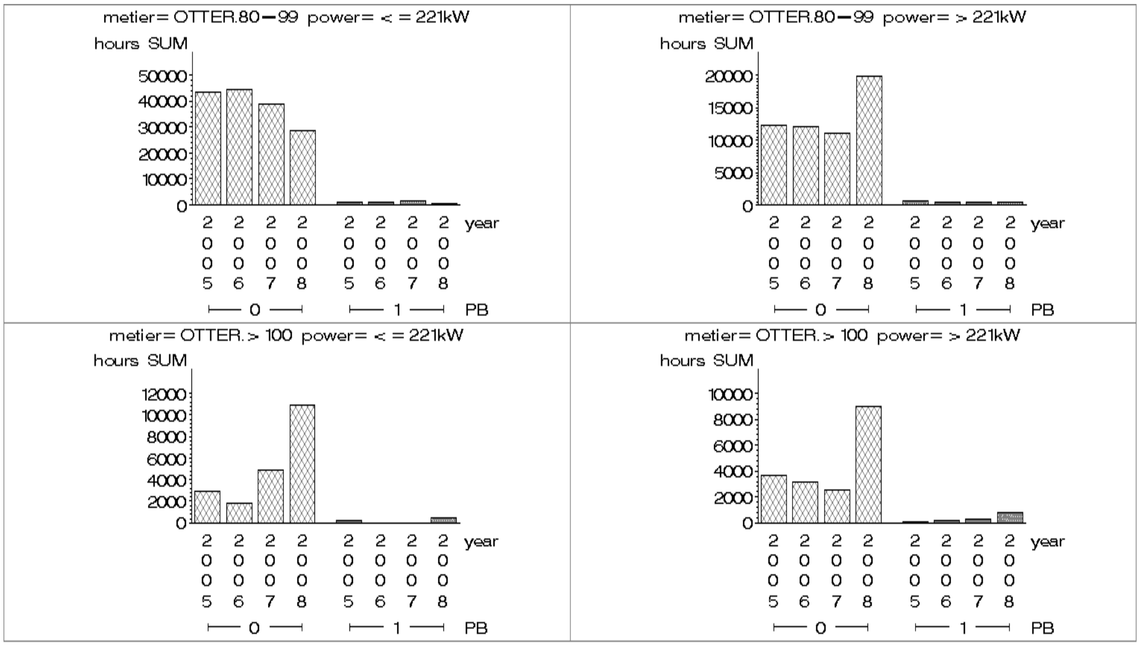


Fig 4.2.2: Dutch effort. Continued.

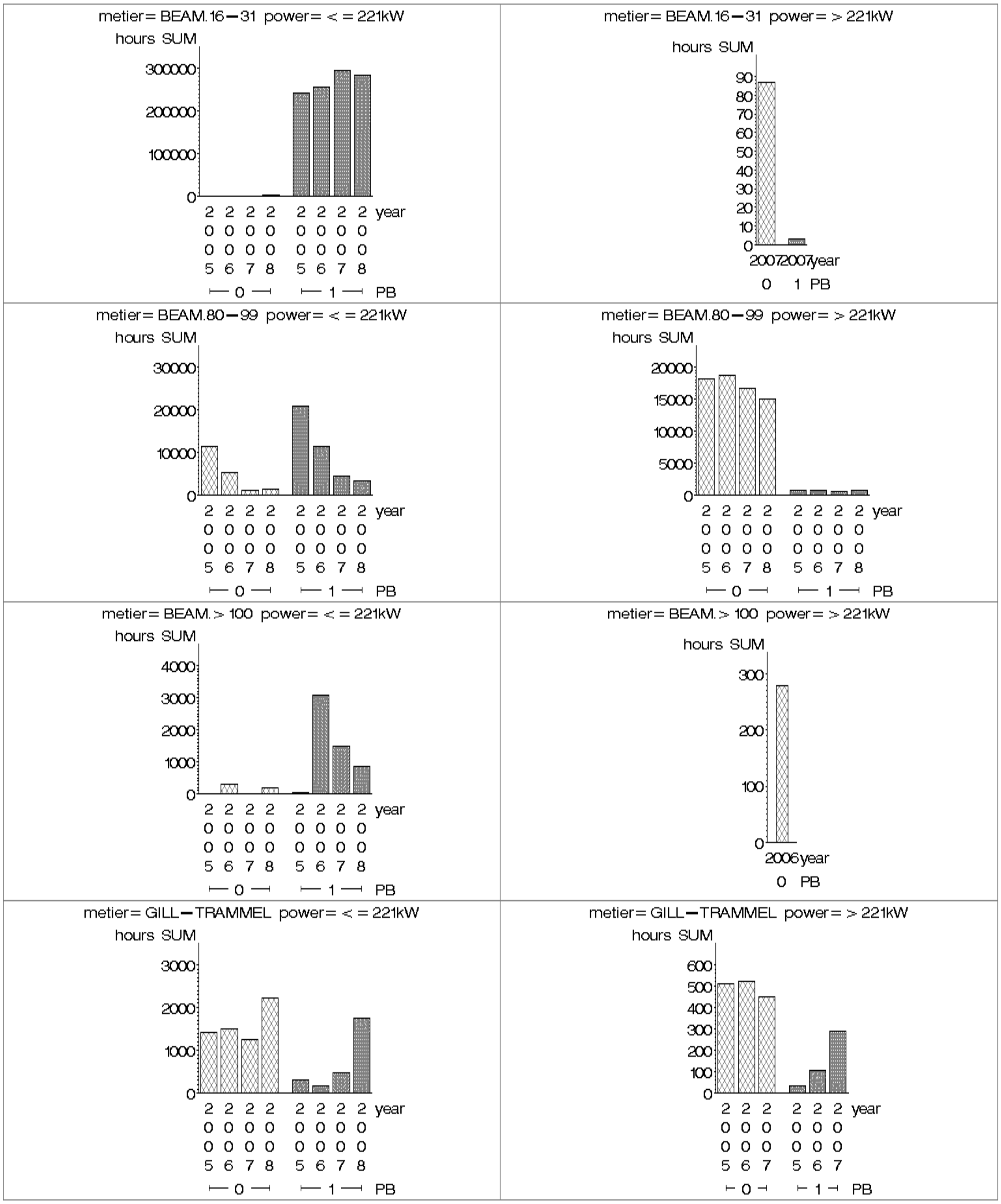


Fig 4.2.3: German effort (hours fishing) by metier and power class for the year 2005 to 2008 outside (bright columns, PB=0) and inside (dark columns, PB=1) the PB calculated from VMS data. Other metiers (OTHER) are potters, dredges, demersal seiners and pelagic trawler. Apparent effort for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

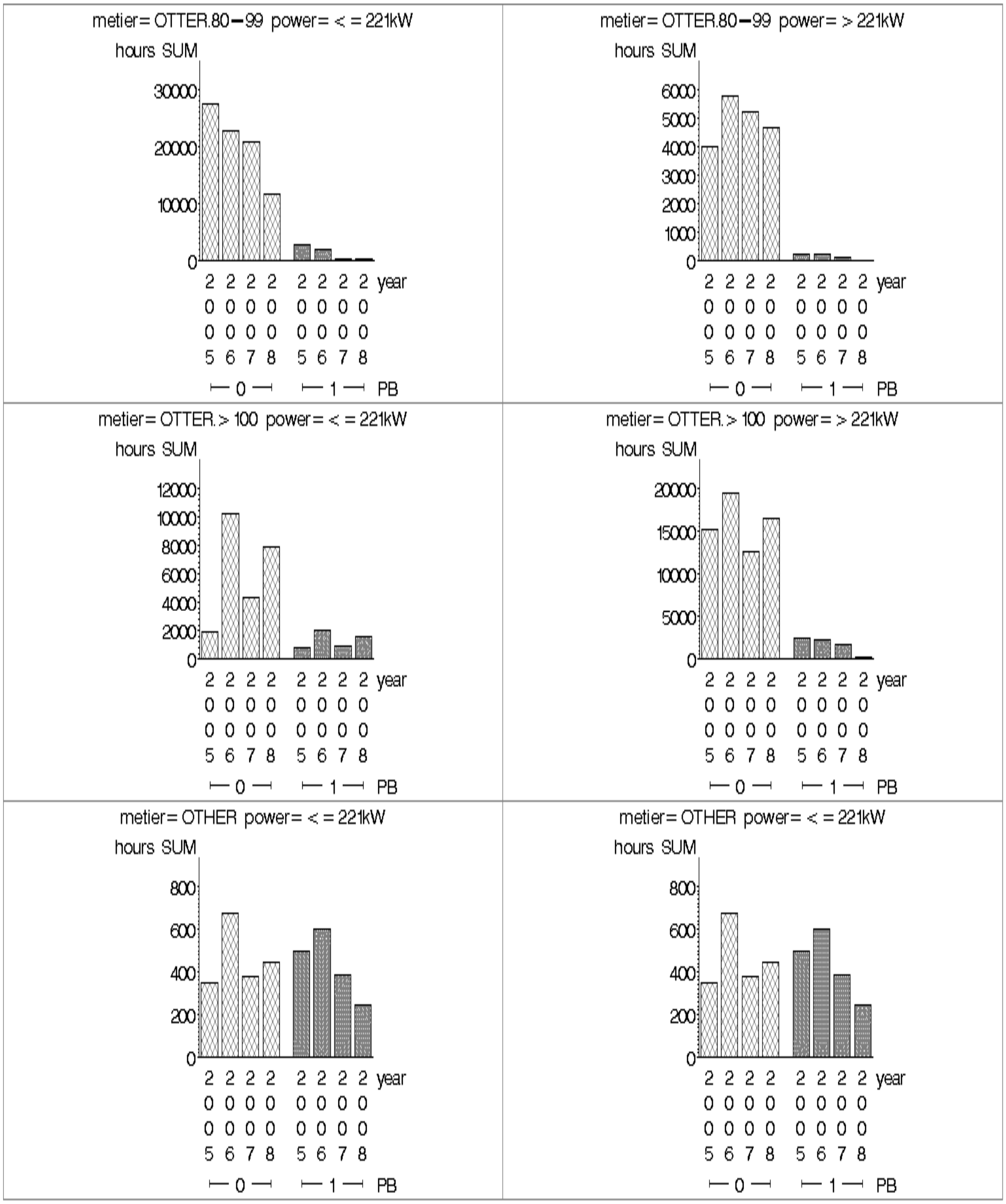


Fig 4.2.3: German effort. Continued.

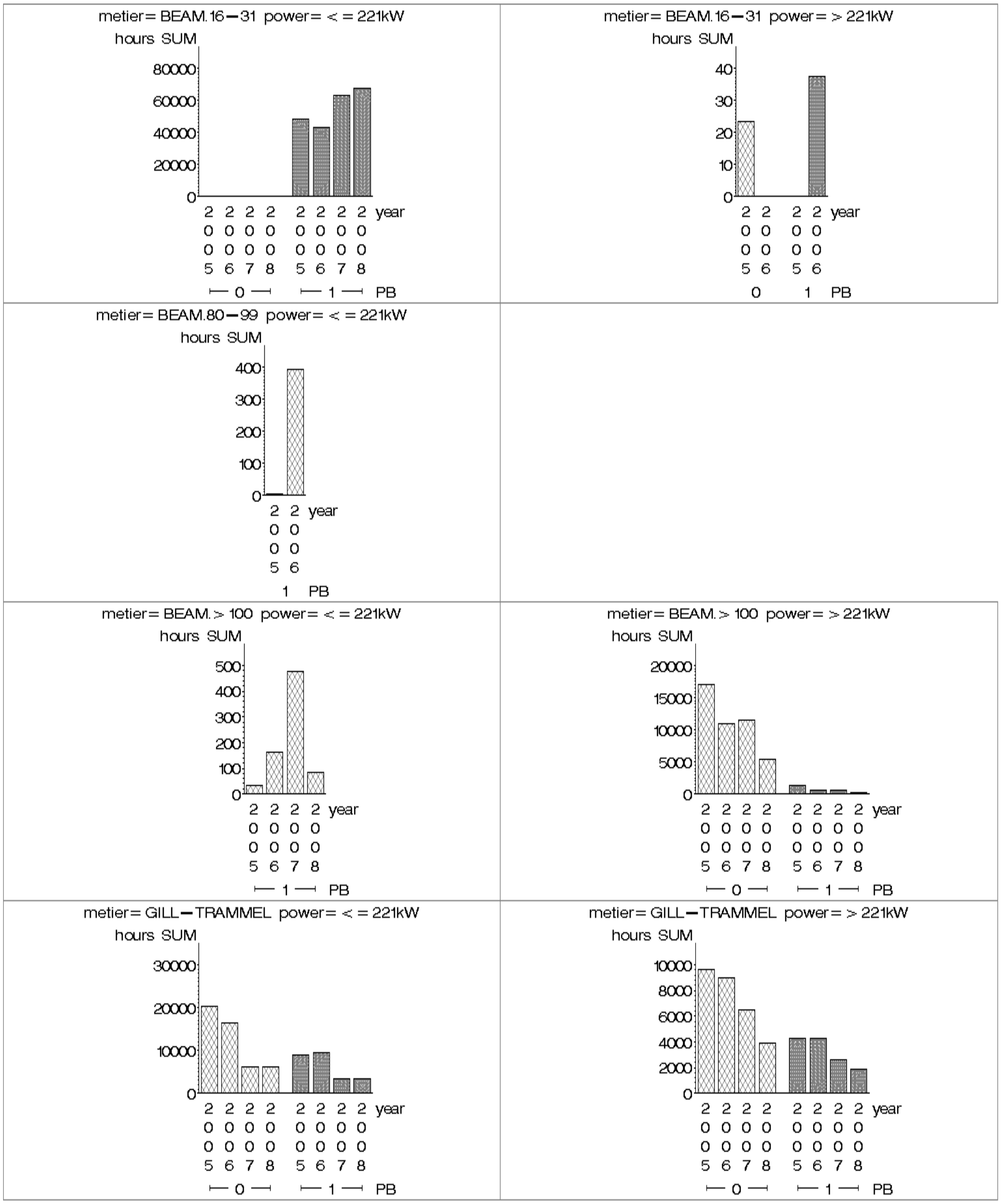


Fig 4.2.4: Danish effort (hours fishing) by metier and power class for the year 2005 to 2008 outside (bright columns, PB=0) and inside (dark columns, PB=1) the PB calculated from VMS data. Other metiers (OTHER) are potters, dredges, demersal seiners and pelagic trawler. Apparent effort for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

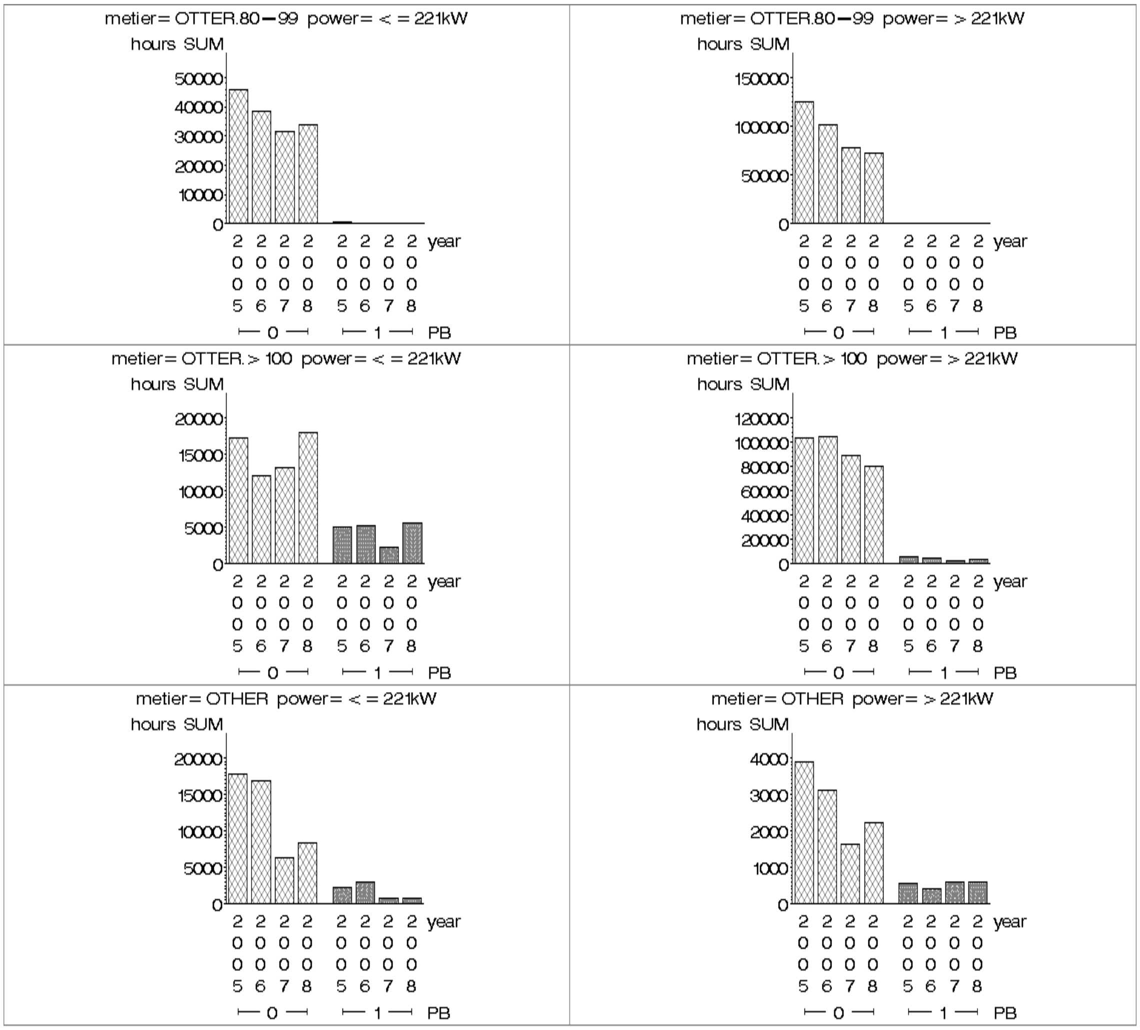


Fig 4.2.4: Danish effort. Continued.

Plaice discard by metier

The objective of this analysis was to link VMS effort, logbook data on catches and spatially resolved discard rates to derive estimates of discards in selected metiers. As matter of fact, errors from the previous analyses on VMS and logbooks are propagated into this analysis step.
Plaice discards are estimated for four different metiers, for which sufficient discard sampling data were available:

- Shrimp fisheries, BEAM.16-31.<=221kW
- Flatfish fisheries, small vessels BEAM.80-99.<=221kW
- Flatfish fisheries, large vessels BEAM.80-99.>221kW
- Mixed fisheries, small vessels OTTER.80-99.<=221kW

In shrimp fisheries, plaice discards were linked to shrimp landings, in flatfish and mixed fisheries, discards were linked to plaice landings.

Discard sampling and aggregation

No discard data were available for the Danish fleet with regard to metiers relevant for plaice discards in the area considered for the investigation. 74 samples were available from the national discard sampling programs. However, time series were of limited length for most of the metiers which hinders full spatial and temporal analysis (Table 4.3.1). Within area-between years variability is considerable, requiring aggregation of data. Thus, for further calculations discards were aggregated to year values for shrimp fisheries, where no spatial distribution of the catches and discards is known. For flatfish and mixed fisheries, discard rates were aggregated to ICES squares to account for spatial variability. For these fisheries, temporal trends of discards are discussed, however, due to limitations of the time series, a year effect is not calculated.

Calculations for flatfish and mixed fisheries

(Note: Discard calculation for shrimp fisheries is explained in section 11.3.1.3) .
Catch is the sum of discards and landings. With only landings data available, discards were calculated in terms of proportion of plaice landings by métier, rMetier.landings, each expressed in terms of weight.
rMetier.landings=discards/landings;
These can be transferred into percent of plaice catch, rMetier.catch,
i.e. r.catch= discards/(discards+landings) through transformation
r.catch=1-1/(r.landings+1)
A mean effect for r.landing is calculated for each year and sampled area (ICES square) by means of a GLM model, and the full rate by year and area is :

r.catch.year.area=1-1/(r.landings.year+r.landings.area+1)

T the discard for each year and area (ICES square) is calculated as :
Discards.year.area=landings.year.area/(1-r.catch.year.area)-landings.year.area

For non-sampled ICES-squares not covered by GLM, extrapolation is carried out by local kriging.

Data

Discard data by month and ICES rectangle are only available for recent years. For the Dutch fleet, the discard data set is presented in Table AppChpt4.3.5. However this metier is only poorly sampled (11 samples).

Table 4.3.1 Temporal coverage of discard sampling by country and metier, GER – Germany , NLD – the Netherlands

power	metier	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	TOTAL
<=221kW	BEAM100-119				GER	GER			GER							3
	BEAM16-31												GER	GER	GER	3
	BEAM80-89	GER	GER	GER	GER	GER	GER NLD	GER NLD	GER	GER NLD	GER	GER	GER			15
	GILL>=120										GER	GER				2
	GILL100-119										GER	GER				2
	GILL80-89									GER						1
	GILL90-99										GER	GER			GER	3
	OTTER>=120									GER	GER				GER	3
	OTTER100-119							GER	GER	NLD	GER			GER		5
	OTTER80-89						GER		GER	GER	GER	GER	GER		GER	7
	OTTER90-99									GER		GER				2
>221kW	BEAM80-89					GER NLD	NLD	GER NLD	NLD	GER NLD	GER	GER	GER	GER	GER	13
	DEM_SEINE100-119													GER		1
	OTTER>=120								GER	GER		GER	GER	GER	GER	6
	OTTER100-119									NLD			GER			2
	OTTER80-89							GER	NLD				GER			3

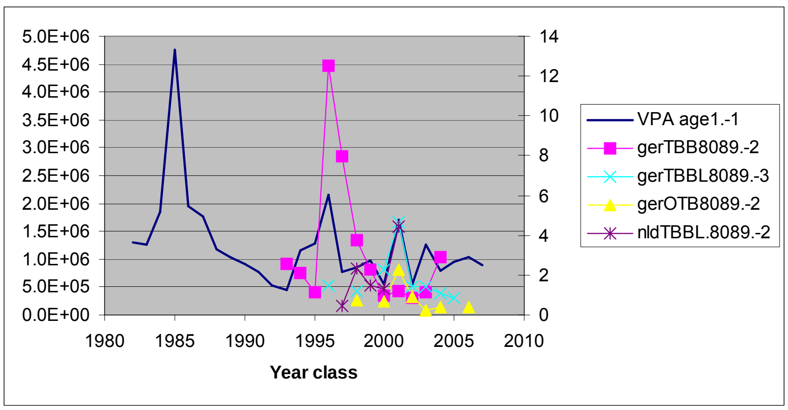
Spatiotemporal variability of discarding

For each ICES square, catches were redistributed according to the distribution of VMS effort into 3*3nm squares (see 4.2 & 4.4) and multiplied by the respective discard rate by ICES square. Thus, annual variability in discards is dependent on changes in VMS effort and catches; but not on changes in the discard rate. For the Dutch subsample of VMS, it is assumed that the subsample is representatively distributed in the ICES square.

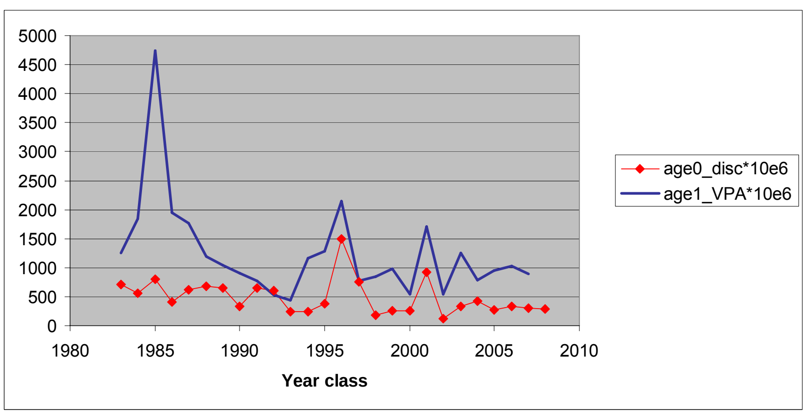
Discards are variable in time and space and dependent on juvenile plaice abundance, i.e. year class strength, and plaice distribution at age. Year class strength was taken as VPA age 1 for plaice (see (ICES, 2009a).

With regard to discard rates in terms of landings (rlandings.year), German BEAM80-89.<=221kW and OTTER.80-89.<=221kW and Dutch BEAM.80-89>221kW show strong effects in relation to the year class 2001 at a time shift of two years (Fig 4.3.2.A). This indicates that by-catch mainly affected age 2 plaice. In turn, large German beamers showed an effect with a time shift of three years with regard to year class 2001. The effect for year class 1996 was strong in German BEAM80-89.<=221KW fisheries, but not so for year class 2001, when only low discard rates were found. In turn, the discard rate for large German beamers for the 1996 year class was low. In shrimp fisheries (BEAM16-31.<=221kW, Fig. 4.3.2 B), year class effects are only apparent for 1996 and 2001. The intermediate year class 2003, which appears in VPA, is not reflected in fisheries discards in terms of increased rates. In turn, for year class 2004, both shrimp fisheries and German BEAM80-89.<=221kW show slightly increased rates. The differences in the discard rates time series are likely due to different spatial preferences by the different age groups, since the fisheries also operate in different areas. This is corroborated by the spatial distribution of modelled discard rates for catch by area (r.catch.area, Fig. 4.3.3). Of the three modelled metiers, all show a strong gradient towards the coast, where in shallow waters juvenile plaice have their nursery grounds (Fig. 4.3.3).

For otter and large beam trawlers, distribution patterns are similar, whereas small beam trawlers show a concentric patch of increased discard rates in the German Bight proper and a decrease towards its margins. On



A



B

Fig 4.3.2 Discarding in relation to plaice year class strength. (A) German (ger) Beam Trawlers (TBB) <=221kW and >221kW (L) and otter boards and large Durch beam trawlers (nldTBBL), mesh size 80-89, against VPA age 1, as ratio of discard over landings ($r_{landings.year}$); (B) Discards of 0-group plaice in shrimp fisheries , in millions. –1, -2, -3 indicate time lag to link to year class.

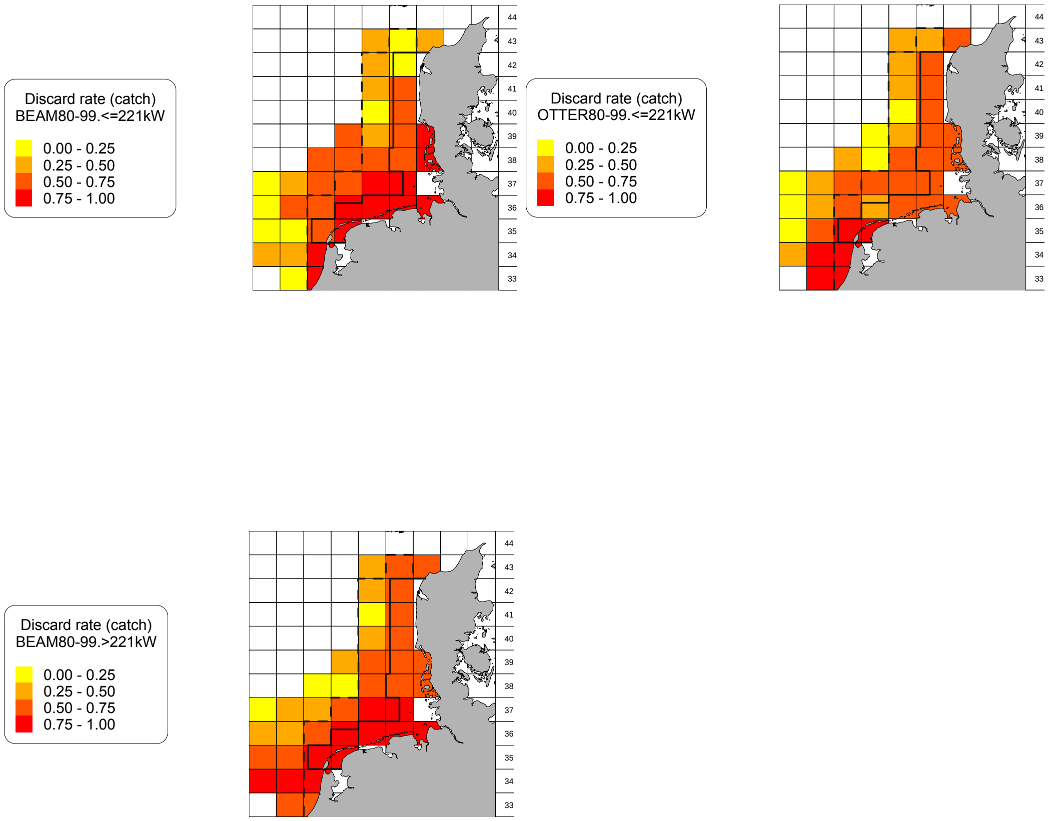


Fig 4.3.3: Spatial distribution of modelled catch discards rates ($r_{.catch.area}$) for three metiers.

average, the mean discard rate based on the number of ICES rectangles analysed in terms of proportion of catch for OTTER80-89.<=221kW is 0.52, followed by BEAM80-89.<=221kW with 0.53 and 0.60 for BEAM80-89.>221kW, respectively.

Shrimp fleet, metier BEAM.16-31.<=221 kW

Data

Discard data by month and ICES rectangle are only available for 3 years. Before 2000, landings were spatially unassigned and effort was not reported.

Catch based assessment

Recent discard data are only available for the German shrimper fleet for the years 2006 to 2008 via the EU data collection programme (Ulleweit et al. 2008).
38 samples were analysed from vessels operating veil nets (Table AppChpt4.3.1). The average weight of plaice caught is 4.5 g per specimen, indicating a by-catch mainly consisting of 0-group specimens. Monthly by-catch rates were obtained as weighted averages with shrimp catch as weighting factor. Except for the month July, low by-catch rates of plaice in shrimp are found. For the month July, 4 samples containing more plaice by-catch than shrimp with very few shrimp in the sample (< 10 kg per haul) caused considerable leverage. On average, for

German and Dutch shrimpers, 4.29 % and 4.2 % of annual shrimp catch landed are discarded in terms of undersized plaice, mainly as 0-group (Table AppChpt4.3.1).

Effort based assessment

In a former EU project (RESCUE, EU Study 94/044), by-catch data were assembled from quarter 2, 1996 through quarter 1, 1997 for the international shrimper fleet for the first time ever. Results from that project were influenced by the very strong plaice year class of 1996. These data are used to evaluate the discard model for this fleet (see below). Prior to RESCUE, only national programmes were undertaken, which are only poorly available to revision because of not being stored in electronic format (Neudecker & Damm, 2010). These data were not considered in this study.

Modelling discards in the shrimp fisheries

The rationale is to base the assessment on catch based rates and compare the results to the effort based estimates published hitherto (Neudecker & Damm, 2010, and references therein). It is assumed that plaice by-catch and discards in shrimp fisheries, DTBB16-31, is dependent on the shrimp catch Cy, the average annual discard rate in terms of shrimp landings, rTBB16-31, an efficiency factor f indicating progress in fishing technology and capabilities, and a factor representing the year-class strength of plaice hatched in year y, Ry:
Results are presented in Table AppChpt4.3.3.

Catch

Catch statistics from the ICES Working Group on Brown Shrimp (ICES WGCRAN) from their 2009 report were applied (ICES 2009b). Dutch data from two sources (LEI and Viris) were assembled into one data set.

Discard rate

The discard rates incorporate seasonal average rates of by-catch and catch for two national fleets, the Netherlands and Germany (Table AppChpt4.3.1). For Danish and Belgian catches, German parameters were applied. Annual catch variability was expressed in terms of seasonal split factor for shrimp catch based on data from ICES WGCRAN (ICES 2009b). Seasonal variability in discard rates was derived from German DCR data (see section before) under the assumption that these rates apply to all national fleets. It was not possible to account for spatial variability in discard rates. However, catch rates of 0-group plaice from the German Demersal Young Fish Survey (DYFS) indicate a strong gradient with relatively lower rates in the northeastern Wadden Sea and higher rates in the Elbe/Weser area and along the islands of the western Wadden Sea (Table AppChpt4.3.2).

0-group plaice year class factor

The year class factor for 0-group plaice is derived from the German Demersal Young Fish Survey (DYFS). It does not apply veil nets, so the catches of young fish are likely representative of their actual abundance. The year class factor was derived as year effect from a GLM model of the log of the catch rates dependent on area and year (see Table AppChpt4.3.2 for areas) for the years 1983 to 2008 to account for variable survey coverage in time and space. The index resembles VPA age 1 structure back to 1994 (ICES, 2009a), so it is assumed to be a fair proxy of year class strength for 0-group plaice one year earlier (Fig. 4.3._4).
For the years examined for discard rates, 2006 to 2008, the rate is set to 1 and all other years are assessed relative to this period (see Table AppChpt4.3.3).

Efficiency factor

Tiews (in Neudecker & Damm 2010) assumed an increased fishing efficiency for modern shrimp fishing vessels as compared to the older fleet. Here, this is taken into account by decreasing fishing efficiency by 0.1 in retrospective decadal steps. However, this change in assumed efficiency may be outweighed by a change in fishing gear in the past, since only since 2002 have shrimpers been obliged to operate separator trawls etc. in shrimp fisheries to protect juvenile flatfish (EC No 850/1998 (25)).

Comparison with effort based discard estimates

From the RESCUE project, 774 million 0-group plaice were estimated to be by-caught and discarded in 1996 by the German fleet segment. The present modelling gives a total of 1498 million 0-group plaice for all fleets, of which 43 % = 650 million may be attributed to the German fleet. In 2008, Neudecker & Damm (Neudecker & Damm, 2010) estimate 112 million 0-group plaice to be by-caught by the German fleet based on the effort index, compared to 120 million in this study. The difference in 1996 is likely subject to the assumed change in efficiency, whereas in 2008 hardly any difference appears.

Evaluation of plaice discarding in shrimp fisheries

Discards have to be evaluated against the background of high natural predation on juvenile plaice. Major predators are crustaceans (e.g. Crangon crangon), fishes and birds (van der Veer & Bergman, 1987). 0-group

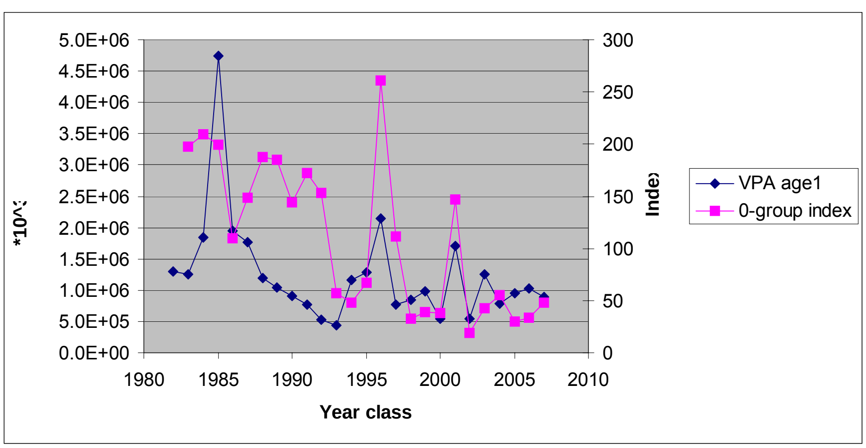


Fig 4.3.4 Comparison of o-group index with VPA age 1 as indicator of year class strength.

mortality rates range from ca. 0.03 per day (van der Veer et al. 2000, Hjörleifsson and Palsson 2001) to 0.67 per month (Lockwood, 1980) for summer months. It may be further hus, it may be assumed that the number of 0-groups in the summer before is about 10 times the number of VPA age 1 specimens, assuming that during winter months natural mortality rate is reduced.
Comparing with Figure 4.3.2B, the number of 0-groups discarded by year class was smaller than the respective number of age 1 specimens in the VPA. Only in 1991 and 1992, did the number of discarded 0-groups equal the number of age 1 specimens in the subsequent year. On average, the ratio between age 1 and discarded 0-group is about 2:1 for the same year class, which means that at age 0, the ratio is 20:1. Based on published natural mortalities as reported above, the 0-group annual natural mortality can be estimated at ca. M=2 as compared to an estimated fishing mortality of ca. F=0.05 by the shrimp fisheries.

Socio-economic parameters of key fisheries by country

Methods

In order to allocate landings to a certain geographic area the VMS data (see above) are combined with the landings data. A straight forward method would have been to allocate the landings reported for a certain ICES rectangle in proportion to the fishing effort spent in this ICES rectangle. Unfortunately, for Dutch shrimp landings no ICES rectangles have been reported so far, leading to only small proportions of landings being allocated by this method (< 10 % for shrimp landings). To overcome this problem, the total landings of each métier and power class are allocated to the effort spent by this métier and power class for each month in each 3 by 3 nm rectangle (see Chapter 4.2). Since the automatically generated VMS data are not always free of misreporting this method loses some accuracy which could have been gained from the information on ICES rectangles, but was the best choice available to compare all three countries. For each landed species (plaice, sole, shrimps), however, more than 98% of the landings were allocated. Exceptions are the small amounts of Dutch shrimp landings by large vessels (>221kW) which could not be allocated (see Appendix Tab. AppChpt4.Oo1,).
Since detailed economic data were not available for all three countries, the landings of each country were multiplied by mean prices of sales by German fishermen in the North Sea to estimate the monetary yield gained from each 3 by 3 nm rectangle.

Results

The monetary yield for the fleets of The Netherlands, Germany and Denmark for the main métiers and power classes aiming for shrimp, plaice and sole are shown in Table 4.4.1 to Table 4.4.2. Whereas in the Dutch fleet the fisheries for plaice and sole are gaining the highest yields (ca. 149 Mio Euro per year) followed by the shrimps fisheries (ca. 52 Mio Euro), the German flatfish fishery gains about 12 Mio Euro and the shrimp fisheries about 52 Mio Euro per year. In the Danish fleet also plaice and sole are the main target species yielding about 26 Mio Euro per year, followed by the shrimp fisheries earning about 13 Mio Euro per year. From the percentages of money earned within the PB it can be seen that several métiers in the German and Danish fleets are highly depending on the PB. This holds especially true for the German and Danish shrimp and flatfish fishers. For further details of each year please see Appendix Tab. AppChpt4.Oo2 (The Netherlands), AppChpt4.Oo3 (Germany) and AppChpt4.Oo4 (Denmark).

Conclusion

A change in management of the PB, especially an opening of the PB for all power classes, might lead to a reduced monetary yield by small fishing vessels and companies along the German and Danish coast. This estimate is, however, dependent on the proportion of yield being shifted from smaller to larger vessels in the near and shallow coastal zones within the plaice box (see chapter 11).

Table 4.4.1: Mean monetary yield (millions of Euro) in the Dutch fleet calculated from the years 2005 to 2008 and percentage of total yield landed from inside the Plaice Box (PB). Apparent yields for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

	Power:	*<=221 kW*		*>221 kW*	
Metier	Species	Mio EUR	% in PB	Mio EUR	% in PB
BEAM.16-31	CSH	52.29	62	0.07	
BEAM.16-31	PLE	<0.01	63		
BEAM.16-31	SOL	0.06	55		
BEAM.80-99	PLE	1.47	13	34.54	7
BEAM.80-99	SOL	13.07	13	102.59	7
BEAM.>100	PLE	0.51	38	4.85	6
BEAM.>100	SOL	0.08	30	0.35	4
GILL-TRAMMEL	CSH	0.02	18		
GILL-TRAMMEL	PLE	<0.01	7		
GILL-TRAMMEL	SOL	0.25	15		
OTTER.80-99	CSH	0.01	9		
OTTER.80-99	PLE	1.56	2	0.7	3
OTTER.80-99	SOL	0.22	2	0.3	2
OTTER.>100	CSH	0.04	5		
OTTER.>100	PLE	0.16	4	0.71	4
OTTER.>100	SOL	0.01	6	<0.01	2

Table 4.4.2: Mean monetary yield (millions of Euro) in the German fleet calculated from the years 2005 to 2008 and percentage of total yield landed from inside the Plaice Box (PB). Apparent yields for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

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	Power:	*<=221 kW*		*>221 kW*	
Metier	Species	Mio EUR	% in PB	Mio EUR	% in PB
BEAM.16-31	CSH	46.8	100		
BEAM.16-31	PLE	<0.01	100	<0.01	3
BEAM.16-31	SOL	0.03	100	0.03	3
BEAM.80-99	CSH	0.04	58		
BEAM.80-99	PLE	0.57	71	1.62	4
BEAM.80-99	SOL	1.22	72	3.6	4
BEAM.>100	CSH	0.04	95		
BEAM.>100	PLE	0.28	92	0.04	
BEAM.>100	SOL	0.01	90	<0.01	
GILL-TRAMMEL	PLE	0.02	27	<0.01	16
GILL-TRAMMEL	SOL	0.72	25	0.08	6
OTTER.80-99	PLE	1.84	6	0.61	4
OTTER.80-99	SOL	0.17	5	0.08	4
OTTER.>100	PLE	1.1	19	0.23	9
OTTER.>100	SOL	0.01	20	<0.01	19
OTHER	PLE	0.18	52	0.25	36
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4.4.3: Mean monetary yield (millions of Euro) in the Danish fleet calculated from the years 2005 to 2008 and percentage of total yield landed from inside the Plaice Box. Apparent yields for vessels > 221 kW and metieres with mesh sizes 80-99 mm likely due to methodological constraints.

	Power:	*<=221 kW*		*>221 kW*	
Metier	Species	Mio EUR	% in PB	Mio EUR	% in PB
BEAM.16-31	CSH	12.67	100		
BEAM.16-31	PLE			<0.01	100
BEAM.16-31	SOL			<0.01	100
BEAM.80-99	CSH	0.02	100		
BEAM.80-99	PLE	0.01	100		
BEAM.80-99	SOL	<0.01	100		
BEAM.>100	CSH	0.04	100		
BEAM.>100	PLE	0.01	100	5.12	5
BEAM.>100	SOL	<0.01	100	0.21	7
GILL-TRAMMEL	PLE	2.08	37	1.14	29
GILL-TRAMMEL	SOL	1.01	48	0.72	44
OTTER.80-99	PLE	0.69	1	2.07	0
OTTER.80-99	SOL	0.16	0	0.37	0
OTTER.>100	PLE	2.13	23	5.32	5
OTTER.>100	SOL	0.05	20	0.17	6
OTHER	PLE	5.76	12	1.03	20

Evolution of fishing power.

Fleet register analysis of potential fleet power.

In this step, we attempted to analyze whether certain métiers developed or decreased in the Plaice Box independently of the surrounding North Sea and Baltic. We considered fleet structure in terms of total vessel power and average vessel power in order to indicate the number and capacity of the vessels commissioned at specific dates. We suppose that capacity is rather a proxy for mid-term allocation of economic resources and investment instead of catch effort, which is ought to reflect actual and short-term economic opportunities.
For this purpose, vessel characteristics registered in harbours representing the PB area (Fig. 4.5.1 red) were compared to vessels registered to harbours outside the PB. Countries contributing to "in Plaice Box" and "out PB" were Denmark, the Netherlands and Germany. Further, for outside the PB, additional fleet data from Belgium and

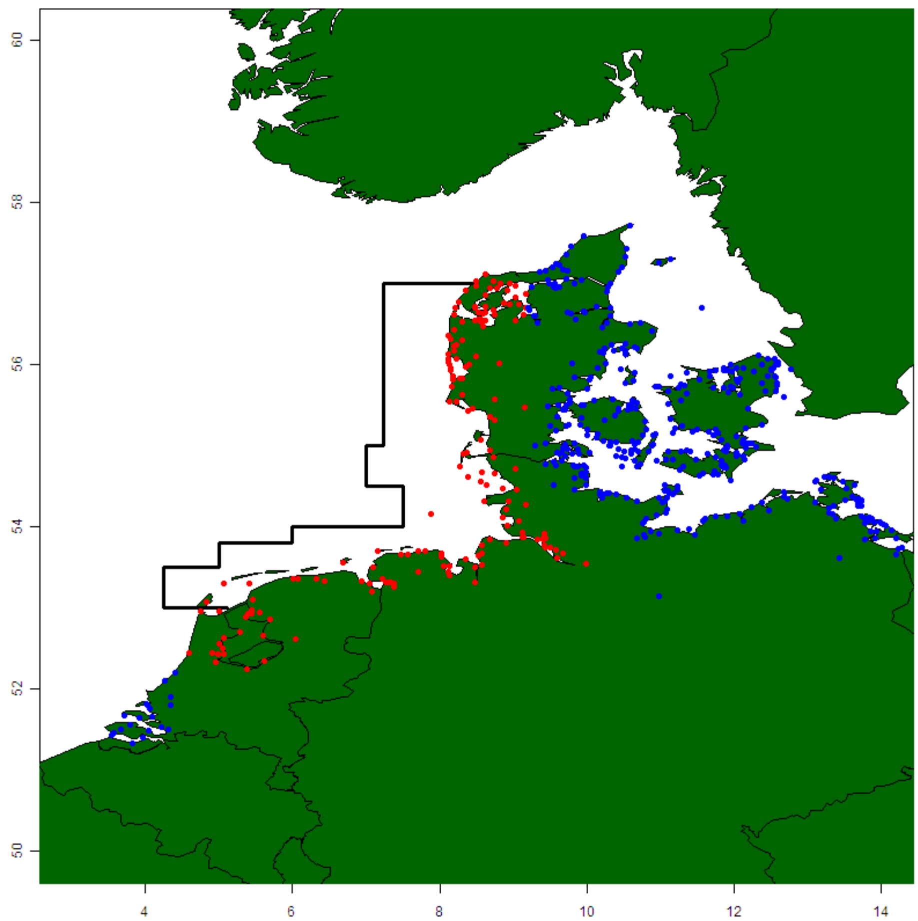


Fig 4.5.1 : Assignment of harbours to inside (red dots) and outside the PB (blue dots) for the analysis of fleet structure

UK were acquired from the European 'Fleet Register on the Net'3. For UK, registrations from East coast ports (Grimsby, King's Lynn, Lowestoft, Yarmouth, Hull, Whitby and Scarborough) as well as the whole fleet were analyzed. As a measure of fleet capacity the natural log of kW power was chosen. To further indicate differences of fleet development in different areas, average vessel power was analyzed (Fig. 4.5.2).

Fleet structure by nation

A snapshot of fleet structure for bottom trawlers for 2008 in presented in Table 4.5.1. For UK beamers, about 75 % is attributed to the The Wash area and the East coast from Yarmouth to Scarborough. Evidently, beam trawlers represent the major fleet segments for Germany and The Netherlands for bottom trawling gear. Comparably, the number of beam trawlers in the UK and Belgium is much lower. Beam trawlers are concentrated in the North Sea, since no beam trawling is undertaken in the Baltic.
Noteworthy is the small number of large beam trawlers for Germany. Denmark, The Netherlands and Germany are considered in detail.

Denmark

Trends in the Danish fleet may be described in terms of a decreasing number of otter trawlers and gill netters, which is less pronounced inside than outside the PB (Figure 4.5.3). In turn, capacities by fleet targeting pelagic species have increased, both in and outside PB. Beam trawlers were only registered to ports inside PB, the short time series for beam trawlers > 221kW ending in 1996 indicates either decommissioning or boats were transferred to another harbour or owner.
Dredging capacity has remained stable over time or increased slightly. Despite a considerable increase in recent years from 2 to 11 registered vessels, beam trawlers <=221kW decreased in the long-term from 19 to 11 vessels.

Table 4.5.1 : Fleet structure for bottom trawlers by country, 2008.

	B	DEU	DNK	GBR	NLD
BEAM					
<=221kW	45	271	11	150	233
>221kW	38	6	1	47	106
OTTER					
<=221kW	0	68	247	864	27
>221kW	2	21	152	246	5

[3] http://ec.europa.eu/fisheries/fleet/index.cfm

Germany

Otter trawling capacity has decreased sharply inside PB and slightly outside the box, whereas capacity for pelagic trawlers has increased outside PB. Gill netters inside the PB decreased, but remained stable outside the PB. Note: this includes by definition all the gill netters in the Baltic (Fig. 4.5.4). Increases were found for dredgers inside PB (no dredgers outside), and beam trawlers inside PB, where large beam trawlers >221kW increased significantly. Small beam trawlers decreased in the long-term in terms of numbers and fleet capacity. Numbers of vessels reached a maximum of 315 in 1997 declining steadily to 261 in 2008 together with the entire fleet capacity.
Outside the PB, small beam trawler capacity increased slightly (from 5 to 10 vessles), whereas large beam trawlers were not found in recent years and likely were decommissioned or transferred to other harbours or owners.

The Netherlands

Within the PB, small beam trawlers have increased over the last 18 years from 65 in 1990 to 166 in 2008 as did fishing capacity by this metier, whereas decreases were indicated outside PB. Large beam trawlers decreased both in- and outside PB. A similar figure was obtained for otter trawlers: small ones remaining stable in the PB, whereas decreases were found outside for both power categories and inside PB for large otter trawlers (Fig. 4.5.5).

Trends by métier and possible implications of EC regulations

Summarizing trends by métier inside and outside the Plaice Box for bottom trawlers segments shows, that only beam trawlers <=221 kW behaved clearly differently inside and outside the Plaice Box (Table 4.5.2). However, this effect is only marginally significant (p=0.058). A mean rate of change of capacity by country (not corrected for absolute fleet capacity which would be influenced from the large Dutch capacities) shows that beam trawlers outside the PB have increased and have thus developed economically. Whereas for small and large beamers inside the Plaice Box, only little development is apparent with a respective rate of change of 1.08 and 0.99.

The trends in fleet capacities points out that PB beam trawlers <=221kW developed as a separate group compared to fleets from adjacent countries. This is corroborated by the trend analysis of mean vessel power in relation to the establishment of the PB.
For beam trawlers <=221 kW from countries directly adjacent to the Plaice Box (DEN. GER, NLD), mean vessel power lies in the same range of 150 to <200 kW. For those countries without direct contact to the Plaice Box (B, GBR), fleets show individual characteristics indicating that they developed according to more local requirements and conditions.

Table 4.5.2 Comparison of evolution of fleet capacity by métier. + positive trend, - negative trend, 0 – no trend, / - incomplete time series not included. IN/OUT – inside or outside the Plaice Box.

Metier	In	Out	Average fleet capacity factor relative to 1990 (in/outside PB)	Fishers exact test
BEAM<=221	+–	++++/	1.08/1.5	P=0.058
BEAM>221	+-/	++-//	0.99/1.39	P=0.70
OTTER<=221	–+	–+/	0.73/0.97	P=0.8
OTTER>221	–	—+	0.51/0.81	P=0.4

The range 150 to <200 kW for the Plaice Box countries indicates a constant mix of weaker, probably older vessels and stronger, likely more modern vessels. This is evident for instance in Denmark, when in the 2000s new vessels were commissioned and the number of vessels increased from 2 to 11 and mean vessel power also increased while the whole fleet capacity has increased (Fig. 4.5.3). In turn, the high mean value for Belgium indicates that all vessels are equipped with powerful engines. At the same time, the total fleet capacity of Belgium has also increased.

EU regulations with respect to the Plaice Box aim at two different features of the fleet via a licensing system and regulations determining technical outfit of vessels permitted to fish inside the box. This is likely to have affected the negative trends for otter trawlers tool, since with recent implementation of cod recovery measures in the North Sea, fishing opportunities have been cut. The trend in beam trawl capacity is likely related to the EU licensing system for fishing vessels as determined by regulations EC 3760/92, 3690/93 and 1670/94, the ceiling of average engine power below 200 kW is a combined effect of the licensing system and EC regulation 850/98, limiting the maximum engine power in the area to 221kW per vessel for bottom trawlers. Effects of the licensing system are further indicated in the trend of engine power for the Dutch beam trawl fleet. Before the licensing systems was installed in the mid-1990s, the fleet was fully restructured and mean vessel power increased almost instantly to the present level after a period of low average engine power at the beginning of the 1990s.

Both the trend of mean vessel power and the trend analysis of fleet capacity for beam trawlers <=221 kW corroborate the hypothesis that the establishment of the PB has had an effect on fleet structure, though the test statistic for the latter was not statistically significant at the 5% level ($p=0.058$) (Fig. 4.5.2).
This means that trends for beam trawlers <=221 KW both in terms of fleet capacity and technical outfit of vessels is linked to the presence of the PB. Comparison with fleets outside the PB, the limitations of the licensing system and the technical derogations likely impaired capacity and technological development as evidenced by average rates of changes (see Table 4.5.2) .

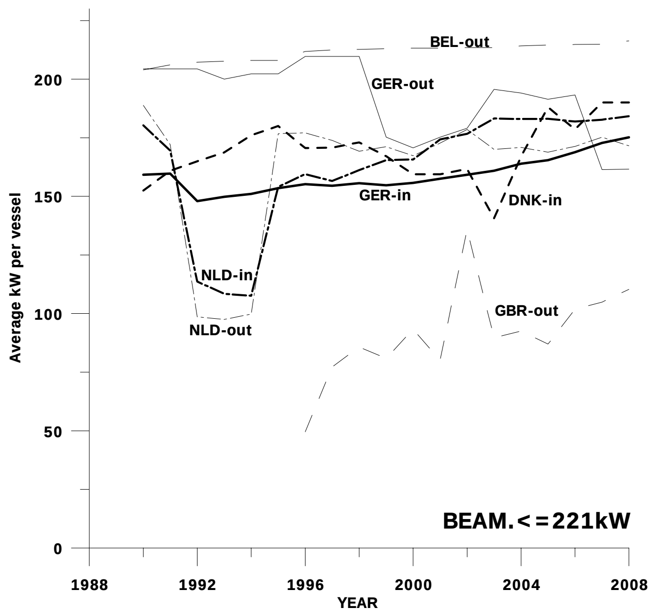


Fig. 4.5.2 Average vessel power in and outside the Plaice Box for the métier BEAM.<=221kW. Countries : Bel- Belgium, Dnk – Denmark, GBR – UK, Ger – Germany, NLD – The Netherlands

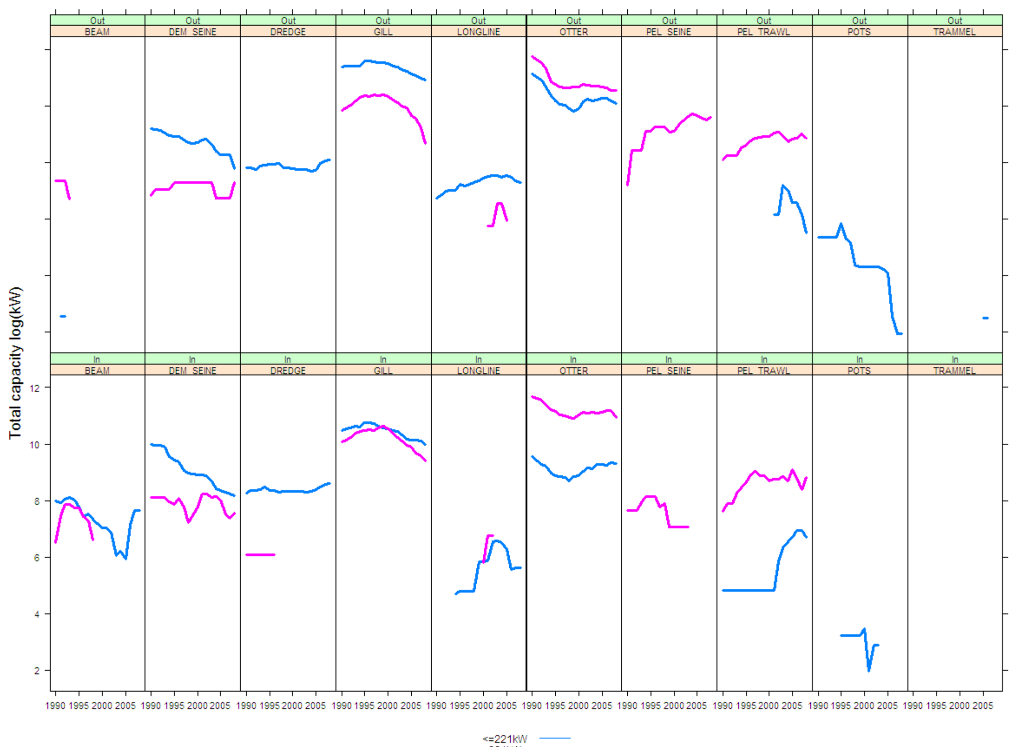


Figure 4.5.3: Evolution of Danish fishing capacity 1990-2008 according to the EU fleet register.

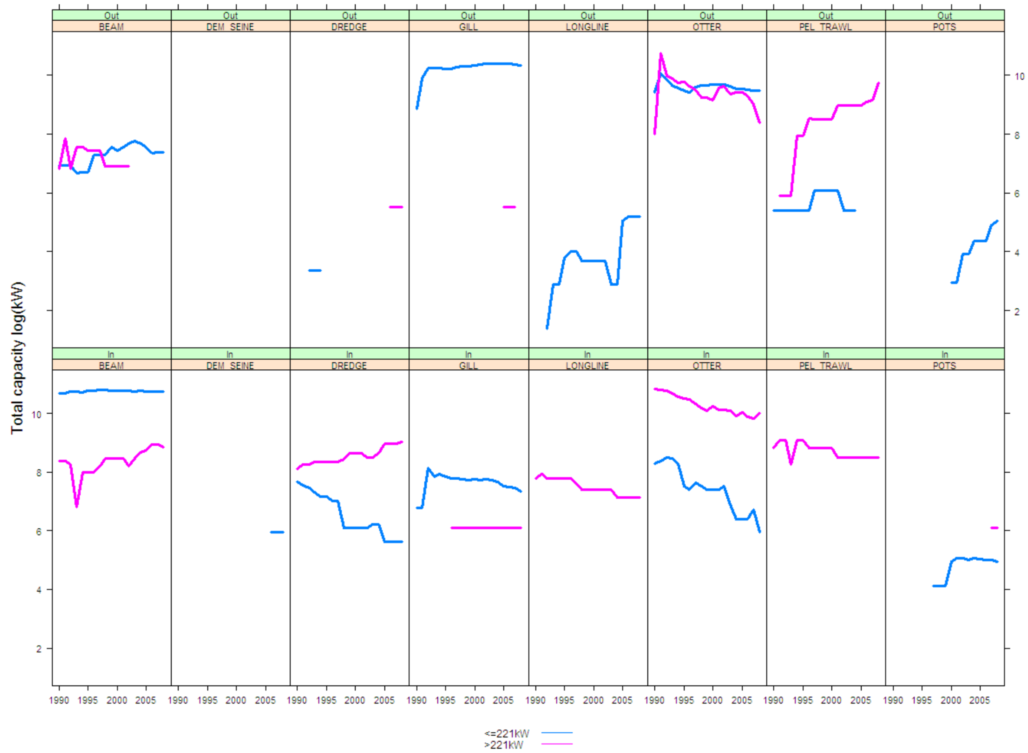


Figure 4.5.4: Evolution of German fishing capacity 1990-2008 according to the EU fleet register.

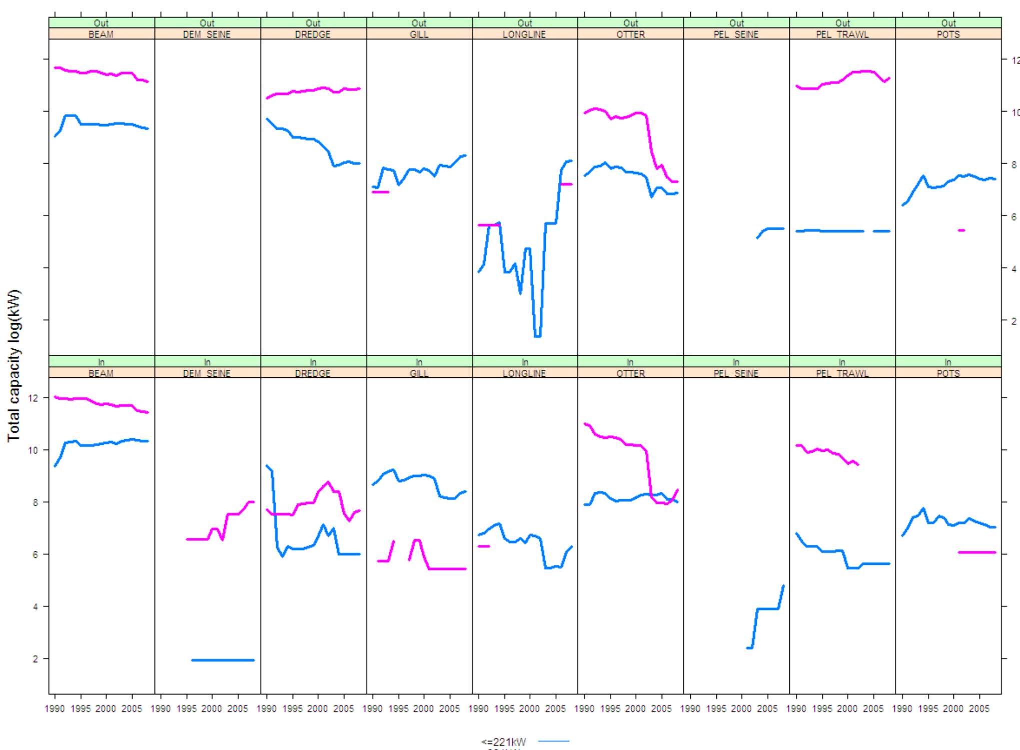


Figure 4.5.5: Evolution of Dutch fishing capacity 1990-2008 according to the EU fleet register.

Chapter 5. Other environmental variables

Data origins and methods

The recent report of the ICES Working Group Oceanography and Hydrography (ICES 2008) recommended the Helgoland Road data as being representative of the North Sea. Water temperature, salinity and nutrients data have been continuously recorded by the Biologische Anstalt Helgoland (BAH). Samples have been taken at the "Helgoland Roads" station (54°11'18''N 7°50'00''E) between the main island and the dune island since 1962 on every weekday (for methods see Hickel et al. 1997). Data were kindly supplied by K. Wiltshire, BAH/AWI (Wiltshire and Manly 2004; Franke et al. 2004); partly unpublished Data archived in the information system PANGAEA – Network for Geological and Environmental Data, www.pangaea.de). The water discharge of the river Elbe is recorded daily from 1960 to 2006, was kindly provided by Eggert (2002) (www.dgj.de/servlet/lbMenu).
The "North Atlantic Oscillation Index" (NAOI) summarizing the main climatic features over Northern Europe was provided by the Climate Analysis Section, NCAR, Boulder, USA, (Hurrell , 1995). It is available as winter-index (Dec – Mar) from 1864 until 2008 (www.cgd.ucar.edu/~jhurrell/nao.html).

Climate patterns

Local and regional environmental parameters such as temperature and salinity as well as storms and currents are forced by superordinated climate patterns. Potentially important is the long term variability in the North Atlantic pressure system, as indicated by the North Atlantic Oscillation Index (NAOI).
The North Atlantic Oscillation (NAO) is the dominant signal of interannual variation in the atmospheric circulation over the North Atlantic (Hurrell 1995). The winter NAO index (Dec. – Mar.) summarises large scale weather pattern over the north-east Atlantic region during winter. It is based on the difference of sea level pressure (SLP) between Lisbon, Portugal and Reykjavik, Iceland. The SLP anomalies were normalized by division of each seasonal mean pressure by the long-term mean (1864-1983) standard deviation. During winters with a high NAO-index, westerly winds in Europe are more than 8 m/s stronger than during winters with a low NAOI. Consequently the moderating influence of the ocean results in unusually warm winter temperatures in Europe (Hurrell, 1995). The long term development was given by Hurrel (1995) (Fig. 5.1).

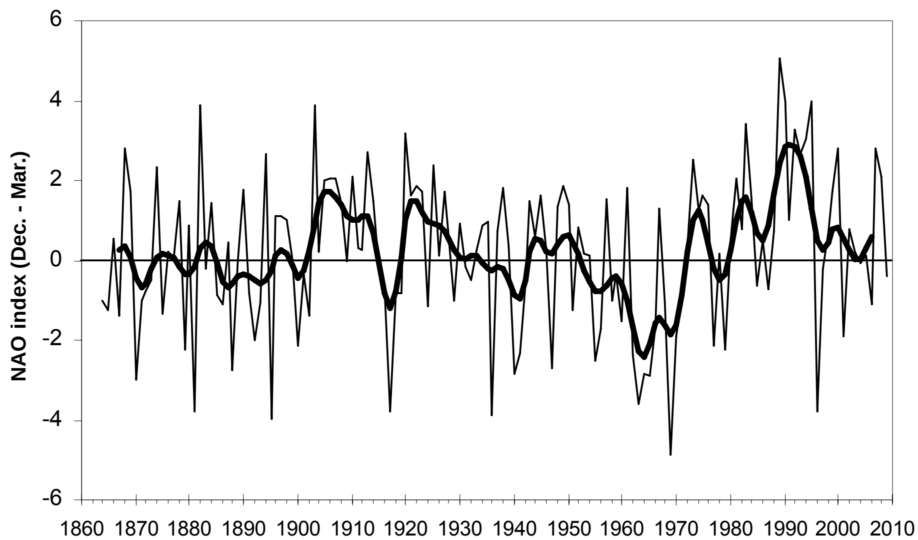


Fig. 5.1. Long term development of the winter NAO-index (Dec. – Mar.) 1864 - 2009 ;
The heavy solid line represents the NAOI smoothed with a low-pass filter with seven weights (1,3,5,6,5,3,1) to remove fluctuations with periods less than 4 years;
[data from J. Hurrel (extended from Hurrell 1995)].

Compared to the long-term development of the NAOI, the period focused upon here starting in 1960 begins with a prolonged phase of a predominantly negative NAOI. For most of the period of the following years starting around 1975, the NAOI was above its long term mean.
During the period of the present investigation, an increasing tendency can be seen towards the early 90s while values since 1996 have fluctuated around zero. (Fig. 5.2).

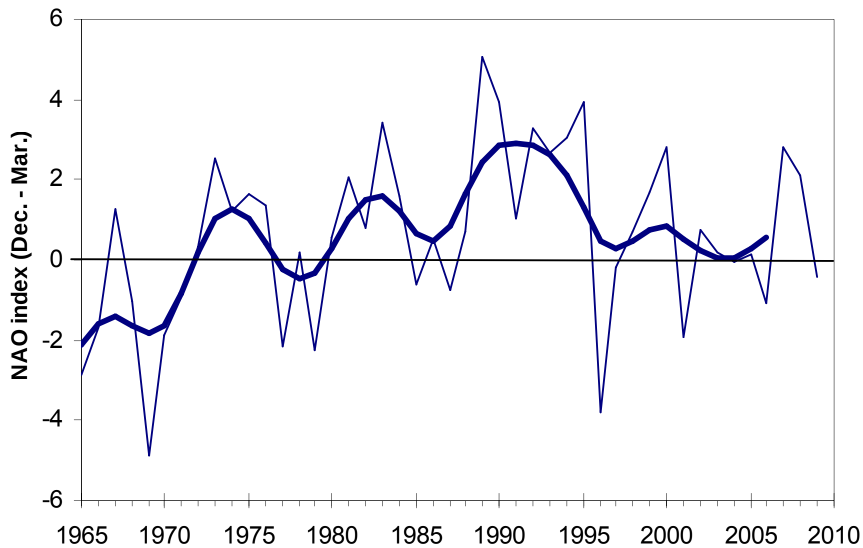


Fig. 5.2. Winter NAO-index 1965 – 2009 enlarged from Fig.5.1.

Large negative values are reached from '68 to '71, in '77 and '79 and then again in '96 and 2001. The values observed in '69 and '96 are amongst the lowest of the last 150 years (The MDS plot in Fig. 8.11. shows a development towards the upper side of the plot, while the distance between the stations remains similar. The average similarity between the communities shows some fluctuations of about 10-15% but no increasing or decreasing tendency over time.

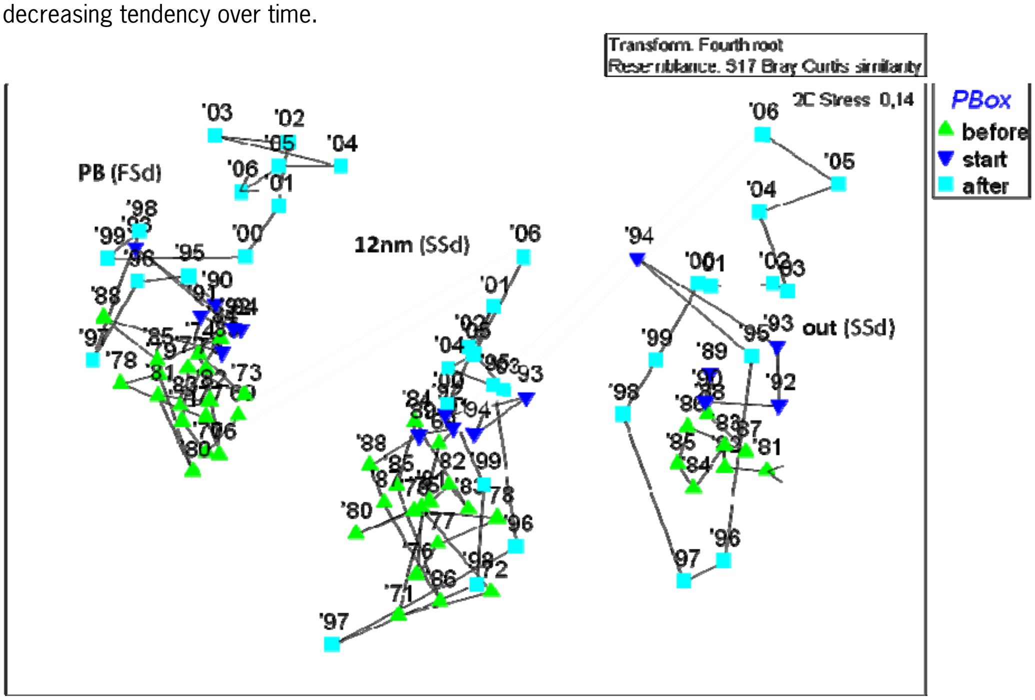


Fig.).

The longest period of a positive NAOI is between '88 and '95. Shorter periods appeared from '72 to '76 and again from '80 to '84 though mostly at a lower level than in the early 90s. After the extremely low value from '96, the NAOI rose again to a high positive value in 2000 and in 2007.

Water temperature

Temperature has an important influence on all marine ecological processes but is particularly important in coastal waters. Plaice may respond by moving to deeper water when water temperature increases beyond the upper tolerance limit (see above). Temperature also affects the food requirements of fish and benthos and affects the competitive processes among species. Mortalities will increase when the lowest winter temperatures fall below, or the highest summer temperatures rise above, their tolerance limits, resulting in steep population declines or even local extinctions. Therefore apart from mean temperatures, the winter minima and summer maxima are of importance for ecological processes.
In recent history, the mean annual water temperature of the German Bight has risen by 0.033 °C / yr, resulting in 1.48 °C over the last 45 yr (Wiltshire et al. 2008). Similar trends have been observed for the North Sea (Edwards, Beaugrand, and Reid 2002) and the North Atlantic (Edwards et al. 2002)..
The mean water temperature at Helgoland during winter (Dec. – Mar.) varied between 3 °C and nearly 7 °C (Fig. 5.3).

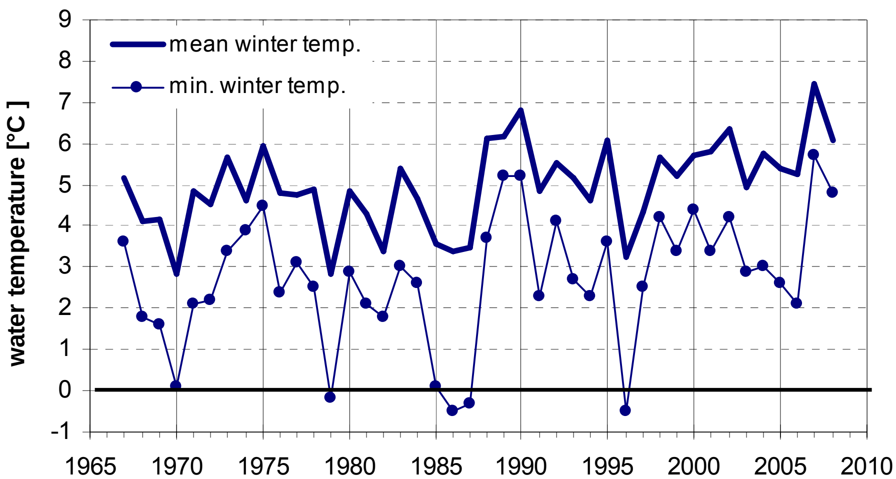


Fig. 5.3. Mean and minimum water temperature between December and March at Helgoland Roads (BAH-data). Cold winters with mean water temperatures below 3.5 °C were observed in 1970, '79, '82, '85-'87 and in 1996. Prolonged periods with mean temperatures above the average of 4.7 °C were observed between '71 and '78 and then again from '88 until 2008 with the exception of ´96. There is a marked shift in the mean winter temperature between 1987 and ´88. During the period from `67 to ´87 it fluctuated around a mean of 4.4 °C while from ´88 until 2008 the mean was 5.5°C.

This pattern is reflected in the minimum water temperatures with a slightly different emphasis. Minimum temperatures of 0 °C and below were observed in 1970, '79, '85 – '87 and '96. Judged by the minimum temperature, the severest winters were those of '86 and '96 followed by '87 and the '79.
The mean water temperature during summer (Jul. - Sep.) varies between 15 and 18 °C (Fig. 5.4). Highest mean water temperatures were reached in 1973, '75, '82/'83, with an increasing trend from ´87 onwards. Lower than average temperatures were recorded in '78 and between '84 and '87.

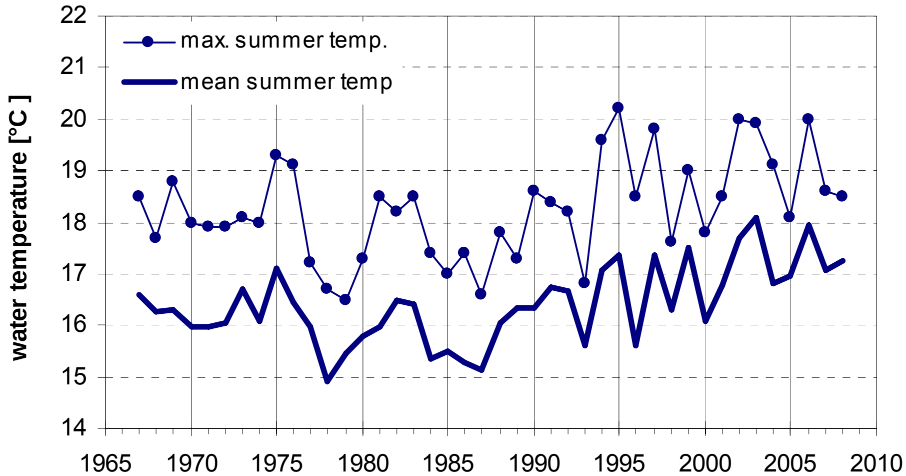


Fig. 5.4: Mean and maximum water temperature between July and September at Helgoland Roads (BAH-data).

This pattern in mainly reflected by maximum water temperatures, that reach values above 19 °C in 1975/76 and in many years from 1994 onwards even around 20 °C, while not rising above 17.5 °C in the periods of '77-'80 and '84-'87.

A comparison of the water temperature from the Marsdiep station at the western end of the Wadden Sea (used in the plaice growth model) with the Helgoland Roads data revealed a high linear correlation between both data sets (R=0.93 (p<<0.1%) for annual mean data and R=0.95 (p<<0.1%) for monthly means). Due to the shallower water and the direct influence of the tidal outflow from the Wadden Sea, the Marsdiep temperature had a larger annual range (15.5°C +/- 2.1 SD vs. 13.3°C +/- 1.2 SD at Helgoland) with summer maxima about 1.5°C (+/- 0.6 SD) higher and winter minima about 0.4°C +/- 0.9 SD) lower than at Helgoland. With its position in offshore waters however, the Helgoland data seem more suitable to represent the water temperature of the whole region of the plaice box and its surroundings.

Salinity

The salinity at Helgoland fluctuated between 31 and 33 PSU and is strongly coupled (negatively) to the total annual discharge of the river Elbe (Fig. 5.5).

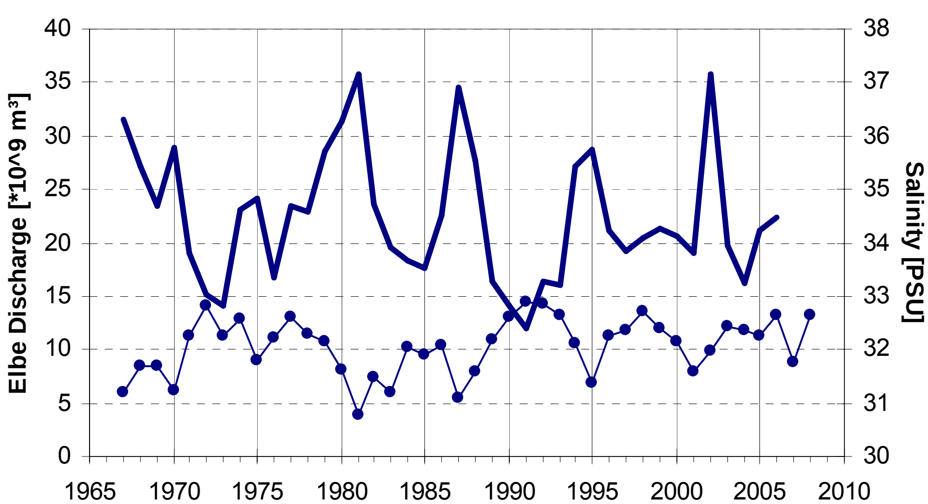


Fig. 5.5: Total annual discharge of river Elbe (Eggert 2002, thick line, left axis) and annual mean salinity at Helgoland Roads (BAH-data, thin lie with dots, right axis).

The largest discharges are related to the lowest salinities while low discharge volumes result in higher salinity values.

Nutrients

The increased discharge of nutrients in the coastal waters is likely to have raised the productivity of the system before the implementation of the PB (Colijn et al. 2002). Since the 1980s however, nutrient levels, in particular phosphate, have decreased, which may have resulted in a decrease in the productivity of the coastal ecosystem (Philippart et al. 2007)..

The main inorganic nutrients phosphate and nitrogen do not fluctuate in parallel, but rather each had a distinct temporal trend during the period from 1960 to 2008.

Phosphate

Mean annual concentrations of phosphate showed a strong increase during the early 70s. All values between 1974 and '86 were well above the average of the period '67 – 2008 (Fig. 5.6).

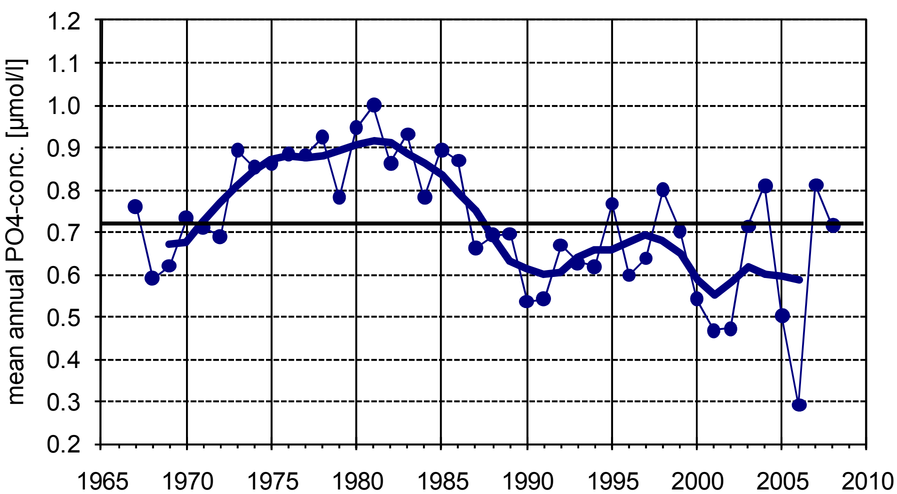


Fig. 5.6: Mean annual concentration of phosphate (PO4) at Helgoland Roads [µ mol/l] (BAH-data). Thick horizontal line marks the mean concentration of 1967 – 2008; the heavy solid line represents low-pass filtered with five weights (3,5,6,5,3) to remove fluctuations with periods less than 3 years.

In the contrary, the period from '88 until '97 was marked by lower concentrations than average, with large fluctuations in the late 90s and 2000s.

Nitrogen

Unlike phosphate, the concentration of the total inorganic nitrogen shows an increasing trend between the late 1960s and the mid 1990s (Fig. 5.7).

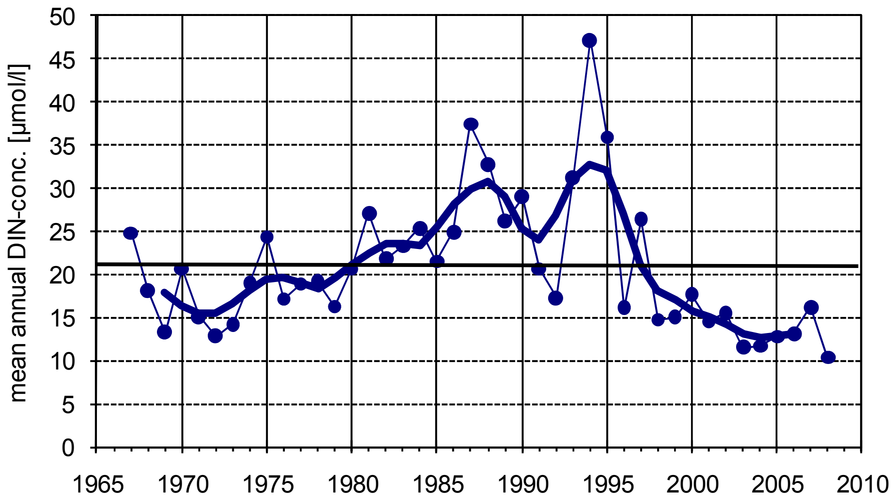


Fig. 5.7: Mean annual concentration of dissolved inorganic nitrogen (DIN = NO3+NO2+NH4) [µ mol/l] at Helgoland Roads (BAH-data). Thick horizontal line marks the mean concentration of 1967 – 2008; the heavy solid line represents low pass filtered data like in Fig. 5.6.
The period between '88 and '96 is marked by large fluctuations in the nitrogen concentrations, reaching peak concentrations in '87/'88 and in '94/'95. In the end of the 90s the concentrations start to decrease again to levels comparable to the (early) 70s and below.

Chapter 6 Changes in plaice dynamics and distribution

Introduction

The Plaice Box was established to reduce the discarding of undersized plaice that are concentrated in shallow waters of the southeastern North Sea. The level of protection is affected by the duration of the time period that the fish are undersized and remain in the closed area as well as the natural mortality and fishing mortality rate in the area (Chapter 3; Pastoors et al., 2000). In previous Plaice Box evaluations, it was shown that the growth rate of plaice decreased and the distribution of the undersize fish moved offshore (ICES 1994; Grift et al., 2004; van Keeken et al., 2007). This chapter revisits the various processes affecting the dynamics of plaice with particular emphasis on the processes affecting recruitment, growth and distribution. The implications for the evaluation of the Plaice Box are discussed in chapter 9.

Material and Methods

Biological data

Biological samples were collected routinely since 1958 from plaice landings by commercial fishers and data on the gender, size, weight, age, sexual maturity were recorded. Additional samples of gender, size and age were collected during routine Research vessel (beam trawl) surveys starting in 1970.

Research vessel surveys

Research vessel survey data were available from the International Bottom Trawl Survey (IBTS) conducted in February – March and three beam trawl surveys (DFS, SNS, BTS) conducted between August – October. The IBTS use an otter trawl (GOV) with a stretched mesh size of 20 mm. Haul duration is 30 minutes at a speed of 4knots. The IBTS covers the total North Sea and is stratified by ICES rectangle in which normally at least two hauls are made. The Demersal Young Fish Survey (DFS), conducted since 1970 in the shallow coastal waters with a 6-m beam trawl with bobbin rope and stretched mesh of 20 mm and estuaries with a 3-m beam trawl with a bobbin rope and a stretched mesh of 20 mm, is focused at the 0-group flatfish. Haul duration is 15 minutes at a speed of 2-3 knots. The Sole Net Survey (SNS) is conducted in slightly deeper coastal waters since 1970 and deploys a 6-m beam trawl and a stretched mesh of 40 mm and is particularly focused at 1- to 3-group flatfish. Haul duration is 15 minutes at a speed of 3.5-4 knots. A 3rd Beam Trawl Survey (BTS) was started in 1985 covering the waters of the southeastern North Sea. The survey is conducted by RV ISIS using an 8-m beam trawl and a stretched mesh size of 40 mm, and is focused at the dominant age groups in the population (age 1 and older). Haul duration is 30 minutes at a speed of 4 knots. BTS survey data are used to study the distribution, whereas the DFS, SNS and BTS surveys are used to study variations in growth. Figure 6.1 shows the study area in the southeastern North Sea and the distribution of stations of the BTS survey.

Population dynamics

Population dynamics are based on the results of the stock assessments carried out by ICES. The plaice assessment includes estimates of discards. Discards are estimated from on board observations since 2000. Prior to this, discards are reconstructed from the growth curve of individual cohorts, the selection characteristics of the gear and the level of fishing mortality of the youngest fully recruited age group. A time series of the reproductive potential of the adult population, total egg production (TEP), was available from the UNCOVER project (Rijnsdorp et al., in press).

Spatial distribution

Distribution maps were generated showing the mean CPUE (number per fishing hour) by age group. This was done by aggregating data from a range of sources over a range of spatial and temporal 'compartments'. These included ICES statistical rectangles, some arbitrary grids, and/or simply whether or not a sample had been taken inside or outside the PB.

Confirmatory statistical 'testing' is difficult with observational data. At the Ijmuiden meeting in October, however, we realized that the PB was really simply an extension of the 12nm zone within which fishing by large vessels (>221kW) had been banned since the mid 1970s. The area outside the 12nm zone, but in the PB, is thus of critical interest because it is here that the fall in fishing effort in 1995 was most dramatic. The area within the 12nm zone in the PB, in contrast, has not been subject to any dramatic shifts in exploitation rates. Hence, if processes occur in both areas it potentially provides evidence for more global environmental effects being responsible. The data were therefore divided into the following four spatial compartments: (1) data inside the PB and inside the 12nm limit, 'in-in'; (2) data inside the PB and outside the 12nm limit 'in-out'; (3) data outside the PB but inside the 12nm limit, 'out-in' and (4) data outside the PB and outside the 12nm limit, 'out-out'. These four zones are plotted in Figure 6.1. This subdivision of our data is thus one of our theoretical frameworks that was taken up throughout the project in a range of analyses.

We then determine statistically whether any contemporaneous changes in temporal trends in the plaice population occurred when the PB was completely closed to large beam trawlers in 1995. To do this we first divided the data into the four areas described above and then constructed a 'dummy' variable denoting simply whether an observation had been made either before or after the closure of the PB which here we deemed to be 1995 when the most dramatic fishing effort reductions took place. The following four linear models were then fitted to the data for age 1s and age 5s from the survey data:

1. cpue=1
2. cpue=year
3. cpue=year+pb
4. cpue=year*pb

Model 1 is the mean level of cpue, model 2 tests whether there is a temporal trend, model 3 whether or not there was a change of level of the trend in 1995; and 4 whether there was a change in the gradient of the slope in 1995. Within each of the four areas (in-in = inside the PB and inside the 12nm zone; in-out = inside the PB and outside the 12nm zone; out-in = outside the PB zone and inside the 12nm zone; and out-out = outside the PB and outside the 12nm zone) nested ANOVA tests permitted the most appropriate model to be selected.

In another analysis, the distribution of 0-group plaice over the nursery grounds along the continental coast was summarised using DFS data by calculating the geometric mean density (numbers per 1000 m2) by 5 m depth zone and averaging the mean density taking account of the surface area of the depth zones down to 25 meter.

Growth

Growth was analysed from the mean length at age estimated from the commercial market samples (only fully recruited age groups) and the beam trawl surveys (pre-recruit age groups). Additionally, growth was analysed by back-calculation of otolith samples from female plaice sampled in January-February in the southern North Sea (Rijnsdorp and van Leeuwen, 1996). The otolith data set was extended with additional samples collected from the 1st quarter market samples of 1995-2008 comprising of around 120 otoliths per year. Otolith samples are length-stratified. Length increments (dL) were estimated for each year (1950-2008) and age (1-15) using the following statistical model. The model included sampling age (sampage) as a covariate to take account of the size-selective mortality.

$$dL \sim Year + Age + Year*Age + \ln(sampage) + \varepsilon$$

Otoliths of age groups that had not yet fully recruited to the fishery (age group <4 years) were excluded. A weight-vector was applied that corrected for the length-stratification of the annual otolith samples. Because growth rate may affect mortality, the sampling age of the otolith was taken into account and all growth increments were expressed as the predicted increment for a sampling age of 4. The validity of the back-calculation method is described in (Rijnsdorp et al., 1990).

The changes in growth were analysed in relation to environmental variables that are known to affect fish growth (temperature, eutrophication, beam trawl disturbance, see also Chapter 5).

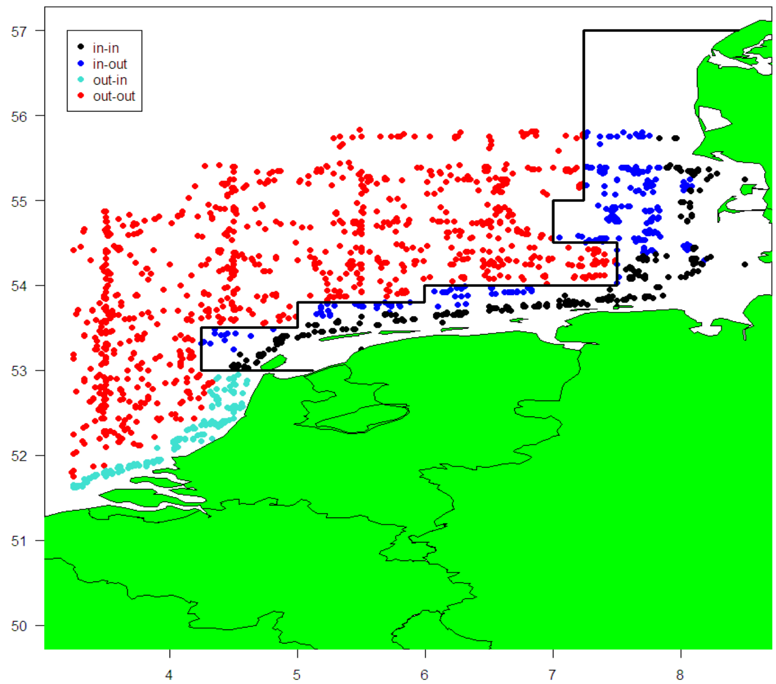


Figure 6.1. Map showing locations of BTS ISIS hauls 1987 – 2008 divided into four areas (in-in) data inside the PB and inside the 12nm limit; (in-out) data inside the PB and outside the 12nm limit; (out-in) data outside the PB but inside the 12nm limit and (out-out) data outside the PB and outside the 12nm limit.

Results and discussion

Population dynamics of plaice

Plaice biomass was rather stable in the 1960s and 1970s and temporarily increased in the 1980s, following the series of above average recruitment (Figure 6.2; see also Figure 2.2). In the 2000s stock biomass is at a level slightly below that of the 1960s. The spawning stock biomass, expressed as the number of eggs produced, has declined since the 1970s, reached a minimum in 2000 (15% of the level observed in the 1960s) and has partly recovered since then to 52% of that level in 2007.

Recruitment shows long-term variations with relatively low values in the 1960s and 2000s and relatively high values in the 1980s. Except for the exceptionally high recruitment in 1963, 1981, 1985, 1996 and 2001, inter-annual variations are rather low. The mortality index shows that the survival was rather low in the 1960s and reached a higher level since the 1970s. The rate of increase of the population biomass, estimated as the sum of the annual catch (landings plus discards) and the change in biomass in successive years, was relatively high in the 1970s and peaked in the early 1980s, and decreased to a lower level since the 1990s. Inter-annual variability in biomass increase rate was relatively low in the 1960s as compared to the period since 1990.

The abundance index of 0- and 1-year old plaice estimated from the pre-recruit surveys corroborate the period of relatively high recruitment in the 1980s (Figure 6.2). The survey indices reflect the pre-recruit abundance which is not yet affected by discarding in the flatfish fishery, although the signal may be affected by variations in the discard mortality induced by the fishery for brown shrimp, in particular for the 1-group (see Chapter 4). The decrease in the abundance of 0-groups in September-October suggests that the overall production of plaice larvae has been at a lower level since the establishment of the PB.

The increase in TEP in recent years coincides with the decrease in overall mortality due to the reduction in fishing effort of the major fleets (ICES, 2009).

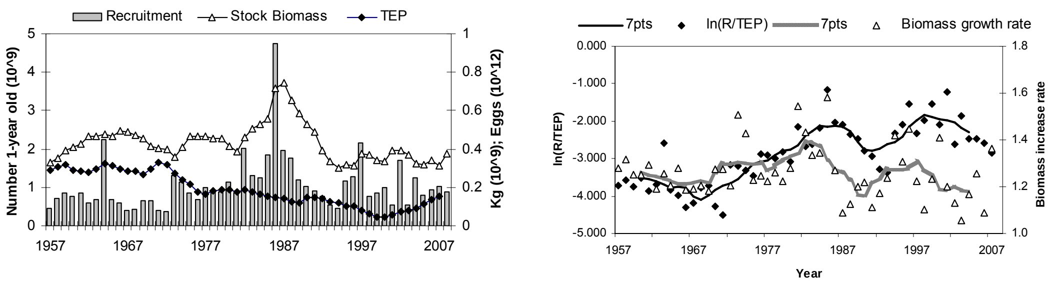


Figure 6.2. Population dynamics of North Sea plaice since 1950 showing the number of 1-year old recruits (109), stock biomass (109 kg) and total egg production (TEP) (10^{12}) and the index of mortality (♦ loge(recruits.TEP-1)) of pre-recruits and the rate of biomass increase (∆). The lines show the 7 point running mean trends.

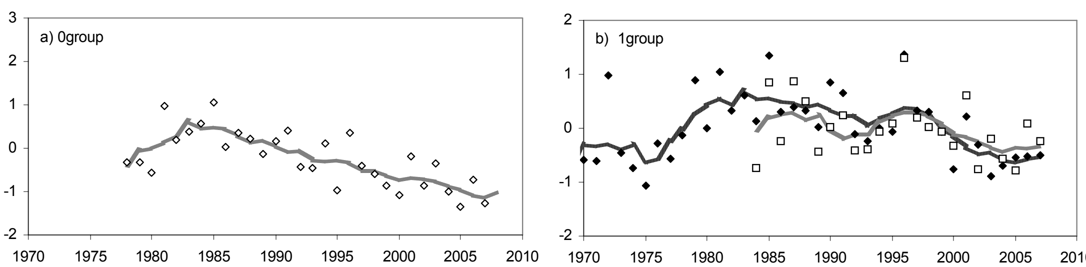


Figure 6.3. Survey index of 0-group plaice (panel a: DFS ∆) and 1-group (panel b: SNS ♦, BTS □). Lines present 5year running means.

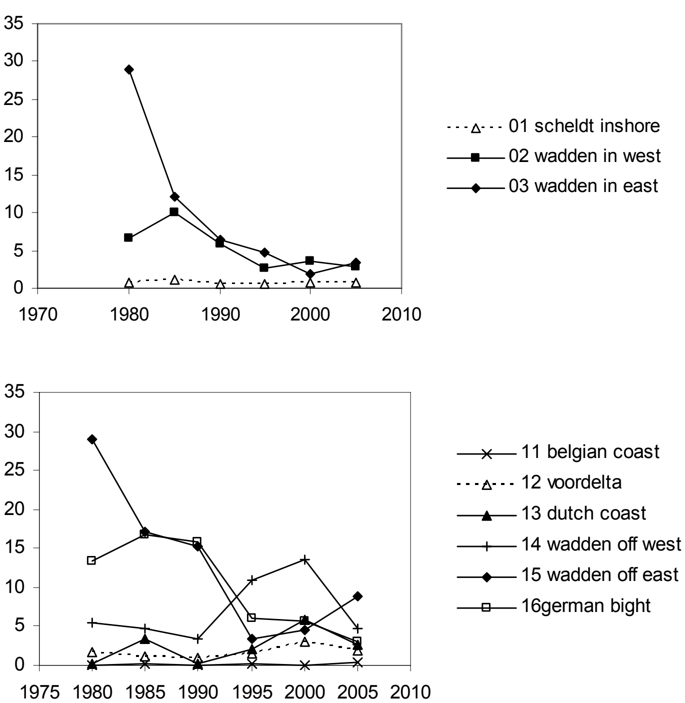


Figure 6.4. Geometric mean density of 0-group plaice (n.1000 m^2) by 5-year period (1980 = 1980-1984, etc) in different nursery areas from Belgium to the Horns Rif (Denmark) as observed in the DFS survey conducted in waters between 3-25 meters. Upper panel shows the estuarine habitats. Bottom panels shows the coastal habitats.

Spatial distribution

The distribution of 0-group plaice over the nursery grounds along the continental coast of the Netherlands, Germany and Denmark was analysed by 5-year period since 1980. Since plaice distribution is related to depth, geometric mean 0-group densities were estimated taking account of the surface area of the 5m depth strata sampled. 0-group densities show a clear geographic pattern with increasing densities from the Belgian coast towards the Wadden Sea and the German Bight (Figs 6.3, 6.4, and 6.5). Since 1995 the densities in the southern nurseries up to the western Dutch Wadden Sea have increased relative to the northern nurseries (German Bight and eastern Dutch Wadden Sea).

Concomitant changes in the depth distribution of the 0-groups were also observed (Fig. 6.8). In particular the waters of the Dutch Wadden Sea and along the Dutch and German coast, 0-group shifted to deeper waters in the 1990s. Similar changes in distribution were observed of different size classes in the beam trawl survey data set since 1985. Results show that all size classes showed an increase in depth between 1995 and 2000, but remained at similar depth in the late 1980s and early 1990s (Fig.6.9). Similar results were obtained from the analysis of the SNS survey data (not shown).

The shift towards deeper water at the end of the 1990s resulted in the occurrence at a lower bottom temperature at the time of the survey. The results indicate that the shift in depth distribution is not due to an immediate avoidance response to the increase in water temperatures around 1990, but occurred much later when temperatures were already high for a number of years.

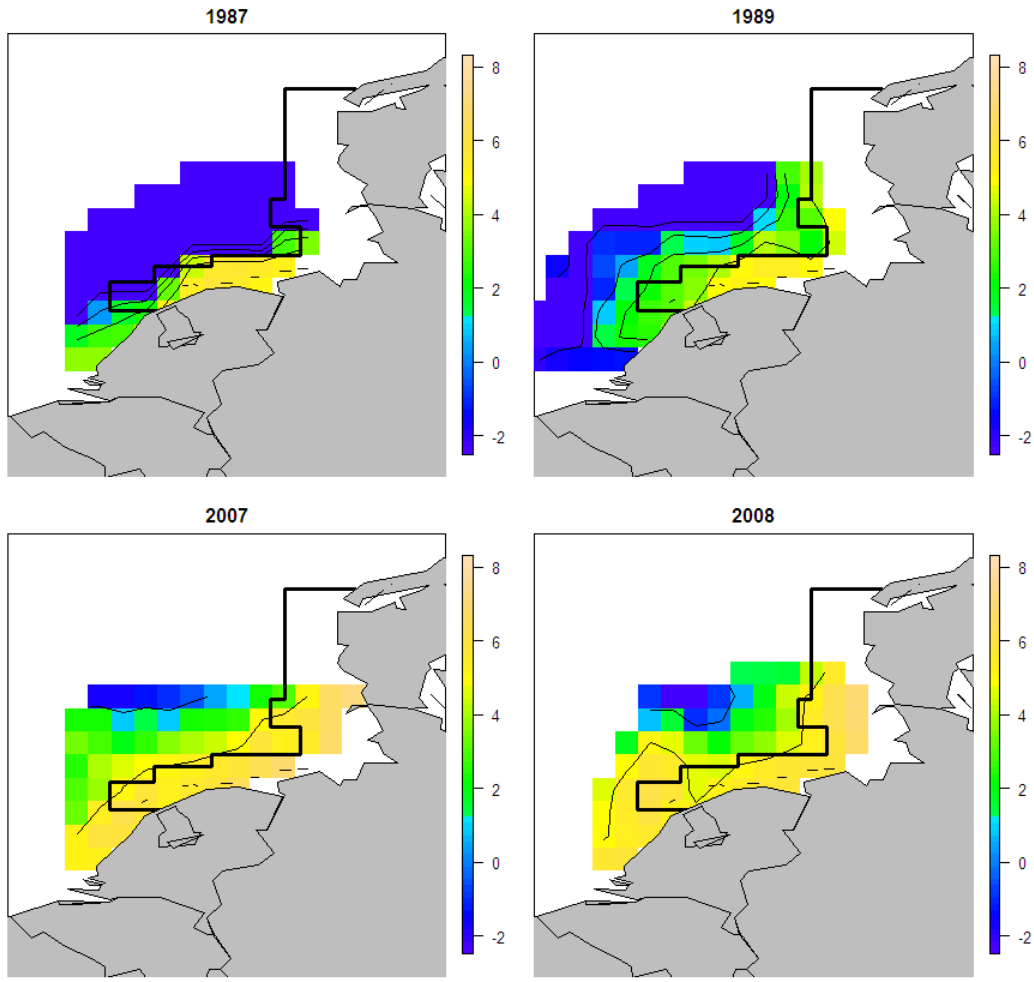


Figure 6.5. Spatial distribution of Age 0 plaice [log(noshr-1)] recorded during BTS ISIS surveys (quarter 3) between in 1987, 1988, 2007 and 2008.

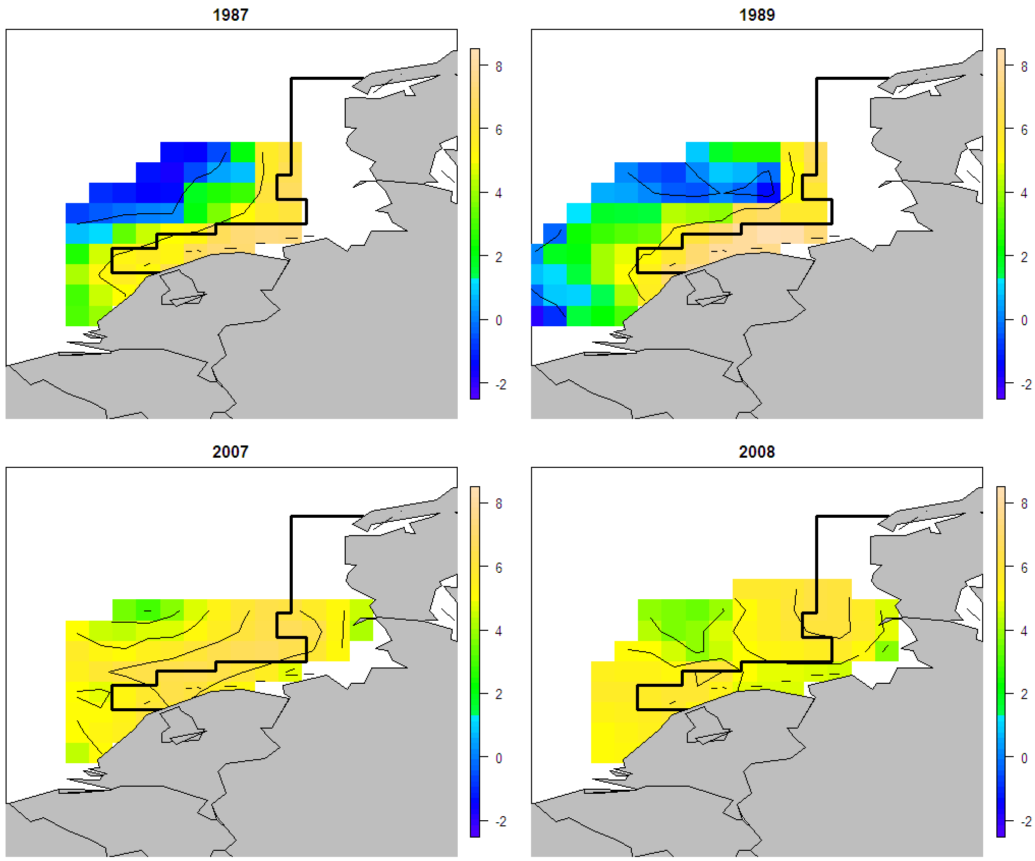


Figure 6.6. Spatial distribution of Age 1 plaice [log(noshr-1)] recorded during BTS ISIS surveys (quarter 3) in 1987, 1989, 2007 and 2008.

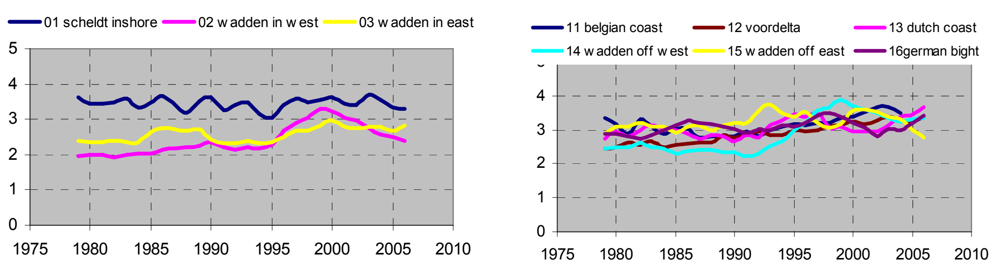


Figure 6.7. The mean depth (5 year running means of the 5-meter depth bins) of 0-group plaice in different nursery areas. Left panel shows the estuarine habitats. Right panel shows the coastal habitats. Depth is expressed in depth bins: 1 = 0-5m; 2 = 5-10m; 3=10-15m; 4= 15-20m and 5=20-25m..

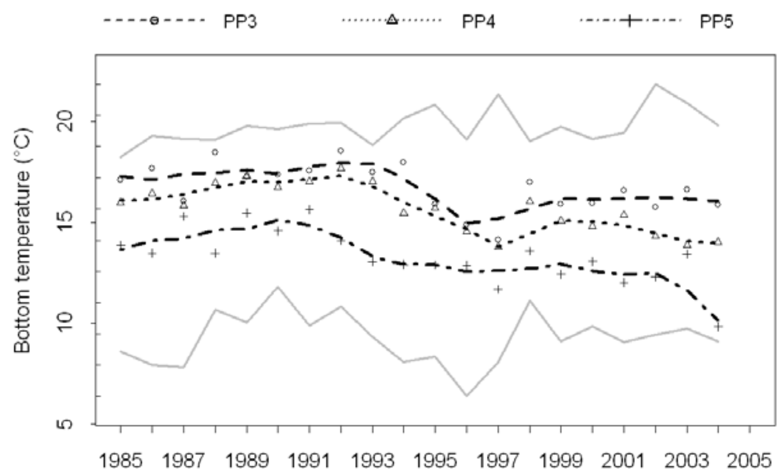


Figure 6.8. Changes in the depth and bottom temperature at which 50% of plaice of a particular size class (PP3 = 15-20cm; PP4 = 20-25cm; PP5 = 25-30cm) occurred within the BTS study area The continuous grey lines indicate the maximum and minimum depth or bottom temperature sampled. The dashed red-line in the upper panel is the mean bottom temperature in the survey area (van Hal et al., in prep).)

The change in distribution is also reflected in the contrasting time trends in abundance as recorded in the BTS survey in the four different areas: in-in (inside the PB and inside the 12 nm zone); in-out (inside the PB but outside the 12 nm); out-in (outside the PB but inside the 12 nm); out-out (outside the PB and outside the 12 nm). (Fig.6.9). The abundance of 0-group shows an overall increase in all four areas reflecting the offshore movement of 0-group into the depth zone sampled by the BTS survey. The abundance of 1-group increased in the area outside the PB and outside the 12 nm zone (out-out), whereas it decreased in the area in the PB and inside the 12 nm zone (in-in). For the age groups 2 and 3, the abundance decreased in the areas inside the 12 nm zone and inside the PB (in-in and out-in), while no clear trend was apparent in the out-out (Fig 6.9).

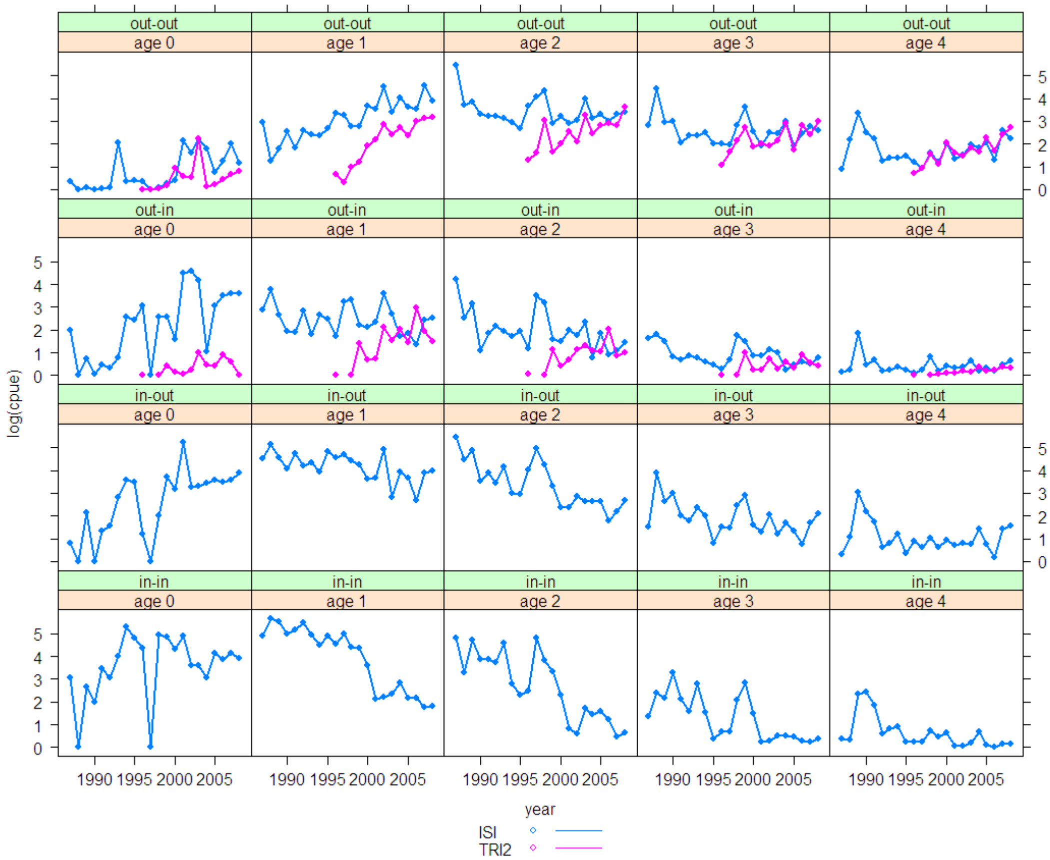


Figure 6.9. BTS survey data 1987-2008. Abundance (log numbers caught per hour) of age 0-4 plaice in four areas: in-in = inside the PB inside 12nm limit; in-out = inside PB outside 12nm limit; out-in = outside PB but inside 12nm limit and out-out = outside both PB and 12nm limit. See also Fig. 6.1.

The shift in the distribution of plaice has important consequences for the bycatch mortality in the flatfish fisheries with 80mm meshes targeting sole. This fishery is characterized by a substantial bycatch of plaice between 15 and 26cm. In order to reduce the discard mortality, an area along the continental coast between 53o and 57oN was closed to larger vessels in 1989 in the 2nd and 3rd quarter, and since 1995 for the whole year. The proportion of undersized plaice that inhabits the plaice box has gradually decreased from about 90% before 1995 to about 20% since 2005. It is noteworthy that not only the proportion of the discard size class in the plaice box has changed. The proportion of small plaice that is too small to be caught by the sole fisheries (<15cm) has decreased in the 2000s from more than 95% to about 80%. The proportion of marketable plaice (>=27 cm) in the plaice box increased in the four years following the closure of the plaice box in the 2nd and 3rd quarter, but gradually decreased since 1994 (Fig. 6.10).

The shift towards deeper water at the end of the 1990s resulted in the occurrence at a lower bottom temperature at the time of the survey. The results suggest that the shift in depth distribution is not due to an immediate avoidance response to the increase in water temperatures around 1990, but occurred much later when temperatures were already high for a number of years. The change in distribution to deeper and cooler waters is consistent with the effect of temperature and food availability on the scope for growth. Bio-energetic theory predicts that the temperature, at which the scope for growth is maximal, decreases when the food availability decrease. A decrease in food conditions is expected given the decrease in eutrophication (Phillipart et al., 2007) and corroborated by the decrease in macrobenthos in the southeastern North Sea (Chapter 8).

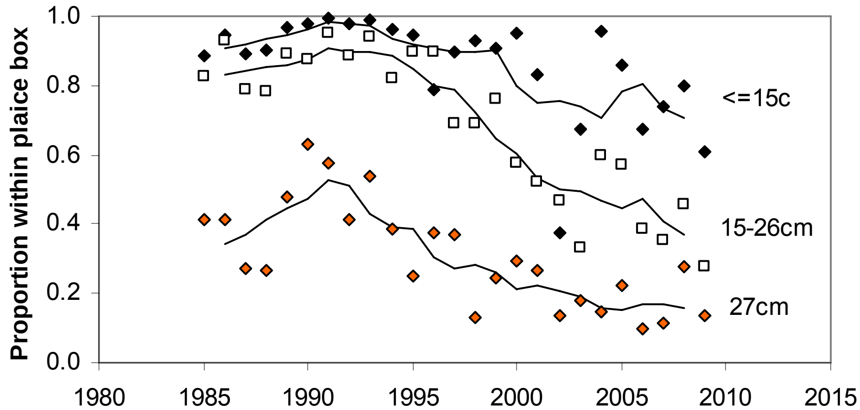


Figure 6.10. The proportion of plaice of three size classes (<=15cm, 15-26cm, >=27cm) that occurs inside the plaice box. Lines show the 5-year running means. Data from BTS Isis.

Growth rate

The time trend in the mean weight at age of plaice showed a dome-shaped pattern with highest weights observed in the 1970s and 1980s (Fig. 6.11). The annual weight increase of 5-7 year old females varied without a trend (results not shown) and contrasted with the decrease in males, as reflected in the almost disappearance of the difference in the weights of successive age groups.

The changes in weight at age of the recruited age groups are due to changes in growth of the pre-recruits, in particular age 1 and age 2. Length at age in the beam trawl surveys carried out at the end of the growing period showed highest lengths in the late 1970s and early 1980s and the decrease in the 1980s and 1990s, except for the 0-groups, as well as a temporary dip in growth rates in the late 1980s and late 1990s (Figure 6.11). The length of 4- and 5-years olds show an overall decrease since 1985. Male plaice show a steeper decrease in size than females. Variations in length of male and female plaice are consistent across surveys and sexes and are all significantly correlated.

Length- or weight at age reflect the cumulated effects of differences in growth rate, but do not reveal when the changes in growth rate actually occur. Back-calculating of the annual growth increments in the otoliths, however, allow us to estimated growth rates directly. Growth rates were significantly different between years and age groups, and were negatively affected by sampling age (Table 6.1). Growth rates were therefore standardized for a sampling age of 4 years, representing the age at which a cohort is fully recruited to the marketable size classes (>=27 cm). Growth rate of 1-group plaice varied around 9 cm and then started to increase in the late 1960s to about 11 cm in the late 1970s and decreased again in the 1980s to a level of about 10 cm (Figure 6.13). Superimposed on this dome-shaped pattern, temporary low growth rates were observed in the mid 1960s, late 1980s and late 1990s. Growth rate of 2-year and 3-year old plaice showed roughly similar patterns, although the variations were less pronounced.

Table 6.1. GLM analysis of the growth rate of female plaice estimated by back-calculation of otoliths.

	Deviance	df	MS	F	P
year	126.0	58	2.17	0.81	0.847
age	57533.7	28	2054.78	767.38	<0.001
year*age	5300.2	969	5.47	2.04	<0.001
logesampage	548.4	1	548.42	204.81	<0.001
error	59990.5	22404	2.68		
total	259096.1	23460			

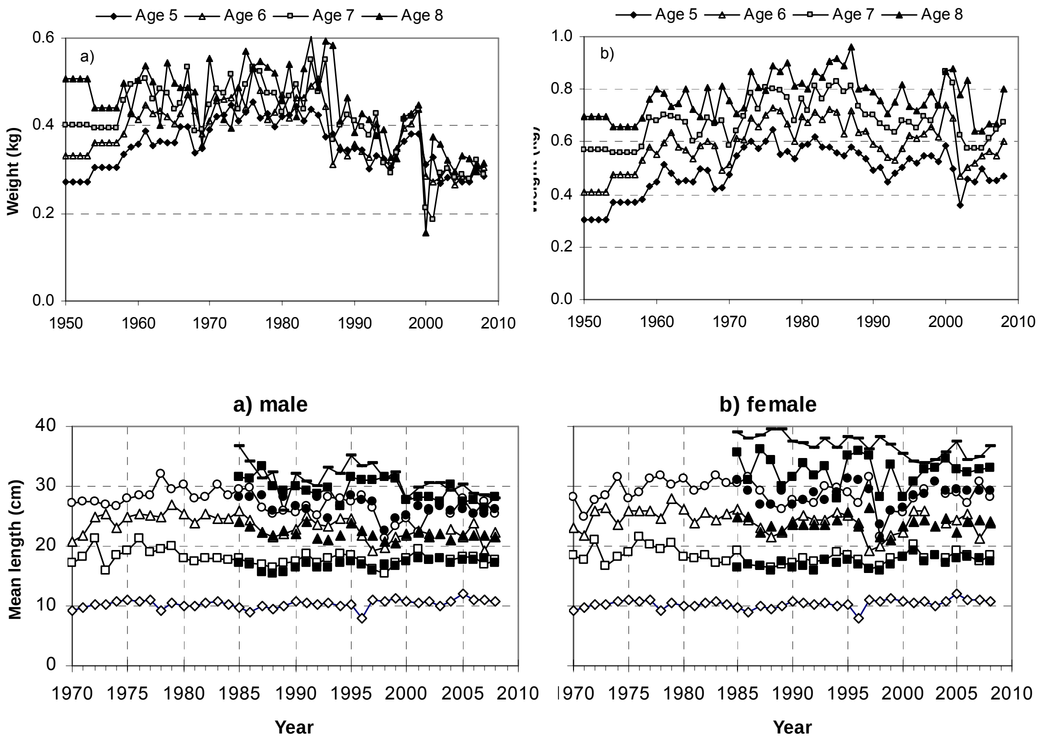


Figure 6.12. Variations in mean weight (upper panel) and length (lower panel) of male (left) and female (right) plaice. Mean weight at age is estimated from the landings. Mean length is estimated from the pre-recruit surveys conducted in late summer and early autumn: DFS (0-group - ◊); SNS (1-group - □; 2-group -∆ ; 3-group - ○); BTS (1-group - ■; 2-group -▲ ; 3-group - ●; 4-group - ▪; 5-group ▬)

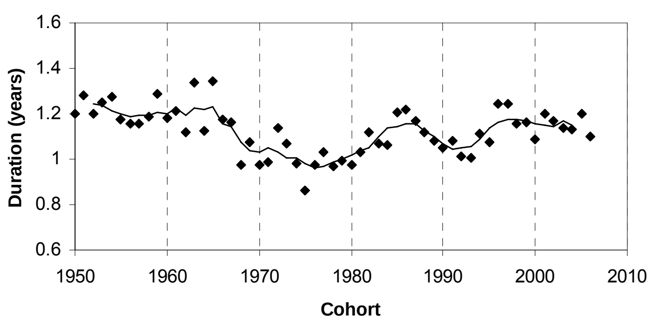


Figure 6.12. Duration (years) of the time period during which plaice is within the discard size range of 17-26cm based on back-calculated growth rate of 1- and 2-year old female plaice. Diamonds show estimate for each cohort. Line shows the 5-year running mean.

The changes in growth rate will affect the time period during which plaice is undersized. The duration of the discard period was estimated for each cohort based on the back-calculated growth rates of age groups 1 and 2 which predominate the discard size class. Compared to the period of high growth, the duration of the discard period increased by 20% from an average of about 1 year in the 1970s to 1.2 years since 1995 (Figure 6.12).

Variations in growth rates were analysed in relation to the environmental covariables: population abundance, temperature during the growing period, eutrophication, and sea bed disturbance (kW-hours of the Dutch beam trawl fleet). We used the time trend in phosphate as a proxy for eutrophication since this index is more appropriate for the limiting factors in the shallow coastal waters where the age groups live that have shown the strongest change in growth rate. Models including the main terms as well as the 2 and 3-way interactions between temperature, eutrophication and sea bed disturbance were tested. The final model was selected based on the lowest AIC of all possible models. The selected models are presented in Table 6.2. All models revealed that growth rate was reduced at high stock size. Eutrophication had a significant positive effect on growth rate, while sea bed disturbance was not selected. The percentage of the deviance explained by the models decreased from about 50% at age 0 and age 1 to 17% at age 3.

Results of a similar analysis of the length of male and female plaice observed in the surveys are presented in Table 6.3. The results were consistent with the analysis of the back-calculated growth rates. Stock size and eutrophication significantly affected both growth rates and length at age. Temperature was significant only for the 0-group. For 1-group, the length differed between surveys (BTS and SNS). For 2- and 3-group, male length was significantly smaller that female length. Sea bed disturbance was selected in the model for 1-group and negatively affected the length at age.

With the parameter estimates of the environmental covariables in Table 6.2 and 6.3, the sensitivity of the response variable for the selected covariables was estimated. The sensitivities of growth rate and cumulative length at age were quite similar. (Table 6.4). An increase of 10% in stock size resulted in a decrease in growth rate or length at age of 0.4-0.8%, whereas a 10% increase in eutrophication resulted in an increase of 0.6-2.1%. Temperature had a strong positive effect on 1-group: a 10% increase in temperature resulted in an increase in growth rate or length at age of 7-12%.

Table 6.2. Selected models on the environmental effects on the annual growth increment back-calculated from otolith growth patterns of female plaice of age group 1 to 3. Levels of significance: *** P<0.001; ** P<0.01; * P<0.05; . P<0.10.

Covariable	Estimate	Std. Error	t value	Pr(>ltl)	
Age group 0 (r2=0.49)					
(Intercept)	-2.822	1.776	-1.589	0.1183	
Eutrophication (PO4)	0.552	0.229	2.416	<0.05	*
Temperature (Q2, Q3)	0.801	0.122	6.587	<0.001	***
Age group 1 (r2=0.50)					
(Intercept)	8.949	0.271	33.065	<0.001	***
Stock size (numbers at age 1)	-1.54E-06	4.14E-07	-3.73	<0.001	***
Eutrophication (PO4)	1.709	0.254	6.738	<0.001	***
Age group 2 (r2=0.36)					
(Intercept)	7.516	0.263	28.613	<0.001	***
Stock size (biomass age 1-2)	-2.80E-05	1.18E-05	-2.368	<0.05	*
Eutrophication (PO4)	1.653	0.317	5.212	<0.001	***
Age group 3 (r2=0.17)					
(Intercept)	6.406	0.162	39.658	<0.001	***
Stock size (biomass age 1-3)	-6.63E-06	2.72E-06	-2.438	<0.05	*
Eutrophication (PO4)	0.574	0.183	3.14	<0.01	**

Table 6.3. Selected models of the environmental effect on the length at age 0 to 3 as observed in the beam trawl surveys carried out in the southeastern North Sea. Levels of significance: *** P<0.001; ** P<0.01; * P<0.05; . P<0.10.

	Estimate	Std. Error	t value	Pr(>ltl)	
Age 0 (r2=0.357)					
Coefficients:					
(Intercept)	2.18E+00	2.70E+00	0.805	0.426	
Stock size (numbers at age 1)	-8.55E-07	4.89E-07	-1.747	0.090	.
Eutrophication (PO4)	9.40E-01	4.53E-01	2.074	<0.05	*
Temperature (Q2, Q3)	5.13E-01	1.64E-01	3.128	<0.01	**
Age 1 (r2=0.376)					
(Intercept)	1.94E+01	8.13E-01	23.817	<0.001	***
as.factor(method)SNS	8.50E-01	2.28E-01	3.73	<0.001	***
stock	-1.91E-06	4.82E-07	-3.963	<0.001	***
po4	8.44E-01	4.60E-01	1.835	0.069	.
Sea bed disturbance (hp-days)	-3.41E-03	9.55E-04	-3.567	<0.001	***
Age 2 (r2=0.353)					
(Intercept)	2.05E+01	6.03E-01	33.909	<0.001	***
as.factor(gender)MAL	-1.09E+00	2.84E-01	-3.843	<0.001	***
stock	-4.89E-05	2.20E-05	-2.227	0.02811	*
po4	4.92E+00	8.77E-01	5.613	<0.001	***
Age 3 (r2=0.435)					
(Intercept)	2.43E+01	7.14E-01	34.065	<0.001	***
as.factor(gender)MAL	-1.68E+00	3.40E-01	-4.927	<0.001	***
stock	-1.88E-05	1.01E-05	-1.858	0.066	.
po4	5.68E+00	9.98E-01	5.689	<0.001	***

Table 6.4. Sensitivity of the response variables growth rate and length at age for a 10% increase in environmental covariables included in the selected models of Table 6.2 and 6.3.

	Back-calculated growth rate (cm.year-1)				Length at age (cm)			
	Age-0	Age-1	Age-2	Age-3	Age-0	Age-1	Age-2	Age-3
Stock size		-0.7%	-0.8%	-0.7%	-0.4%	-0.5%	-0.6%	-0.5%
Eutrophication	0.6%	1.8%	2.1%	0.9%	1.0%	0.5%	2.2%	2.1%
Temperature	12.8%				7.5%			
Sea bed disturbance						-1.2%		

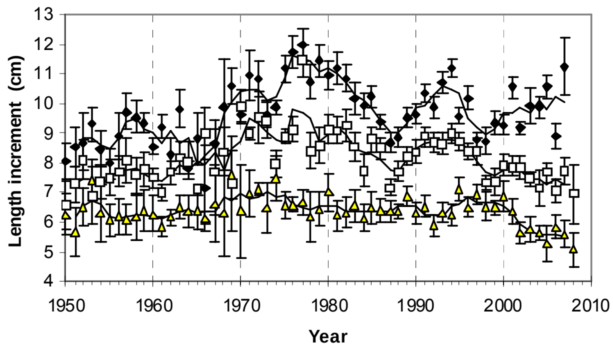


Figure 6.13. Length increment (cm) back-calculated for 1-year (♦), 2-year (□) and 3-year (∆) old female plaice.

Results of the trend analysis in the BTS data

For the age 1s model 2 (cpue=year) was the best for the age 1s in three areas (in-in, in-out, out-out) while model 1 was selected for the out-in region. The fitted models are plotted in Figure 6.15 and the results of the nested ANOVAs can be found in the Appendices to Chapter 6. In the PB both trends were negative although in-in was steeper. There was no evidence that anything 'unusual' happened in 1995. That is to say the trend was downward in the period before the PB was closed and the closure did nothing to change this. There was no statistically discernible trend in the 12nm zone outside the PB. Outside the PB (out-out) the gradient of the significant year term was positive; but again there was no (statistical) evidence of any change in 1995.

This was not such a useful approach for the Age 5s (Fig. 6.15) and the trend is less well described by the linear model, especially before 1995 when patterns in all areas show a dome between 1987 and 1994 with the peak centred on 1990. Nevertheless the models and plots are informative. The overall pattern of trends in the age 5s is rather similar to that in the age 1s. There was a significant downward trend for 'in-in', and flat trends for 'in-out', and 'out-in'. The only area where the interaction term was selected was out-out (Fig. 6.15, bottom right) and although statistically 'significant' the differences in slope are small.

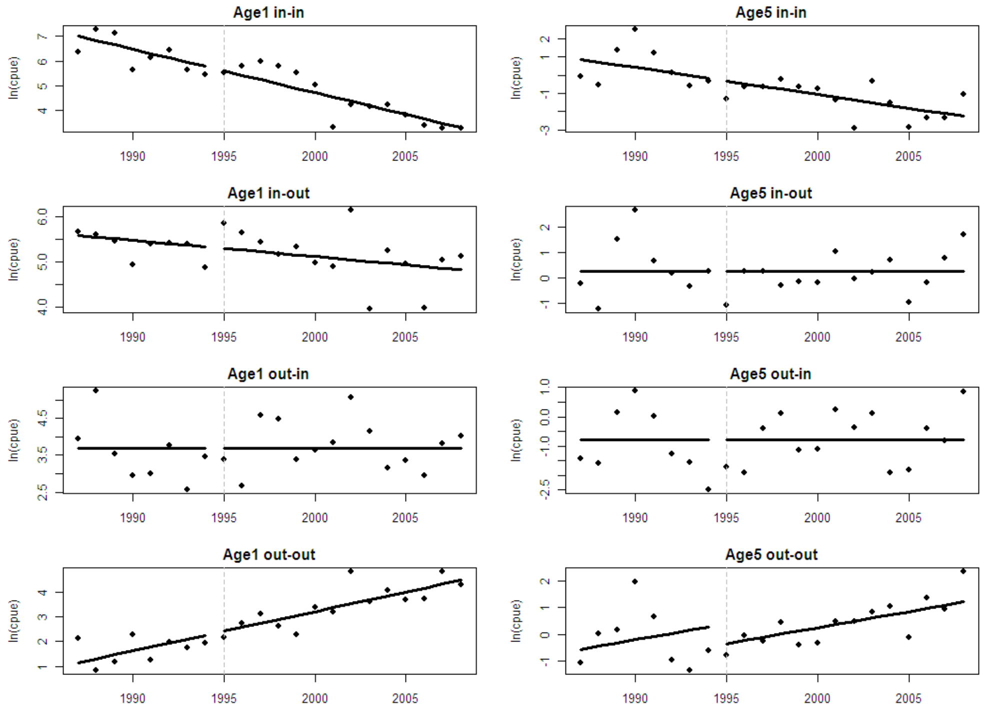


Figure 6.15. Temporal trends in the abundance of Age 1 and Age 5 plaice in four areas of the south-eastern North Sea. In each plot the model selected is plotted.

The same approach was then tried using the Dutch effort data from the logbooks. In this case it was not possible to split the data into those recorded in the four areas described above. Here we could, perforce, divide the data into only two spatial subsets: those recorded inside the PB and those outside. In this instance there was clear evidence of a sharp change in the trend in fishing effort in both areas in 1995 and model 4 (cpue=year*pb) was selected to summarise both although the shape of the trends was quite different in each area. Inside the PB (although much of this effort will be outside the 12nm zone) effort was, and is, much lower than outside (Fig6. 16) and was falling already between 1990 and 1995. After 1995 there was a stepwise reduction followed by a continued decline. Outside the PB overall effort was increasing between 1990-1994 after when it has also declined.

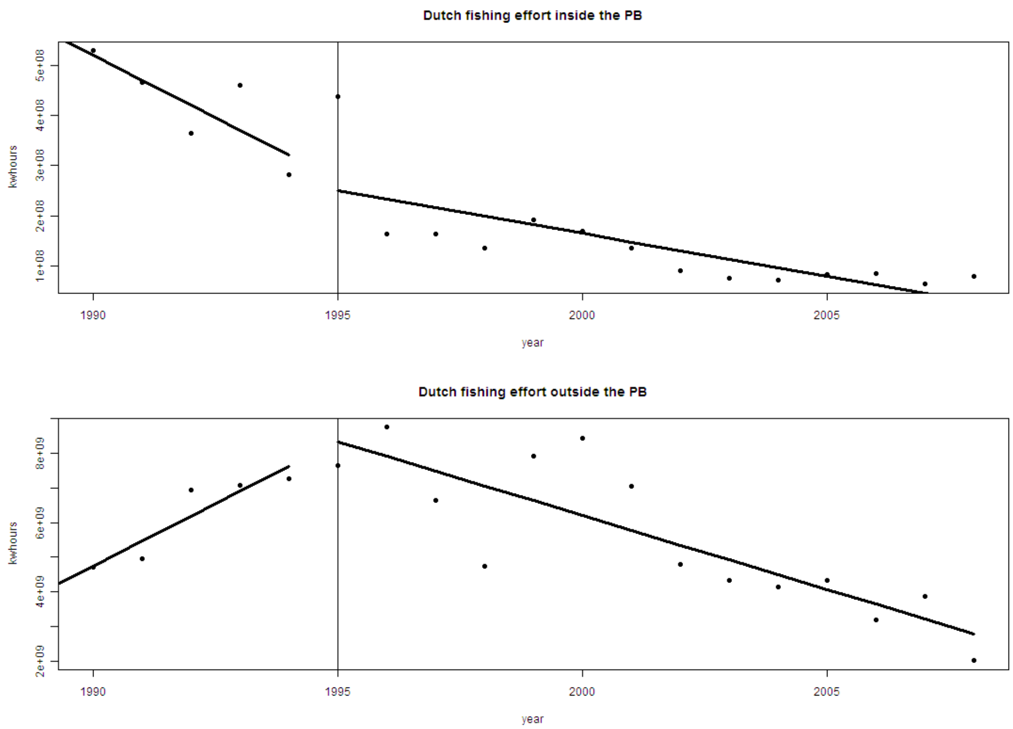


Figure 6.16. Temporal trends in Dutch fishing effort 1990-2008 inside (top) and outside the plaice box.

Conclusions

Pre-recruit surveys showed that 0-group and 1-group abundance decreased since a peak around 1980, suggesting multi-annual variations in larval supply to the continental nursery grounds.

Time trends in growth of plaice showed a dome-shaped pattern with high growth in the late 1970s and early 1980s and correlated with the dome-shaped pattern in eutrophication. Superimposed on this dome-shaped pattern, growth was reduced with high population abundance. The density-dependent effect was relatively small. A 10% change in density resulted in a change in growth of less than 1%.

The change in growth of pre-recruit plaice resulted in a 20% increase in the time period that plaice are in the discard size class from 1 year in the 1970s to 1.2 year in the 2000s.

Survey data clearly showed that plaice has moved to deeper waters. The change in distribution occurred in the mid 1990s, several years after the increase in water temperature around 1989. The change in distribution was observed in all pre-recruit age groups and was not restricted to certain areas but occurred both inside the 12 nm zone, inside the PB as well as outside the PB.

Time trends estimated from BTS survey data in the abundance of age 1 and age 5 plaice are similar in all four areas (see Fig. 6.15). Abundance falls in the in-in area and rises in the out-out area and there was no significant difference in trend associated with the complete closure of the box to large beam trawlers.

The change in distribution is consistent with a behavioural response to a change in the temperature at which the scope for growth is maximized under a decrease in the availability of food.

Due to the change in distribution, the proportion of the undersized plaice that occurred inside the PB decreased from about 90% in the 1980s to about 30% in recent years.

The increase in the time period that plaice are in the discard size class in combination with the lower proportion that occurs in the PB will result in an increase in the discard mortality.

The reduction in the fishing mortality, due to the decrease in the fishing effort, allowed the plaice stock to increase despite the continued high level of discarding.

Chapter 7 Fish Community (Assemblages and Diversity)

Databases

In order to study the effects of the plaice box on fish assemblages and diversity, data from the Dutch BTS ISIS survey between 1987 and 2008 and from the German DYFS between 1989 and 2008 were utilised.

The Dutch BTS ISIS survey

The Dutch Beam Trawl Survey (BTS) with the Dutch RV Isis takes place every year in August and covers a wide area, both inside and outside the plaice box. Thus, data could be aggregated in 4 spatial categories:

in – in = inside the plaice box and within the 12 nm zone
in – out = inside the plaice box and outside the 12 nm zone
out – in = outside the plaice box and within the 12 nm zone
out – out = outside the plaice box and outside the 12 nm zone.

For each of these areas catch data were aggregated as the mean catch per unit of effort (numbers per hour) by species. Because the level of identification changed over the observed time period some of the taxa had to be aggregated to the next higher taxon. This was particularly true for the genus Callionymus (dragonets) and for the family Gobiidae (Gobies). Because pelagic species such as herring, sprat, mackerel and horse mackerel are taken only coincidentally with beam trawl catches, those taxa were excluded from further analysis.

The German DYFS

The German Demersal Young Fish Survey (DYFS) was initiated in 1989 and was carried out on commercial trawlers utilizing a 3 m beam trawl. Sampling was carried out each year in September. The abundance of species was standardized to 1 ha (10,000 m^2). Different areas in the Wadden Sea were investigated (Fig. 7.1). Figure 1 already shows that the effort was not evenly distributed over time within each of the areas and only the area "Buesum" (see Fig. 7.1) yielded a consecutive series between 1989 and 2008. Therefore, this area was selected for the analysis of possible changes in the fish assemblages and diversity. For the further analysis, several stations had to be excluded from the data, because they were positioned in areas that were not sampled every year. All sampled stations lay inside the plaice box. For the same reasons as above, all pelagic species were excluded as well from the analysis.

Data analysis

The PRIMER v6 Package (Clarke and Warwick 1994) was used to analyse the catch for similarity of species composition. Multidimensional Scaling (MDS) based on the Bray-Curtis Index of similarity was utilised to detect differences in fish assemblages between the different years and areas where appropriate. In order to minimize the influence of the very abundant species on the assemblage analysis, all data were fourth-root transformed prior to calculating the Bray-Curtis index of similarity.

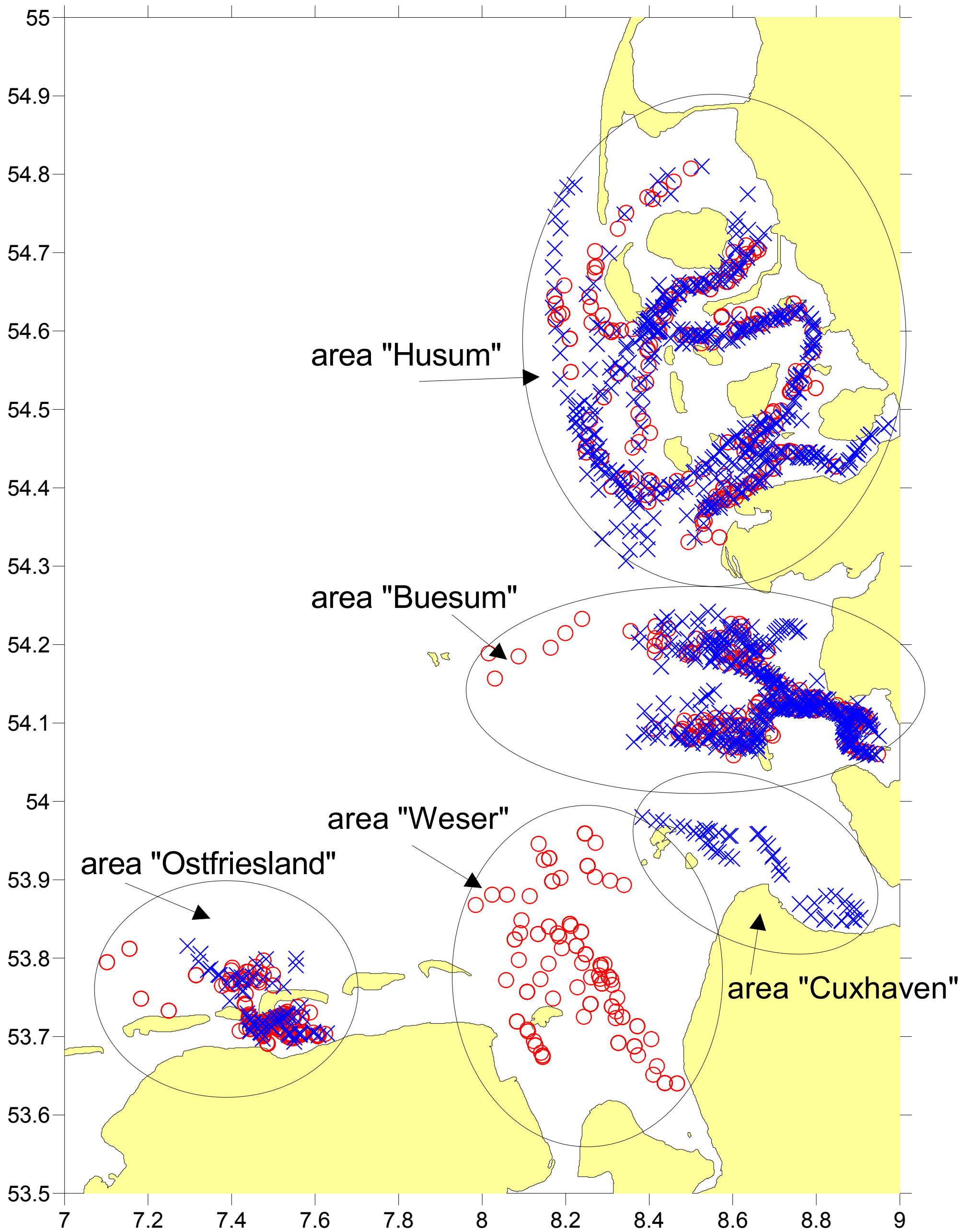


Figure 7.1: The catch positions of the German DYFS 1989 - 2008. Blue crosses indicate stations sampled between 1989 and 2001, the red circles those stations sampled between 2002 and 2008.

Results

The Dutch BTS ISIS survey

With respect to the total catch of demersal fish species the comparison between the four areas showed that the number of caught fish remained quite stable in the areas outside the plaice box. Inside the plaice box total catch was considerably higher than outside at the beginning of the time series but declined afterwards towards values closer to those outside the plaice box (Fig. 7.2)

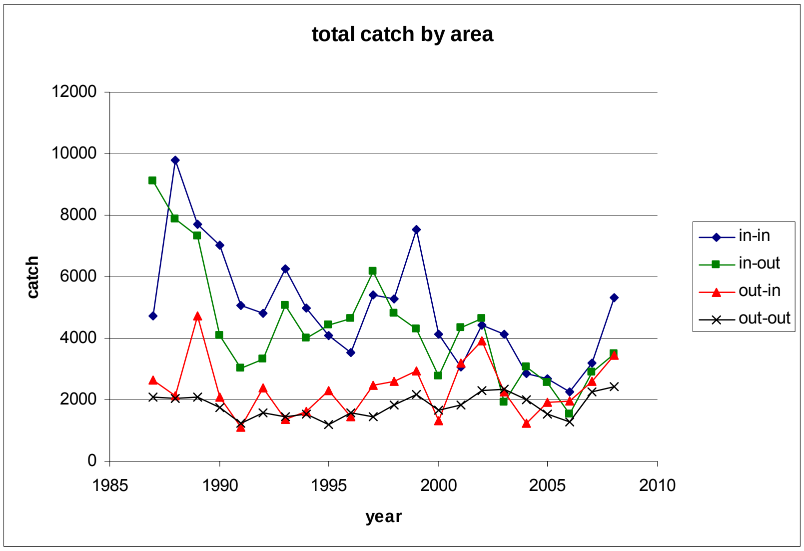


Figure 2: total mean catch per unit of effort by area

The total number of demersal species was always highest in the area that was both, outside the plaice box and outside the 12 nm zone and varied between 27 and 37 but was mostly above 30 species. In the other areas the number of species was always lower, mainly between 20 and 30. There was no trend to either more or less species over time for all areas (Fig. 7.3).

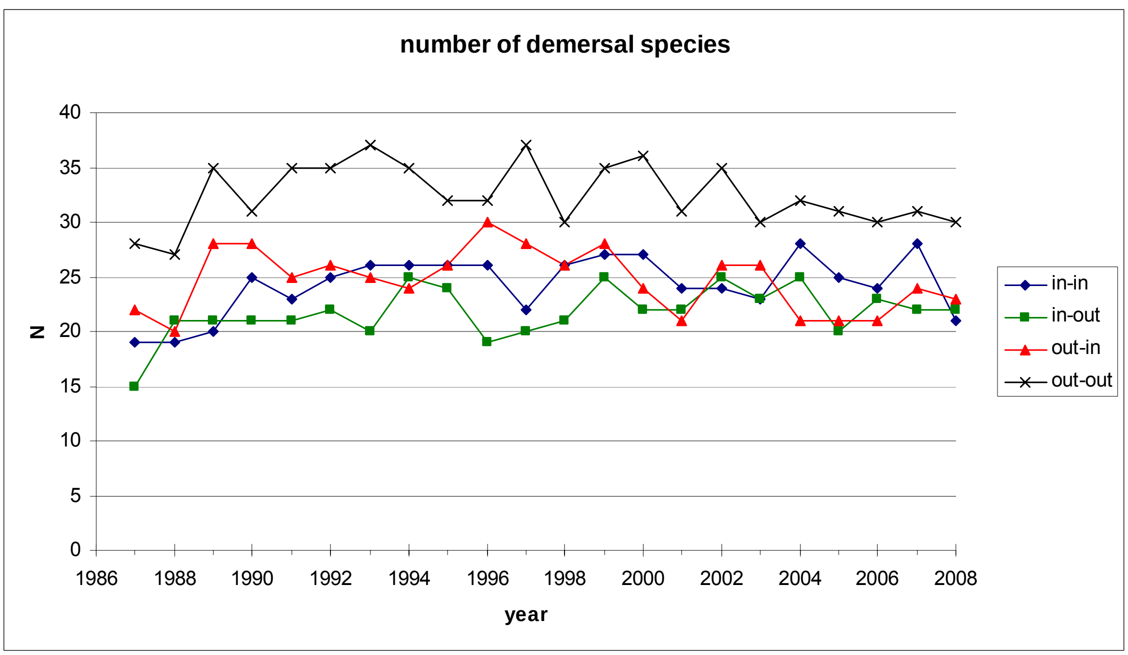


Figure 3: The number of species caught per year and area from Dutch ISIS BTS surveys

Both diversity indices, the Shannon-Wiener H' and Pilou's evenness J were lowest at the beginning of the time series for all areas and increased until 1995 followed by a sharp drop in diversity in 1996 (Figs. 4 & 5). After that, diversity increased again to values mostly between 1.5 and 2.0 and remained more or less stable until the end of the time series. Values inside the 12 nm zone were higher than outside it.

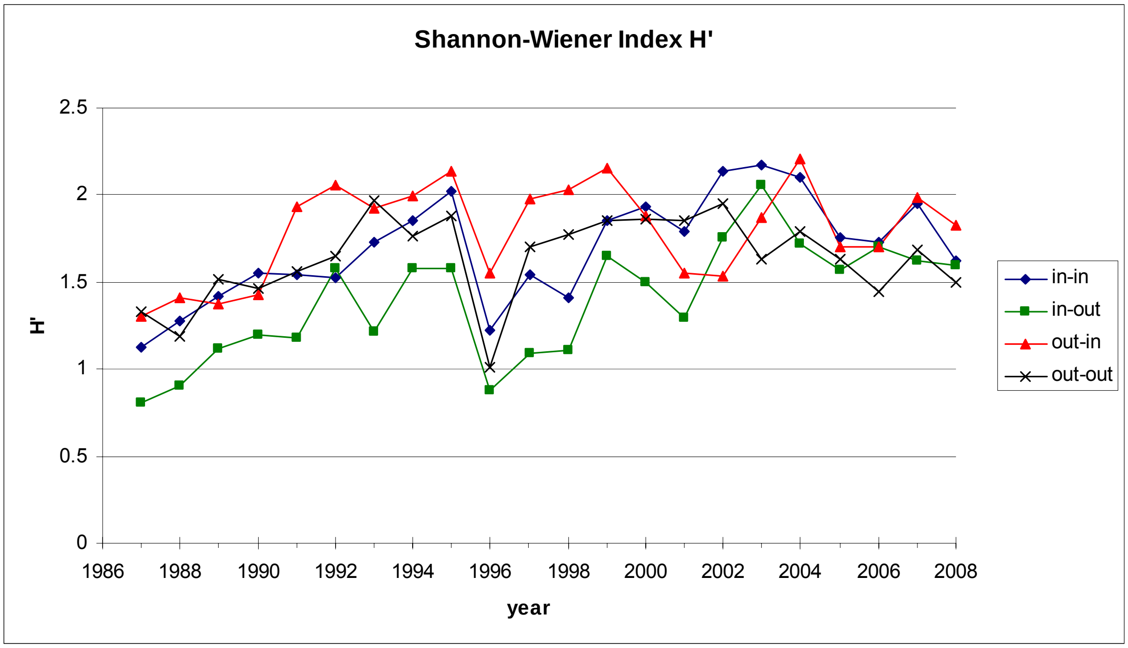


Figure 7.4: The Shannon-Wiener diversity index H' by year and area from Dutch ISIS BTS surveys

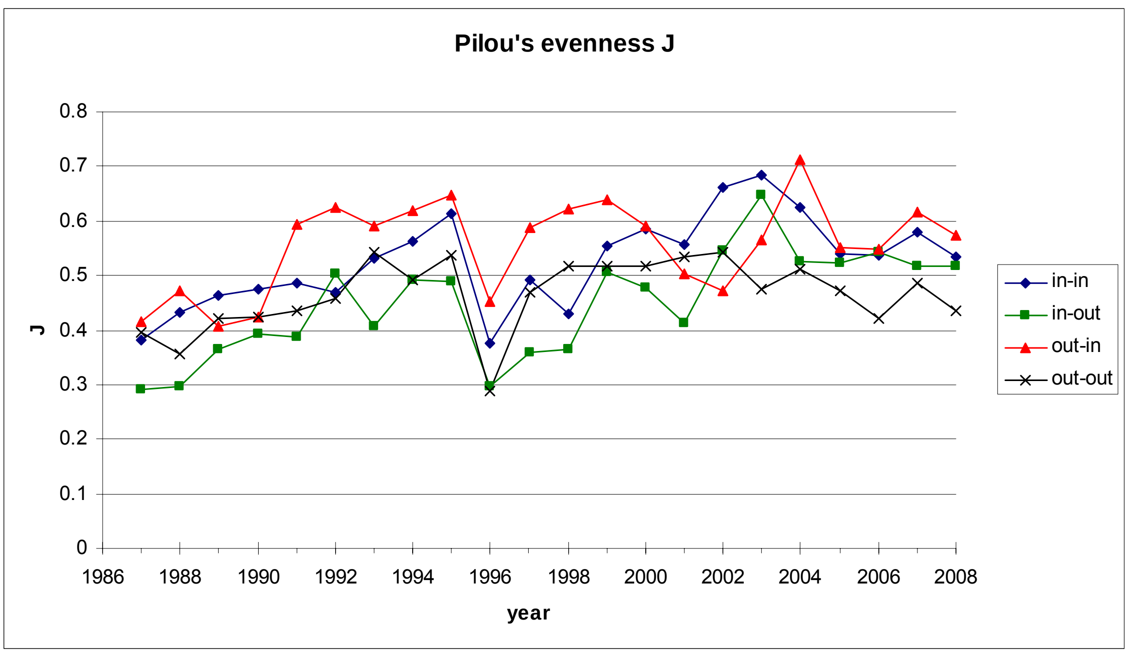


Figure 7.5: Pilou's Evenness index J by year and area from Dutch ISIS BTS surveys

Several species showed conspicuous trends in their abundance as summarized in table 1. Inside the plaice box, several species declined in their abundance, particularly in the area inside the 12 nm zone: plaice, turbot, brill and sole all decreased while only scaldfish, dab and lemon sole increased in abundance. Scaldfish, solenette and flounder increased outside the 12 nm zone and inside the plaice box, while dab and sole decreased there. Outside the plaicebox and inside the 12 nm zone only dab showed a slight decrease, while scaldfish, solenette, whiting, lemon sole, flounder and plaice increased in abundance. Outside the 12 nm zone and outside the plaice box hooknose and cod decreased in abundance, plaice only decreased until 1995 but increased to values slightly above its original abundance afterwards. Other species that increased over the complete period were scaldfish, solenette, tub gurnard, lemon sole and flounder. Overall there were more species increasing in their abundance outside the plaice box than inside the plaice box. This seems a bit contradictory to the observation that total fish abundance did not show any trend over time outside the plaice box. However, most of the species increasing in abundance only occurred in small numbers while the total catch was chiefly driven by highly abundant species like dab and plaice that did not change over time.

Table 1: Trend in abundance indices of selected species from Dutch BTS ISIS surveys between 1987 and 2008

	in – in	in – out	out – in	out – out
A. cataphractus – hooknose	no trend	no trend	no trend	decrease
A. laterna – scaldfish	increase	increase	increase	increase
B. luteum – solenette	no trend	increase	increase	no trend – slight increase
C. lucernus – tub gurnard	no trend	no trend	no trend	increase
G. morhua – cod	no trend	no trend	no trend	no trend – decrease
L. limanda – dab	decrease → 2004 then increase	decrease	no trend – slight decrease	no trend
M. merlangus – whiting	no trend	no trend	no trend – slight increase	no trend
M. kitt – lemon sole	no trend – slight increase	no trend	no trend – slight increase	increase
P. flesus – flounder	no trend	no trend – increase	no trend – slight increase	increase
P. platessa – plaice	decrease	no trend	no trend – slight increase	decrease → 1995 then increase
P. maxima – turbot	not trend – slight decrease	no trend	no trend	no trend
S. rhombus – brill	decrease	no trend	no trend	no trend
S. solea – sole	decrease	no trend - decrease	no trend	no trend

in – in = inside plaice box and inside 12 nm zone
in – out = inside plaice box and outside 12 nm zone
out – in = outside plaice box and inside 12 nm zone
out – out = outside plaice box and outside 12 nm zone

The MDS ordination of the species similarity matrix for all years and areas revealed that the fish assemblages outside the plaice box and outside the 12 nm zone showed a large degree of resemblance of more than 80 % over the complete time series. These assemblages grouped well separated from all other areas that were grouped in one cluster of more than 70 % resemblance (Fig. 7.6). None of the areas showed conspicuous trends with respect to changes in species assemblages over time.

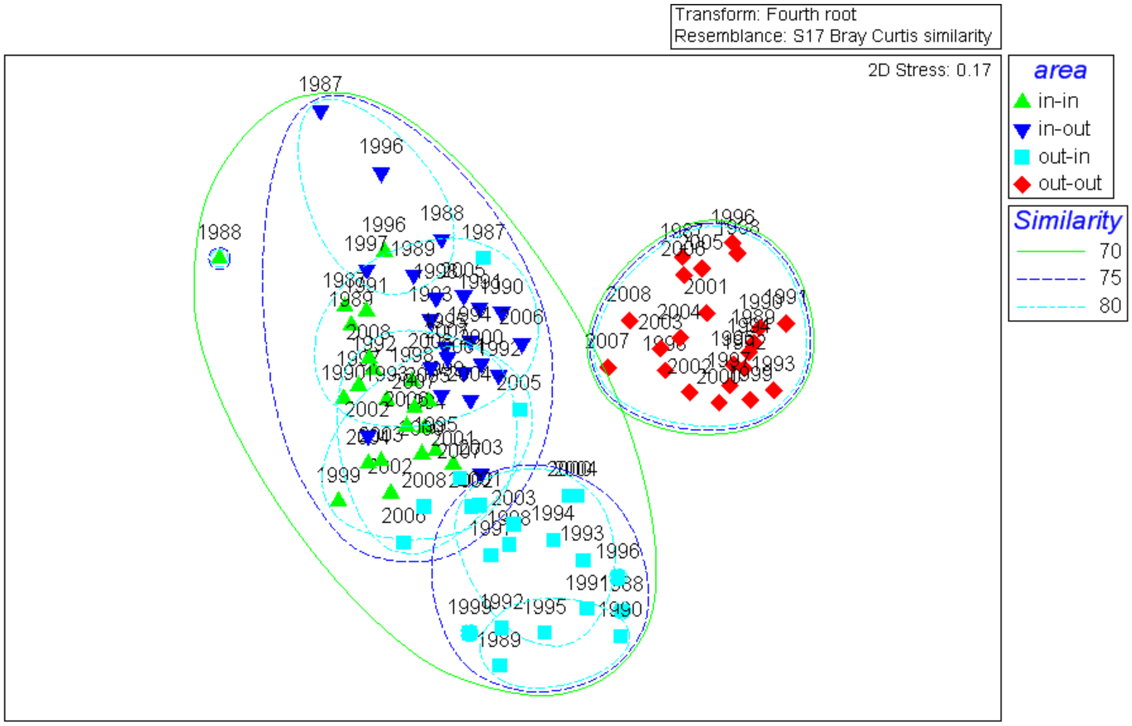


Figure 7.6: Two-dimensional MDS ordination of the Bray-Curtis similarity matrix for annual mean fish species assemblages in the four different areas in-in, in-out, out-in and out-out. The distance between to data points corresponds to the amount of dissimilarity between two corresponding species assemblages.

The German DYFS

The total catch in mean numbers of fish caught during each survey varied strongly between the years but showed no trend over the complete time series (Fig. 7.7). The high variability in total catch was driven by a small number of species that fluctuated conspicuously between very high and low to very low numbers between consecutive years. These species were dab (Limanda limanda), whiting (Merlangius merlangus), plaice (P. platessa), gobies (Pomatoschistus spp.), and the pipefish Syngnathus rostellatus. Dab was conspicuously abundant only at the beginning of the time series, peaking at an average catch of 413 individuals per ha in 1991 but occurred only in low abundance (< 40 ha-1) afterwards. Whiting peaked in abundance in 2001 with a mean abundance of almost 450 individuals per ha but occurred in much lower numbers (mostly < 20 ha-1) in all other years. Plaice occurred in conspicuously increased abundances in 1996 (mean catch > 803 ha-1) and 2001 (mean catch > 412 ha-1). Gobies were very abundant in 1989 (mean catch > 313 ha-1) and in 2004 (mean catch 590 ha-1). The pipefish S. rostellatus was very abundant in 2004 peaking at 395 individuals per ha.

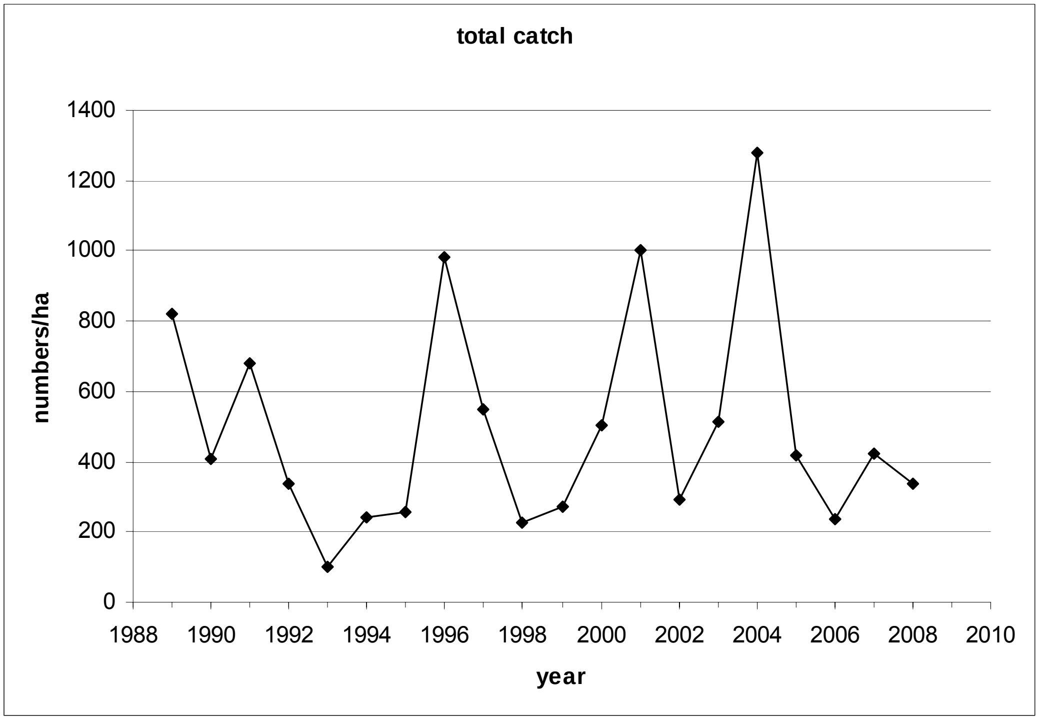


Figure 7.7: The total catch in numbers per hectare caught per year in the Buesum area during German DYFS

The number of demersal species caught each year varied between 11 and 20 but fluctuated chiefly between 15 and 18 species per year (Fig. 7.8). There was no trend either to higher or to lower numbers of species discernible. This was also reflected in the Shannon-Wiener H' (Fig. 7.9). The index fluctuated chiefly around the comparatively low value of 1.5. Interestingly, the Shannon Wiener index showed a similar sharp decline in 1996 comparable to that in the Dutch BTS data.

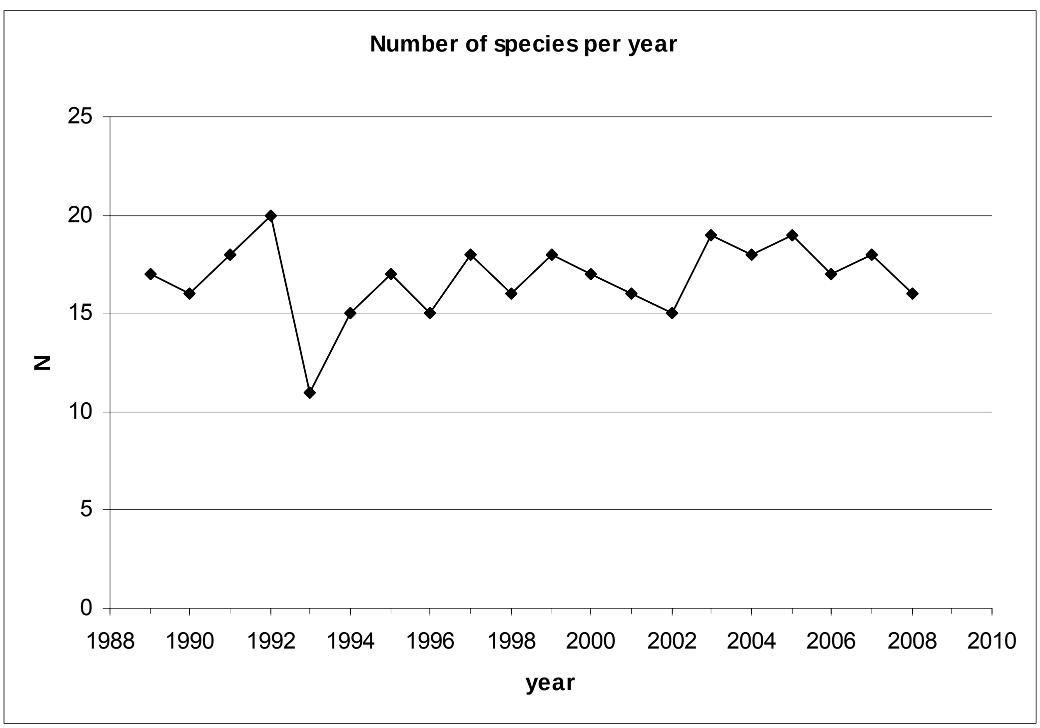


Figure 7.8: The number of species caught per year in the Buesum area during German DYFS

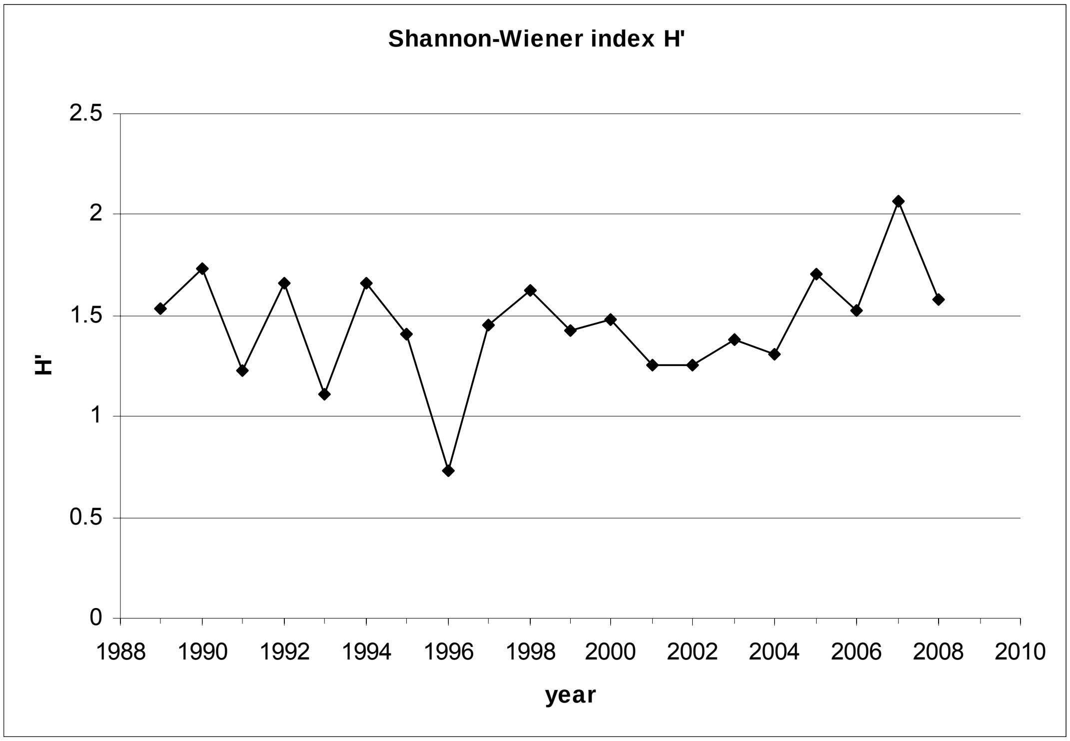


Figure 7.9: The Shannon-Wiener diversity index H' by year for the Buesum area during German DYFS

The species assemblages were similar by more than 70 % resemblance for most of the years, except 1991, 1993, and 2002 which had a resemblance to all other years of only > 60 %. There was no trend discernible in the MDS ordination of the species similarity matrix (Fig. 7.10).

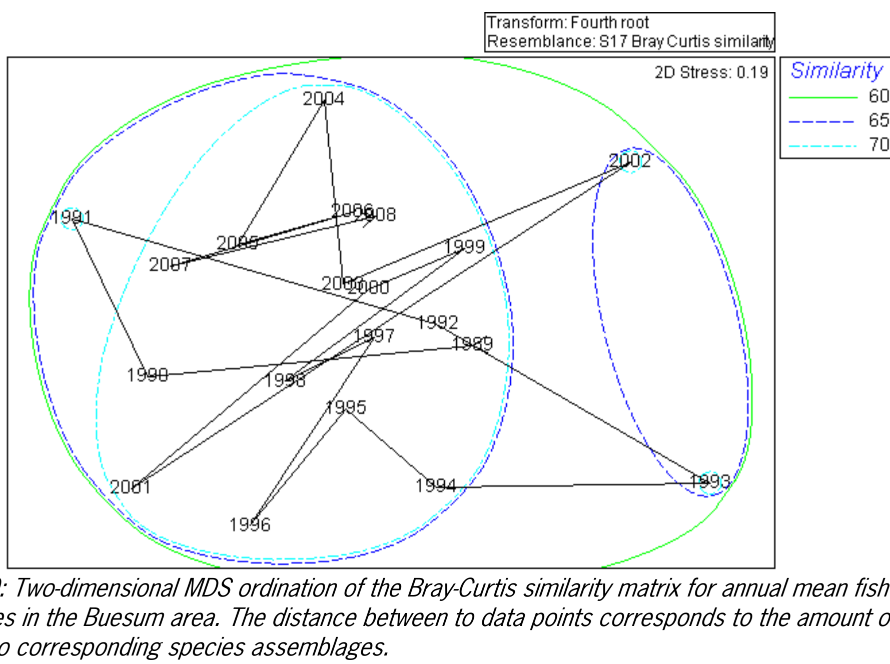


Figure 7.10: Two-dimensional MDS ordination of the Bray-Curtis similarity matrix for annual mean fish species assemblages in the Buesum area. The distance between to data points corresponds to the amount of dissimilarity between two corresponding species assemblages.

Conclusions

- The total mean catch rates of demersal fish decreased inside the PB.
- Outside the plaice box total mean catch rates of demersal fish remained at the same level.
- The decline inside the plaice box was predominantly due to a decline of the dominating flatfish species plaice, dab and sole.
- The decline in total fish abundance inside the plaice box was not matched by an increase in total fish abundance outside the plaice box.
- Despite the decline in dominant fish species, the structure of the fish assemblages inside the plaice box did not change significantly because those species, particularly plaice and dab, remained dominant.
- There was no indication that the closure of the plaice box had any effect on the fish diversity or fish assemblages.
- Data from German DYFS rather suggest that fish assemblages are more likely to be affected by differential recruitment and/or subsequent migration into coastal areas in the different abundant species.

Chapter 8 Benthic community

Summary

The Plaice-Box (PB) border more of less follows a natural border between benthic habitat types and no appropriate monitoring program was set in place when the PB was established. This makes separating PB effects on benthic communities from the effects of climate, eutrophication and pollution very difficult. Based on the presently available data, which were originally collected for different purposes, no significant spatial differences were found to be associated with the PB, within the same community type.

However, for a number of stations in- and outside of the PB, long term series are available that do show marked community changes in the mid-90s coinciding with the (partial) closure of the area to fishing. Multivariate analyses indicated that differences between stations outside and inside the PB existed; even before the start of the closure of the PB area to beam-trawling. The difference persisted during the subsequent 15 years. Temporal trends in the average composition of the benthic macrofaunal community in both areas were similar..

Furthermore trends in diversity indices were not clearly different between the two areas. Benthic biodiversity varied in response to climate (the effect of cold winters is particularly obvious) but no relation with the establishment of the plaice box is apparent. This indicates that more global factors influenced compositional changes. Species differences between the two areas appeared to be related to species that were potentially important food sources for plaice. Trends in prey species and prey groups indicate that prey, especially polychaetes, inside the PB has decreased since the mid nineties by a factor of 5-8 times. This may explain why young plaice moved out of the PB. Overall, however, benthic biomass and abundance have decreased since the 1980s both within and outside the PB, with a similar relative decrease in the main food items of plaice (polychaetes and small bivalves) in all areas. While the overall level of food items in the coastal waters within the box was much higher than outside, the general trend of the temporal development was similar in all areas. Secondary production was higher in coastal waters both before and after the establishment of the PB, but no significant difference could be found in the quantity of secondary production either within or without the PB.

Changes in the densities of a number of benthic species that also contribute to the diet of fish, notably decreasing densities of opportunistic polychaetes, however, were observed both inside and outside the PB. These temporal trends seem at present, therefore, rather to be related to large-scale factors such as eutrophication and/or climate. The deficiencies of suitable data resulting from the spatial design of the PB precludes unambiguous inferences about effects of the partial closure to fishing based on existing spatial data sets.

Introduction

In 1989 the “plaice box” ("PB") was designated with the aim to protect juvenile plaice by reducing fishing mortality. After only seasonal closures during the first years, the area was effectively closed to larger vessels (> 300HP) all year round since 1995. In the forthcoming years it however appeared that young plaice were moving out of the box despite the fact that the area was now closed for heavy geared beam trawlers. Various suggestions have been made for these observations. One is that there was a change in food availability or quality, i.e. changes in the benthic community.

Large changes in the benthic communities during the last century have been observed in the North Sea by various authors, that have been attributed to fishing, climate and/or eutrophication effects (Schroeder, A. n.d.; Philippart et al. 2007; Frid, Garwood, and Robinson 2009). To evaluate the effects of the reduced fishing intensity (see Chapter 4) in the PB on the development of the benthic fauna, several data sets from the Dutch and German continental shelf have been analysed. For an appropriate assessment of the effects of the PB on benthic communities, a specific sampling program would have to be designed and tailored to the particular questions in focus. As these types of data were not available, data from several studies with different original purposes in the area were used for the evaluation. Time series data from specific locations are supplemented by several large scale surveys. Particular emphasis is placed on benthic invertebrates that form the major food for plaice and sole. A comparative analysis of temporal trends is used to evaluate differential temporal developments in the PB and in adjacent areas.

Time trends in the benthic community of the PB on the Dutch continental shelf

Methods and results

Here we analyse benthos data collected annually in and close proximity to, but outside the PB area. The samples were collected between 1991 and 2006 within the BIOMON program (RWS). The hypothesis is that; due to the decrease in trawling by large beamers, the benthic community within the box will have different stress levels and therefore will have followed another temporal development compared to surrounding areas with similar communities.

Multivariate analyses

Within the BIOMON sampling program (Mulder M. 2009) a total of 51 stations with positions in and around the PB area have been sampled. Data were extracted from the BIOMON database and imported into Primer software package (vs. 6, (Clarke and Gorley 2006)) for community analyses. The species abundance data were fourth root transformed and sites compared by calculating a Bray-Curtis similarity matrix. This matrix was subsequently analysed by non-metric MultiDimensional Scaling (further called MDS).
Beforehand, stations clearly lying within the PB were marked as "in". Neighbouring stations in a similar depth range and sediment type were classified as "out", the remainder of the stations as "not". By means of a multidimensional scaling of all stations for the year 1995, we checked whether this selection was homogeneous in terms of fauna and thus appropriate to make a comparison of fauna within and outside the PB. The results are given in the MDS plot in Figure 8.1.

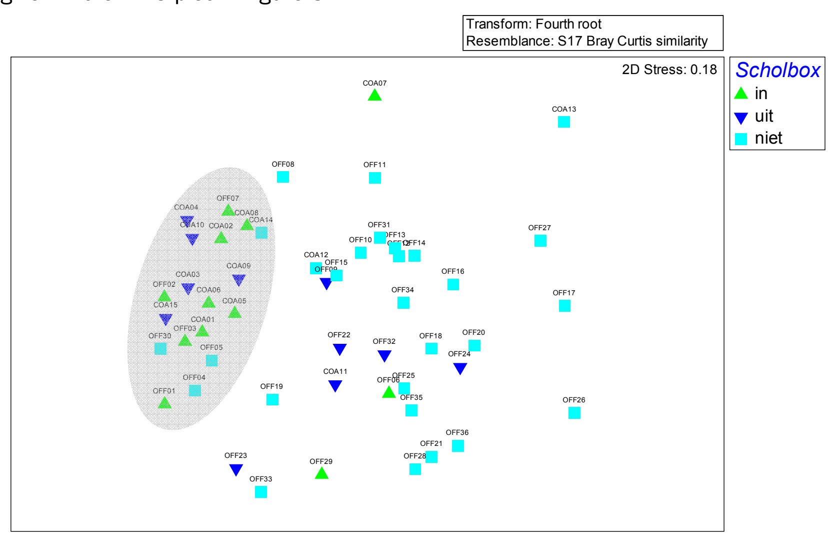


Figure 8.1. MDS plot used for the selection of stations to be included in the analyses. Labels denote station codes, e.g. COA07, coastal station number 7; OFF03, offshore station number 3 etc. Symbol size and colour according to the a priori set classification into the categories, in, out, not. The stations within the shaded area are those being selected for the analyses.

Figure 8.1. shows that not all stations initially marked as lying within the PB ("in") have a fauna representative of most of the "in-box" stations. The same holds for stations which at the outset were kept out. Some of the latter have a fauna which is quite similar to that of the PB itself. This meant that three stations which were a-priori regarded as being not relevant in the comparison ("niet") were, on basis of their similar fauna included and regarded as being representative for stations lying outside the PB. Similarly, three stations which are lying within the PB but appeared to have a different fauna compared to most of the other "in" stations were omitted. This

secondary selection and categorization of stations minimised the effects of comparing different macrobenthic communities.

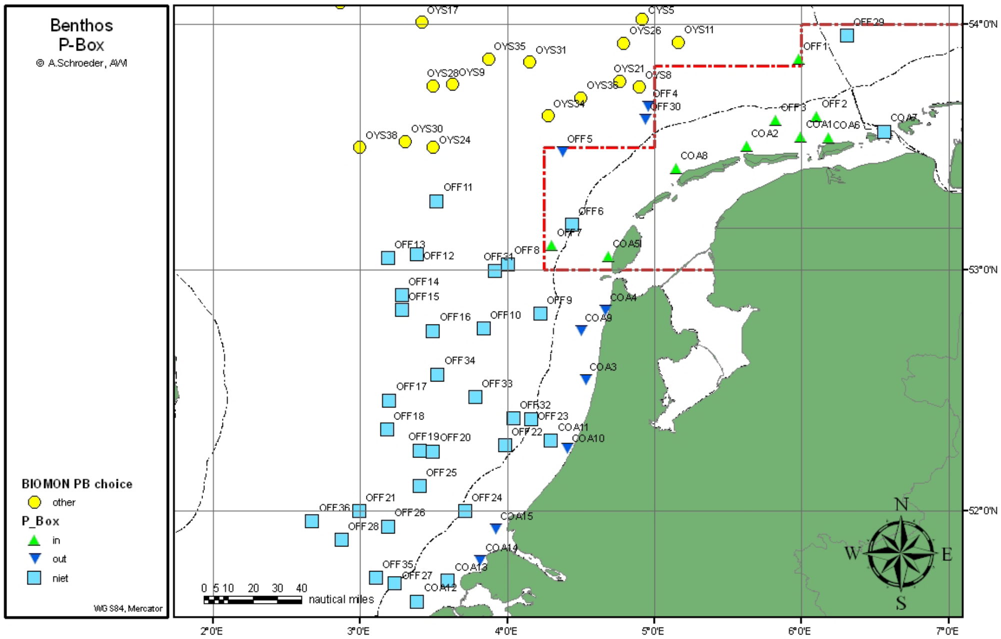


Figure 8.2. BIOMON stations chosen for the analysis.

Thus on basis of this first analysis, we made a new and final distinction between stations fitting "in" and those as lying "out", but all having very similar benthic communities (Figure 8.2). The validity of this choice was verified by applying MDS to all individual year-station combinations. This test gave similar results and did indicate that we did not have to change the distinction any further. In the remainder of the study we used the in/out data as being defined above. We carried out three types of analyses. Multivariate time trend analyses by second stage analysis (Clarke et al. 2006), univariate analyses using generalized additive models on community descriptors of diversity and abundance, and thirdly we applied GAM modeling (Wood 2006) on the abundance of selected plaice prey species from within the PB.

Comparison of Time trend and second stage- analyses

We hypothesized that closure of the area for heavy geared beam trawlers would lead to a different development of the benthic fauna when compared to an area directly outside the closure but open to trawling for beam trawlers with engine powers larger than 221kW. To check this hypothesis we firstly wanted to compare average time trends of community development in and out side the box. The fourth root transformed data for the two groups were averaged to give an average composition for each group and this matrix was again transformed into a Bray Curtis similarity matrix and analysed by MDS (8.3).

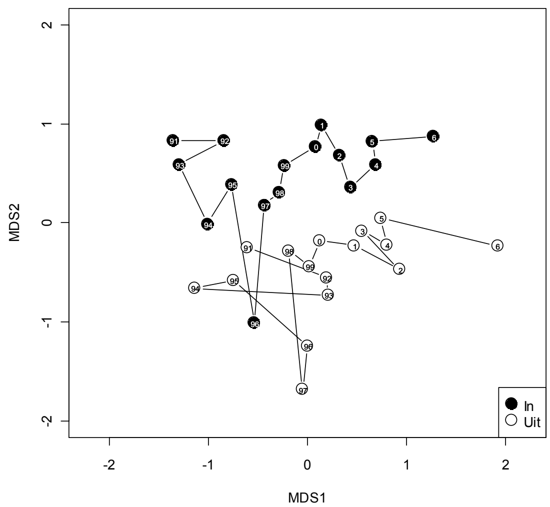


Figure 8.3. MDS graph showing changes in community composition over time for the stations within (filled symbols) and outside (open symbols) the PB.

The second-stage analysis consisted of extracting and comparing two matrices, namely one matrix of the similarities in average community composition between years of the stations inside PB area, and another matrix containing the similarities between years of the area outside of the PB. These two matrices are then compared using the rank order of the paired years using the Spearman rank correlation index. The significance is tested using permutation. A high correlation means that the two multivariate patterns through time are similar. One should, however, keep in mind that this correlation is relative, based on ranks, and not necessarily in composition. Thus a high correlation means that the relative position of for example 1999 in both areas is similar in the development of the average composition in each area.

Figure 8.3 shows that despite our selection of stations with similar communities (Figure 8.1), there still was a difference between the two areas that remained during the whole study period. Both groups are almost completely separated along the vertical MDS axis with the years inside the PB in the upper half of the graph and the years outside the PB in the lower half. Only in 1996 does the community composition of the stations inside the PB change to something comparable to the stations outside the PB. The similarity between in and out remained rather constant with a fluctuating difference of about 10 -15 %. No trend was visible. This continuous difference is corroborated by a permutation test on the similarity matrix that indicates a highly significant value (ANOSIM test, $R=0.4$, $p<0.0001$). This means that the multi-dimensional ordination of average community composition of years within and outside the box is extremely unlikely to be random. The figure furthermore indicates that there is a directional development along the horizontal axis which is related to time. The community composition in both areas moves from the left side to the right side from 1991 to 2006. This directional movement can also be tested by generating a matrix in which the distance between years is ordered by the number of years between each pair and comparing this matrix with the Bray-Curtis matrix (RELATE procedure in Primer) using the Spearman Rank order correlation index. This analysis shows a highly significant directional development for both data sets ($R=0.4$, $p<0.001$, and $R=0.8$, $p<0.001$ for respectively outside and inside the PB). Thus the communities both within as well as outside the box had a very similar development over time.
The 2nd-stage analysis indicates that both groups follow a similar trajectory ($R=.5$, $p<0.0001$). Thus, the similarity in time development of both groups of stations (in/out), despite their slightly differing fauna suggests that processes other than local ones play a role in the control of the composition of the benthic community. The results furthermore suggest that the banning of only large beam trawlers from the box did not make a difference to the bottom fauna as total. Ideally one should have compared data from within the PB before and after closure. Such data are however not available.

Compositional changes

We then investigated in more detail what caused the differences in community composition in and outside the closed areas. With a SIMPER analysis we determined which species contributed to the observed difference between both areas. It appeared that some of them are important food items for plaice. Like the polychaete Magelona spp., and the bivalves Spisula subtruncata and Ensis directus. Thus it appeared worthwhile to investigate the time trends of some of these species or species groups in more detail in a univariate sense (see below).

Table 8.1 Results of SIMPER analyses over all years indicating which species contribute to the observed differences in the communities. Average abundances (Av.Abund) are fourth rooted densities per m².

	Group in	Group uit				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Magelona papillicornis	2.52	1.37	2.43	1.39	4.89	4.89
Spisula subtruncata	0.99	2.22	1.64	1.40	3.30	8.19
Ensis directus	0.62	2.04	1.55	1.62	3.11	11.30
Mysella bidentata	0.81	2.16	1.54	1.97	3.10	14.40
Bathyporeia elegans	1.84	0.47	1.46	1.65	2.94	17.34
Spiophanes bombyx	2.73	2.97	1.43	1.21	2.87	20.21
Magelona mirabilis	1.19	0.51	1.32	0.89	2.66	22.86
Magelona johnstoni	1.04	0.57	1.29	0.83	2.60	25.46
Lanice conchilega	1.60	2.06	1.19	1.04	2.40	27.86
Nephtys hombergii	1.26	2.19	1.17	1.65	2.34	30.21
Montacuta ferruginosa	2.09	1.33	1.08	1.42	2.17	32.38
Tellina fabula	2.73	2.47	1.07	1.29	2.15	34.53
Urothoe brevicornis	0.55	0.86	1.03	1.04	2.06	36.60
Urothoe poseidonis	3.37	3.34	1.02	1.46	2.06	38.66
Nemertina	1.98	1.23	0.99	1.34	1.99	40.65

Univariate analyses within and between the box

Another way of analysing time trends in communities is to characterise the communities on the basis of parameters which describe diversity in number of species and or numbers of individuals. For a description of the univariate time trends we used generalized additive modelling (GAM) by means of the package mgcv (Wood, 2006). We applied this method for four commonly used indices: Number of species, total abundance, Pielou's evenness index and the Shannon Wiener index.

Number of species

Figure 8.4 describes the trend in the development of the number of species for stations within and outside the PB. It is evident that the average trend described by the smooth function is very similar both within and without the PB. The number of species is slightly higher within the PB when compared to outside the PB (blue line) . With time, the difference, however, has tended to become smaller. The overlap in confidence limits is however so large that the difference between the two areas is (statistically) insignificant. (For clarity they have been omitted from the graph). It is however obvious that in 1996 a sharp drop in the number of species took place, probably related to the severe, cold winter. This anomalous year (1996) can also be observed in the multivariate MDS plot (Figure 8.1.3). In the years following (up to about 2003) the numbers of species increase. There after a decrease set in.

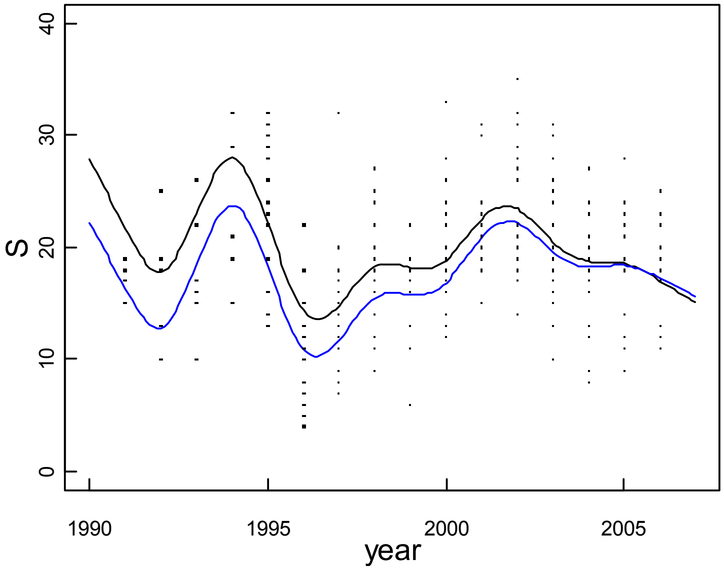


Figure 8.4. Number of species per sample over time. Black line the fitted GAM model for the stations within the box, blue line the trend for stations outside the PB. Confidence limits are not drawn for clarity, but overlap is so big that insignificance of the two models fitted is evident.

Number of individuals

The total number of individuals over time has also been summarized by GAMs (Figure 8.5). (Note: the models contained a correction on basis of a gamma distribution for the error structure which improved the fits). For both the stations inside and outside the PB similar trends were observed. Peak numbers of individuals in 1994-1995 were followed by an abrupt decrease in 1996. A slight recovery is evident up to the mid 2000s. Total number of animals however never reached there abundance seen in the mid 1990s. Over the last years a small decrease in the numbers of individuals is visible.

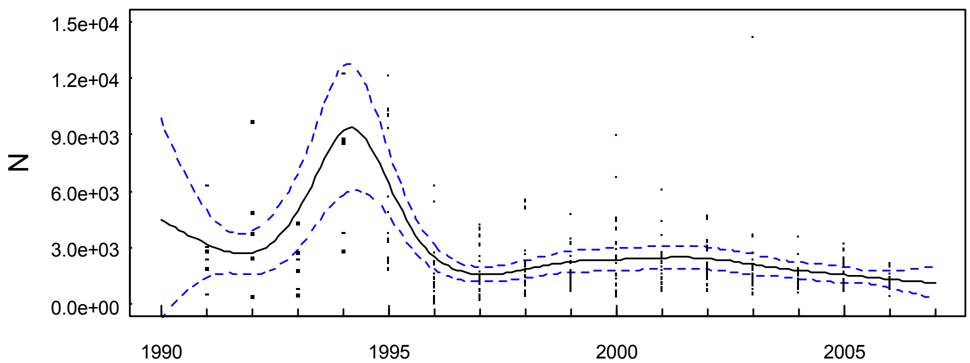


Figure 8.5. Reconstructed trend in the number of individuals per m² in and outside the PB. No difference could be detected in the trend between both areas i.e. adding the factor in/out did not improve the model. Suggesting that the trend in numbers of individuals in both areas is very similar.

Pielou's index

Figure 8.6 shows the development of Pielou's index over the years. Pielou's index is linked to the Shannon Wiener Index. Pielou's index gives how close the H' (Shannon Wiener) has approached to its maximum attainable value. Figure shows that Pielou's "J" increases with time suggesting that the community becomes more diverse, i.e. individuals get more evenly spread over the different species.

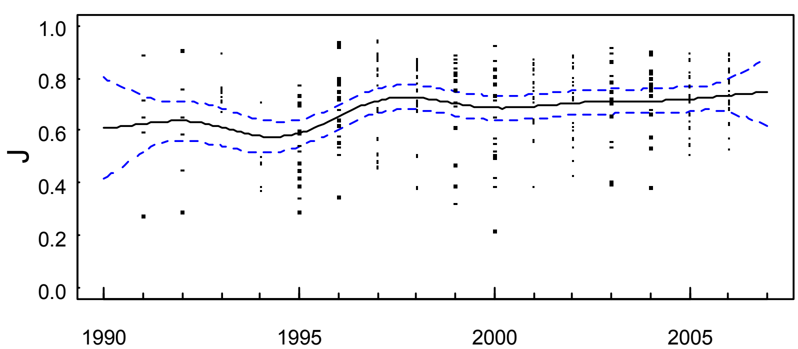


Figure 8.6. Pielou's index over time.

Shannon Wiener Index

The Shannon-Wiener diversity index expresses the amount of uncertainty involved in finding a specific species from a randomly taken sample. If Shannon-Wiener is high the chance of finding that one specific species is low. Similarly a low Shannon Wiener index tells us that the number of species is limited and the chance of finding that specific species then becomes more predictable. Figure 8.7 shows the time trend in the Shannon Wiener index over time. (Note: the model did not improve if factor (in-out box) was taken into account). In conclusion there is no difference between the "in" and "out" stations. The trend suggests that since the mid nineties H' increased, i.e. the community tended to become more diverse and less predictable if a random sample would have been taken. Here again the year 1996 seems to be exceptional.

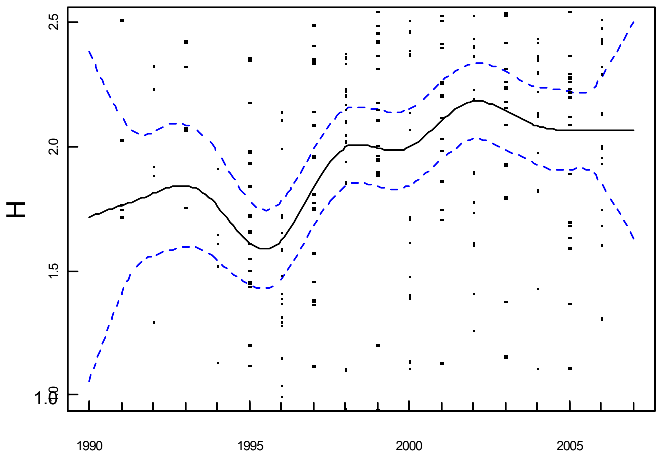


Figure 8.7. Temporal trend in the Shannon wiener index (based on ln) in the PB. Increasing values suggest that the community complexity increased between 1996 until 2003.

Time trends of potential food items for plaice in the PB.

A number of macrobenthic species has been recognised as food item for plaice (Rijnsdorp and Vingerhoed 2001). In the following analyses we looked into more detail in the time trends in terms of abundance for these species or species groups in the PB. The trends are summarized in Figure 8.8 in which smoothed trends with confidence limits are given. Models were fitted on fourth root transformed numbers. In Figure 8.1.8 predicted values and errors are back calculated to real numbers. Total polychaeta (Npolych) shows a declining trend since about 1995. Underlying this trend is the decrease in abundance of Magelona spp (Nmagelona) and all combined Nephtys species (Nnephtys). The time trend in another polychaete food item, Lanice, is less clear.
Juvenile bivalves are also important food items for plaice but the trends showed no clear pattern over time in individual species (Nensis, Nspisula) nor in the pooled and entire bivalve species assemblage abundance (Nbivalvia). The data thus suggest that food available for plaice, especially the polychaete component, has decreased over the years. Total abundance dropped by a factor 5 to 8 compared to the mid 1990s. This may have caused the plaice to move out of the area as food availability had dropped.

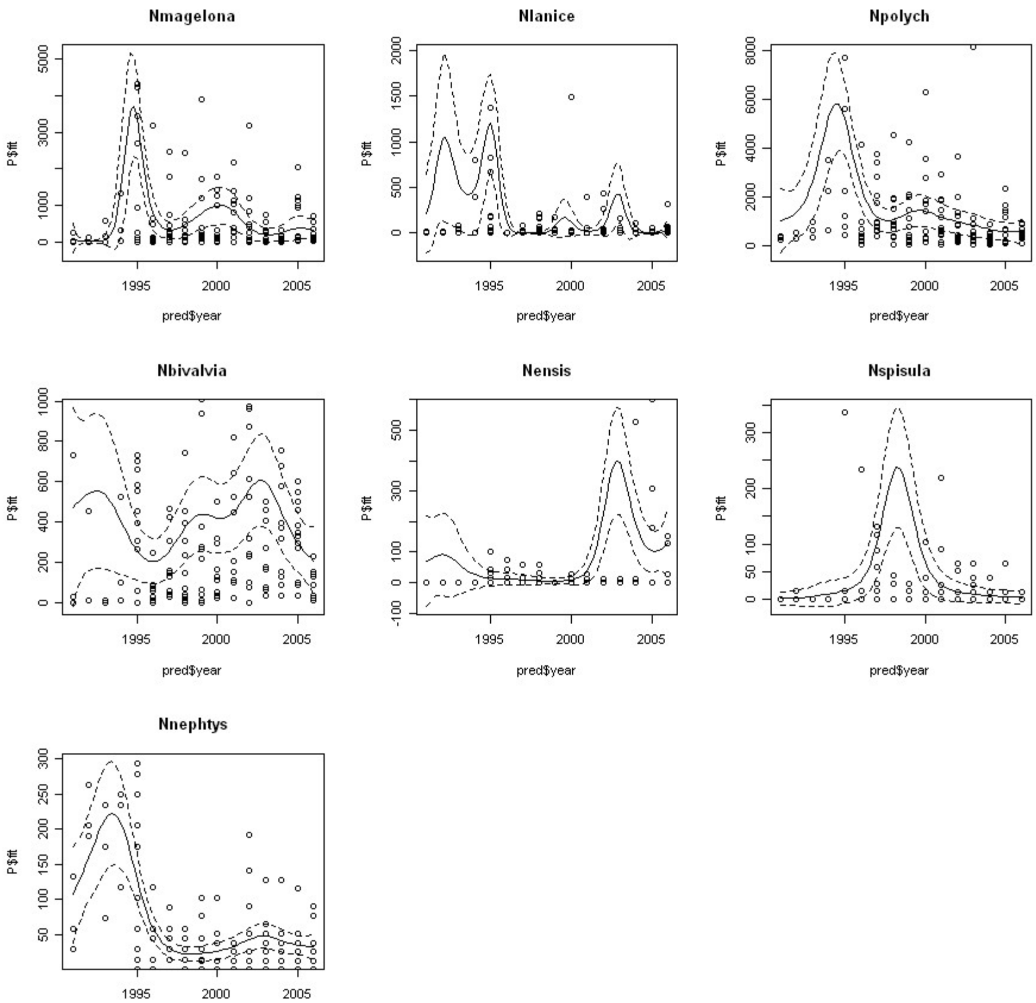


Figure 8.8. Trends of individual species, species groups and taxa, based on numerical abundance. Automatic axis scaling (max = fit + 2 X SE). Some individual points are outside the axis range and because of their magnitude. They would if included compress the entire graph to a straight line.

Changes in the benthos in the German Bight in relation to the establishment of the Plaice Box

Methods & Results

The PB was partially closed in 1989 (2nd and 3rd quarter), the fourth quarter since 1994 and full closure in 1995 (whole year). This implies that the PB has effectively been closed since the 2nd quarter 1994. These periods are marked by light and darker shadings in the plots of long term series data

The 12 nm zone had been closed to fishing vessels >300HP since 1975. Therefore the effects of the establishment of the PB are mainly expected in the area outside the 12 nm zone, but inside the PB. No change in fishing intensity is expected within the 12 nm zone due to the PB. The expected effect of the establishment of the PB on the three areas is summarised in Tab. 8.2.

Tab. 8.2: Expectable changes in fishing intensity through the establishment of the PB.

	Outside	Plaice Box (outside 12 nm)	12nm zone
Fishing intensity	relative increase	relative decrease	no change

Thus the analysis of benthic communities here focuses on the distinction in development within these three areas. Large scale survey data that cover the whole area within and outside of the PB are taken two points in time: from 1975 (data from Salzwedel et al. 1985), long before the PB and from 2000 (data from from Rachor & Nehmer 2003), five years after the establishment of the PB. Benthic community long term series data are taken from annual spring sampling at three permanent stations in the German Bight lying (a) outside the PB (WB 42m depth, silty sand); (b) inside the PB but outside the 12 nm zone (FSd, 26m depth, fine sand) and (c) inside the 12 nm zone and the PB (SSd, 36m depth, silty sand) (detailed description in Schroeder 2003).

Community composition

As the border of the PB more or less follows the 30 m depth contour, it also follows quite well the natural border between benthic associations (Salzwedel, Rachor, and Gerdes 1985; Rachor and Nehmer 2003); Fig. 8.1).

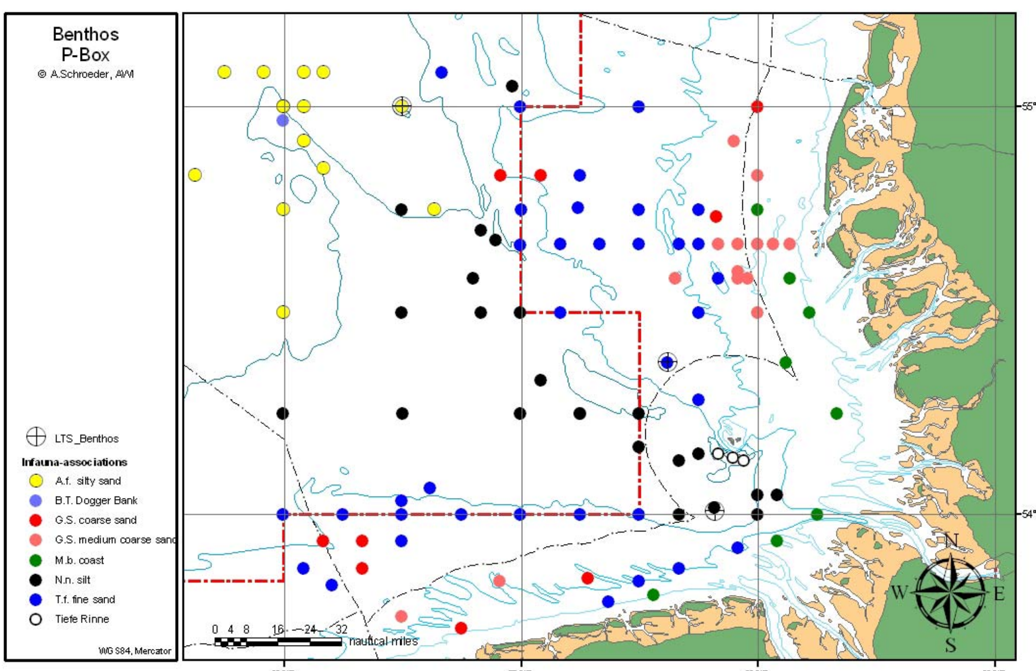


Fig. 8.9: Benthic macrofauna associations in 2000 (from Rachor & Nehmer 2003). Long term series stations are marked by a cross-circle

An analysis of the whole data set mainly delineates the distinction of the benthic communities. But even a separate analysis for those associations where data from inside and outside the PB exist, shows no distinction between the stations inside vs. outside the PB (Fig. 8.10)

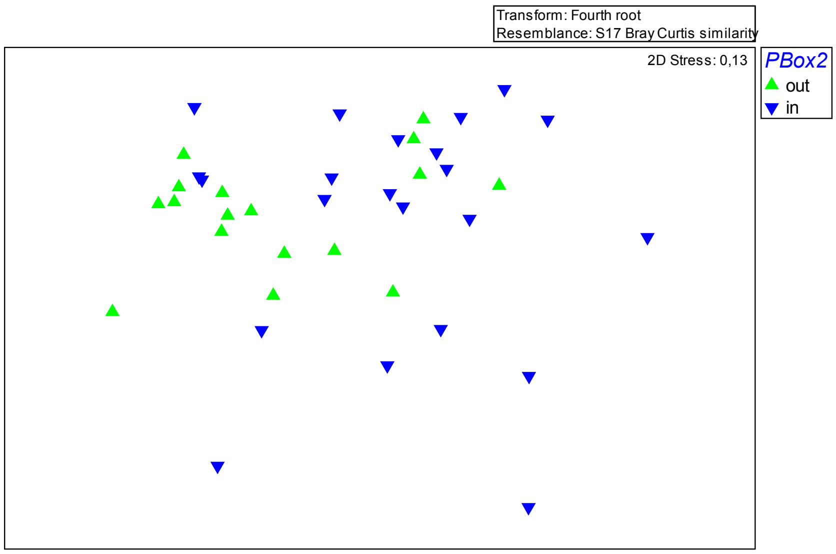


Fig. 8.10: MDS plot of benthic community composition within the Tellina-fabula-association in 2000 relative to the stations' position inside or outside the PB. Based on 4th root transformed Bray-Curtis similarity of densities per m² (data from Rachor & Nehmer 2003). ANOSIM R=0.075, n.s.

The analyses of the large scale data do not permit any distinction of the fauna that can be related to the effect of the PB. Analyses of the long term series from stations within and outside the PB seemed more promising for distinguishing large scale effects from e.g. climate or eutrophication from direct effects due to the reduction in fishing effort resulting from the establishment of the PB. If the communities inside and outside the PB would develop differently after the installation of the PB (i.e. from '89 resp. '95 onward), this would represent a strong indication for an effect of the PB. Any parallel development, however, would rather indicate effects of large scale patterns from e.g. climate or eutrophication.

A joint analysis of all long term series data shows the clear spatial distinction of the benthic communities, which is larger than the temporal variations in communities. This is due to the different environmental factors found at these stations, reflected in the depth and sediment differences. However, the general temporal development of the benthic communities at three long term stations inside the 12 nm zone ("12nm"), inside ("PB") and outside ("out") the PB is in parallel. The MDS plot in Fig. 8.11. shows a development towards the upper side of the plot, while the distance between the stations remains similar. The average similarity between the communities shows some fluctuations of about 10-15% but no increasing or decreasing tendency over time.

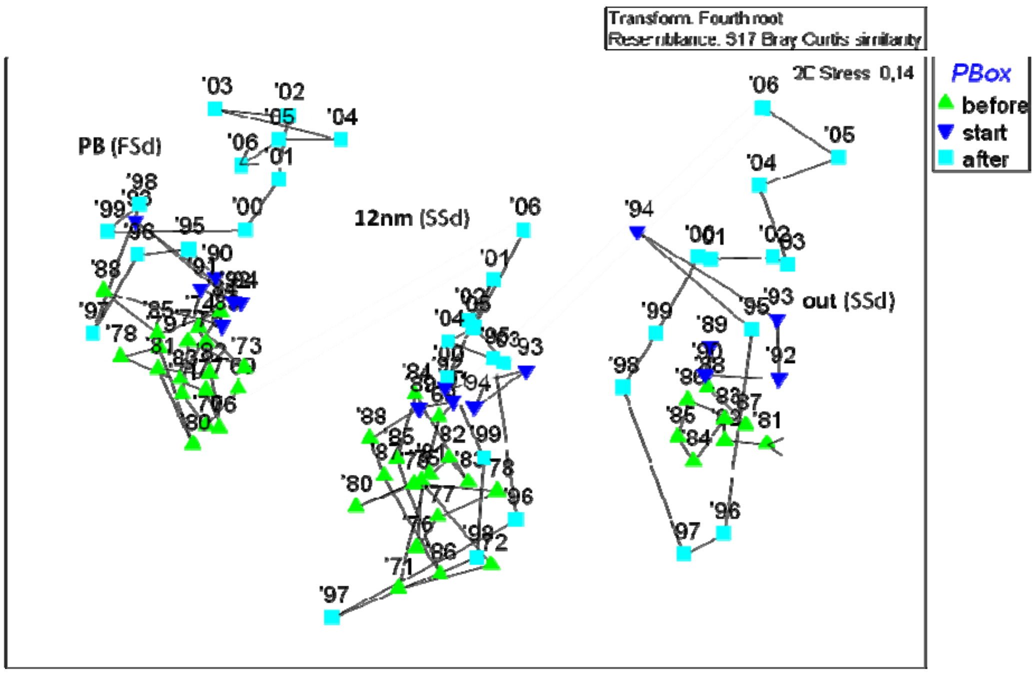


Fig. 8.11:Long term development of the benthic communities 1869 – 2006 in three areas of the German Bight outside of the PB ("out", silty sand), inside the PB ("PB", fine sand) and inside the 12 nm zone (and the PB; "12nm", silty sand;

Marked community changes in the mid-90s coinciding with the (partial) closure of the PB to fishing, however, are visible at all stations. The years '96 (and '97) take a prominent position caused by marked community changed associated with the extremely cold winter in 1995/96 (Schroeder 2003). Average composition of the benthic macrofaunal community in all areas changed through time in a similar way. This indicates that local and regional community development seems to be forced by superordinated climate patterns.

Benthic community density and diversity

The similarity in community development is also reflected in the sum parameters like total number of organisms (N), species number (S), evenness (J) and diversity (H') (Fig. 8.12). Absolute values at the respective stations are shown as dots connected by a line, and the long term trend is represented by a 5y-Low pass filter (weights: 3,5,6,5,3) to exclude short term fluctuations. The long term trends represented by the smoothed lines in Fig. 8.2.4 and 8.2.5 exclude short term fluctuations and reduce the influence of spatial variation on the data.
While annual variation in total organism densities (N) is different between areas, the overall trend seems similar with a decrease from the late 70s until the mid-late 90s and high densities around the year 2000. Absolute densities seem higher in the 12 nm zone, but the temporal development is similar as at the other stations. The number of species (S) follows a similar pattern with lowest values in the late 90ies following the extremely cold winter of 1995/96.

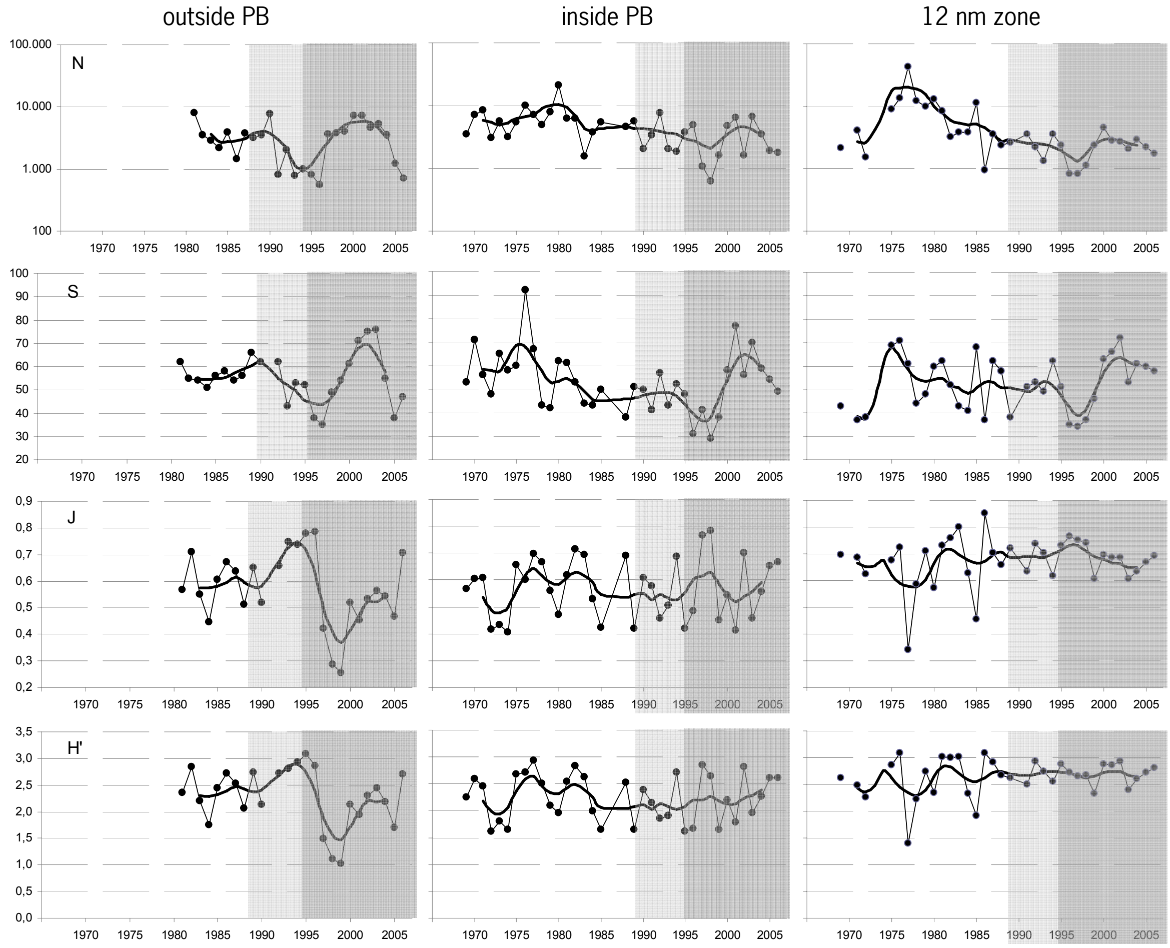


Fig. 8.12: Sum parameters for long term series in relation to their position relative to the PB: Outside the PB (silty sand, Amphiura-filiformis-ass.), inside the PB but outside the 12 nm zone (fine sand, Tellina-fabula-ass.) and inside the 12 nm zone (silty sand, Amphiura-filiformis-ass.). N: total number of organisms per m²; S: Number of species per 0.5m²; J: Pielou's evenness index; H': Shannon-Wiener diversity index. Solid line represents 5y-Low pass filter (weights: 3,5,6,5,3) to exclude short term fluctuations.

The evenness (J) shows even stronger year to year variation, but some more similarities in the long term trend. In general the evenness in the 12 nm zone is higher than inside PB with a few marked falls in 1977 and 1984 associated with mass occurrences of Phoronids. The overall level of evenness at the fine sand station inside the PB is lower and interannual variation in J is more pronounced, associated with frequent dominances of opportunistic species, mostly small polychaetes. The evenness at the silty sand station outside the PB increases until 1996, then strongly drops to its lowest values associated with a strong dominance of (juvenile) Amphiurids and then slowly recovers to previous levels until the mid 2000s. The Shannon-Wiener diversity index (H') more or less follows the same pattern as J, which is not surprising as it is mostly determined by the dominance structure of the community and only to a lesser extend by the total species number.

Apart from the differences at these stations that were present even before the installation of the PB, the overall development of these sum parameters is very similar. The markedly different development of 'evenness' at the silty sand station outside the PB is explained by temperature sensitivity of the dominant species of this benthic association: especially in the outer parts of the German Bight. Amphiura filiformis normally dominates the community by numbers but it is, however, sensitive to low temperatures and almost completely disappeared in 1996. In these areas, it quickly recovered after 1996 with extremely high numbers of juveniles. In the stations closer to the coast A. filiformis, however, took much longer to reach its former densities (Schroeder 2003). The community composition at the latter stations is different and often dominated by opportunistic species like Phoronids and small polychaetes.

Abundance of main plaice and sole food organisms

Dominant food items for plaice are polychaetes (e.g. Pectinaria, Nereis, Magelona, Lanice, Owenia) and small Bivalves (e.g. Tellina, Abra, Phaxas, Spisula & Ensis spatfall), other taxa are rather unimportant (Rijnsdorp & Vingerhoed 2001). For smaller fishes, polychaetes are the main food item. The contribution of bivalves (plaice) and crustaceans (sole) increases with increasing body size (mainly >20cm) (Rijnsdorp & Vingerhoed 2001). The differences in the diet found in different studies may be related to a different food availability at the place and during the time of the investigation. The diet of plaice and sole thus comprises mainly short-lived, highly productive benthic organisms.

As the species of small polychaetes that dominate in an area may differ widely between different sediment types and single species' densities of these opportunistic species fluctuate strongly between years, a presentation of single species plots does not represent the food supply for demersal fishes very well. Instead the total number of polychaetes seems an appropriate measure for the available food for small plaice and sole. It decreases strongly in all time series from the late 70s until the late 90s. After 2000 polychaete densities increase again outside the PB due to large number of Pholoe and in the 12 nm zone due to large numbers of Owenia. The overall level, however, is on average two to four times (max 9 times) higher inside the PB and in the 12 nm zone than at the station outside the PB.

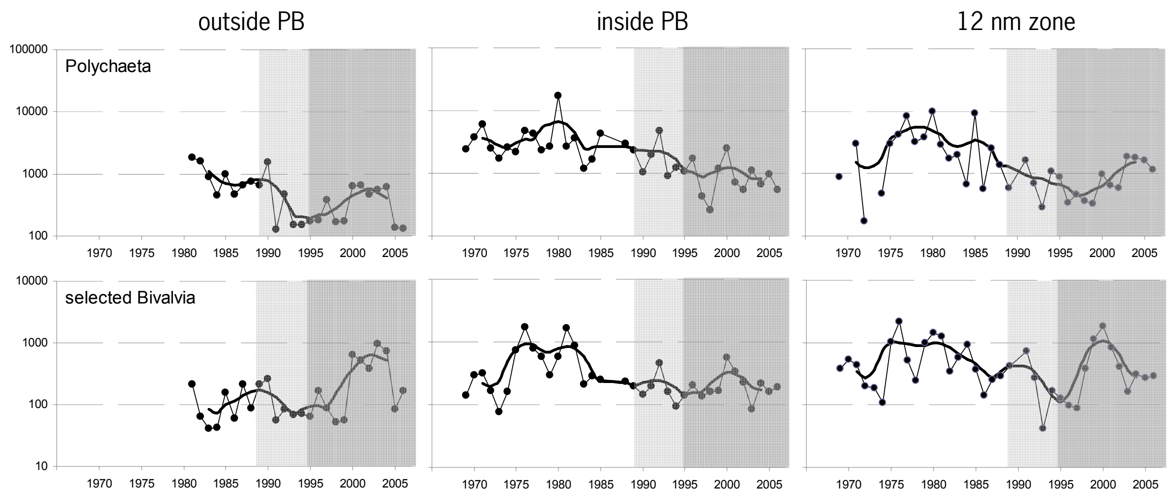


Fig. 8.13: Abundance of main food items of plaice and sole in long term series in relation to their position relative to the PB: Outside the PB (silty sand, Amphiura-filiformis-ass.), inside the PB but outside the 12 nm zone (fine sand, Tellina-fabula-ass.) and inside the 12 nm zone (silty sand, Amphiura-filiformis-ass.). Polychaeta: total number of polychaetes per m²; selected Bivalvia: main food species of plaice and sole: Tellina, Abra, Nucula, Phaxas, Spisula. Solid line represents 5y-Low pass filter (see above).

As only certain species of bivalves constitute flatfish food, out of the whole spectrum of bivalves at the given stations, a selection of suitable species was compiled to represent the main bivalve diet, comprising the genera Tellina, Abra, Nucula, Phaxas and Spisula. These were pooled, because at each station a different species was dominant (which was often almost absent at other stations) and thus the presentation of single species plots appeared less instructive than the sum of suitable species. This again showed a similar pattern as the polychaetes. A decrease in abundance from the mid-70s until the late 90s and larger densities again around the year 2000 at both station in the PB and in the 12 nm zone. The latter increase, following the year 2000, was also visible at the station outside the PB. However during the period 1981 to 1999 the densities fluctuated around a similar value, though at a much lower level than at the station in the PB.

Benthic secondary production

Benthic secondary production was estimated by empirical models from biomass, abundance and environmental data (Brey 1999, 2001). Unfortunately biomass data from the long term series are only available for recent years, therefore no long term development of benthic secondary production can be presented here. Reliable biomass data in enough detail for the empirical models on a wide spatial scale are only available for certain years. Therefore spatial differences in benthic secondary production are presented from two large scale investigation in the year 1975, long before the installation of the PB and in 2000, 5 years after the permanent installation of the PB.

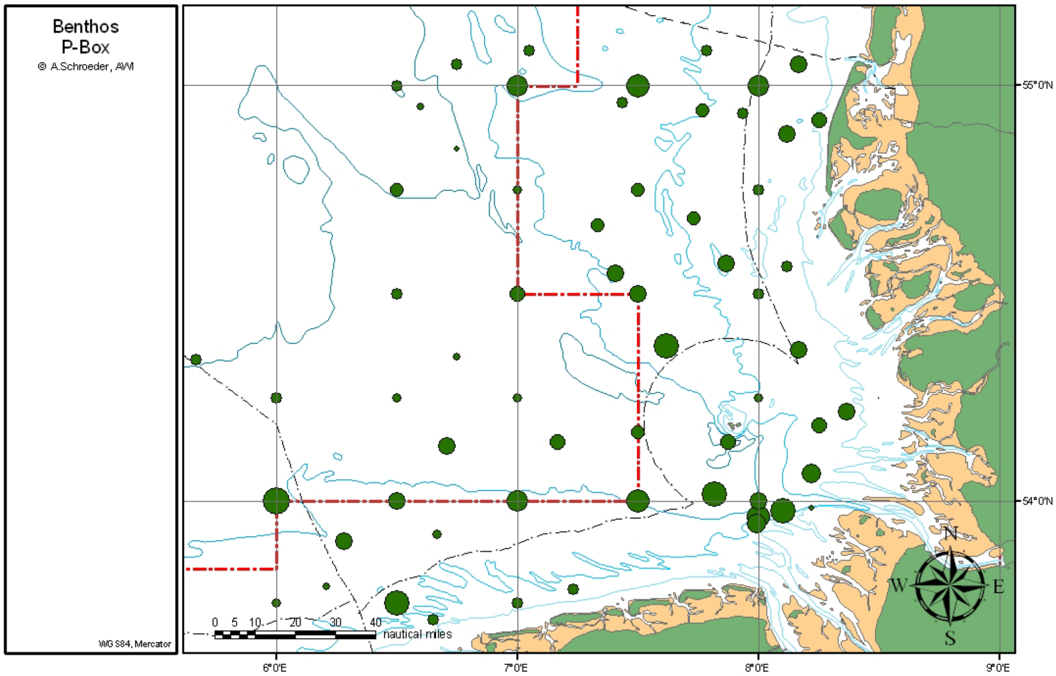


Fig. 8.14: Spatial distribution of benthic secondary production in the year 1975 calculated by empirical models (data from Salzwedel et al. 1985)

In the 1975 survey, the total benthic secondary production in the coastal areas (e.g. 12 nm zone) is slightly higher than further offshore (Fig. 8.2.6).

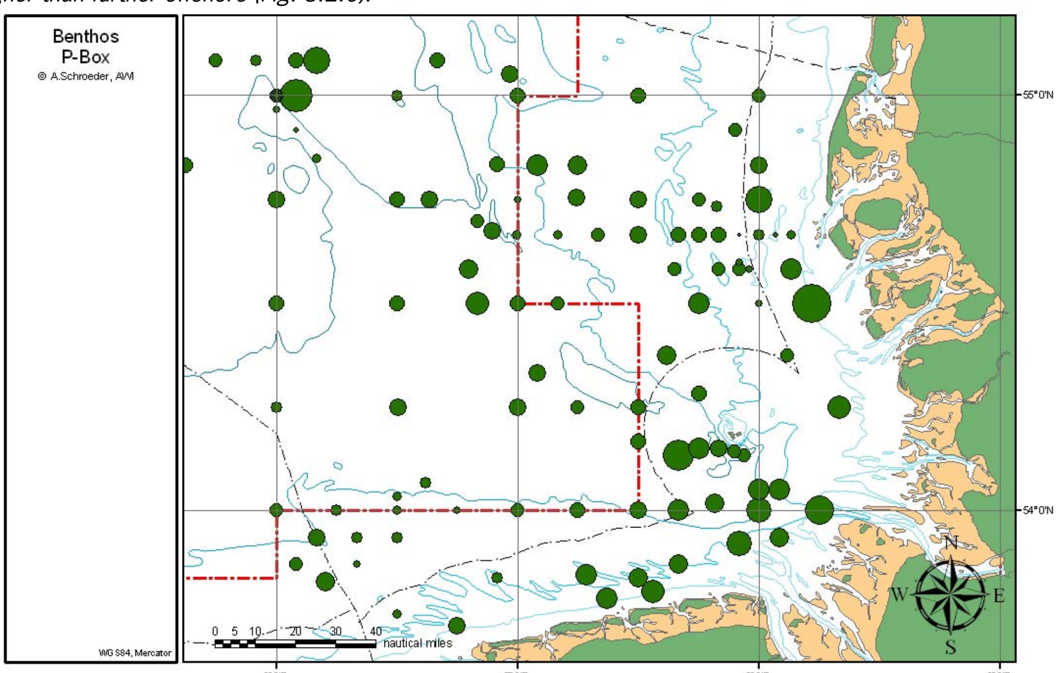


Fig. 8.15: Spatial distribution of benthic secondary production in the year 2000 calculated by empirical models (data from Rachor & Nehmer 2003)

The total secondary production was higher in 2000 than in 1975, but the decreasing tendency with increasing distance from shore was still visible (Fig. 8.2.7)

This is also reflected in the mean values shown in Fig. 8.2.8 (stations on the border of the PB calculated as “out”).

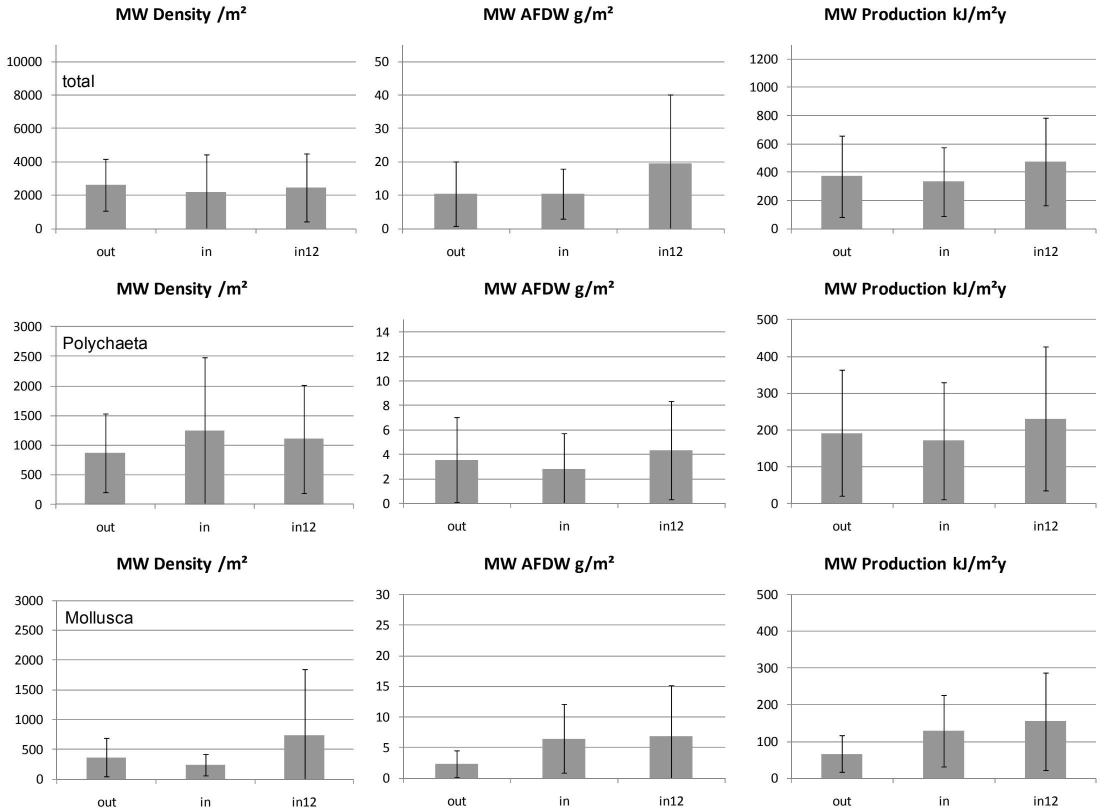


Fig. 8.16: Differences in mean organisms density (“MW Density”), biomass (as ash free dry weight “MW AFDW”) and benthic secondary production (“MW Production”) in the year 1975 in relation to the PB (Mean +/- SD; data from Salzwedel et al. 1985)

In 1975, the total density of organisms was similar in all three areas (Fig. 8.2.8). However, the benthic biomass and secondary production was higher in the 12 nm zone than in the areas further offshore. Also the production of polychaetes was slightly higher in coastal areas and the production of bivalves was higher in the 12 nm zone than in the PB, where it was still about twice at high as outside the PB.

In 2000, the benthic organism density, biomass and secondary production was higher than in 1975 in nearly all areas. As visible from the long term series (Fig. 8.12 & 8.13) the year 2000 was characterised by especially high organism densities and especially high number of bivalves. This highlights the problem of comparing only two separate points in time, which may represent a relatively unusual situation compared to the long term average. Still, as the temporal variations were similar in all long term stations, the relative comparison of the areas from the large scale surveys should allow valid conclusions.

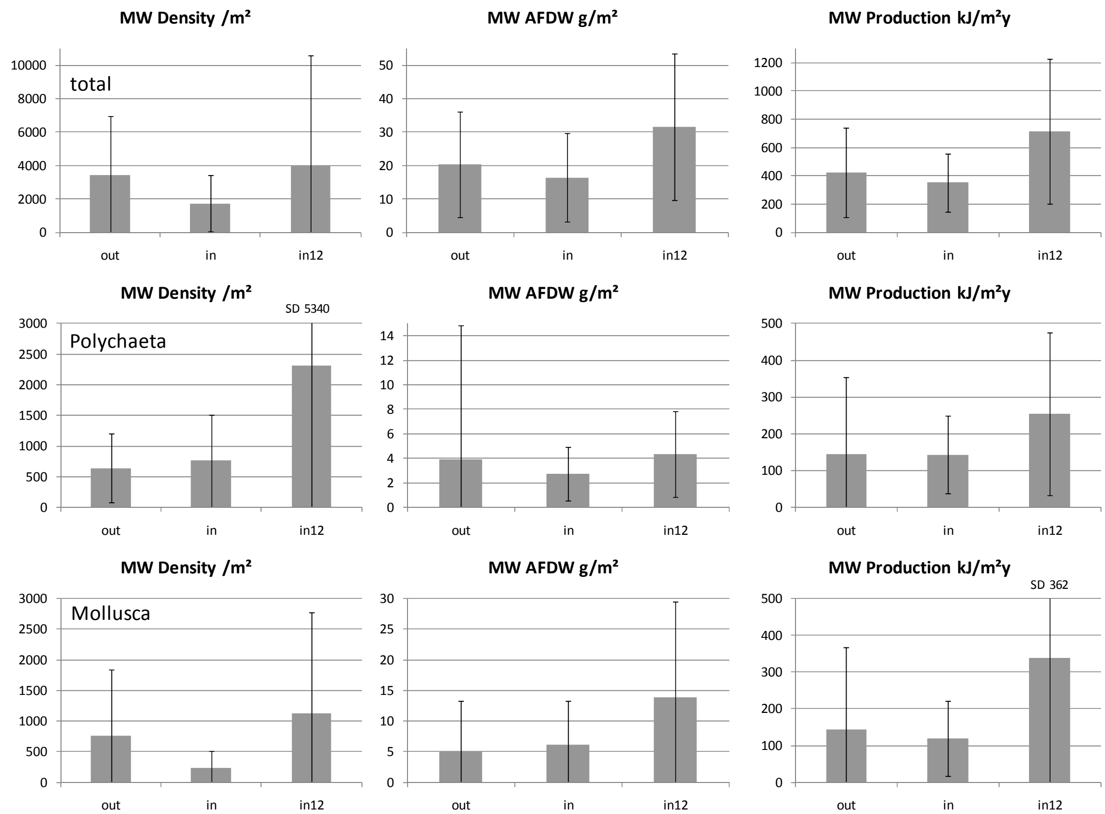


Fig. 8.17: Differences in organisms density ("MW Dichte"), biomass (as ash free dry weight "MW AFDW") and benthic secondary production ("MW Production") in the year 2000 in relation to the PB (Mean +/- SD; data from Rachor & Nehmer 2003).

The benthic secondary production of the 12 nm zone was markedly higher than that of the areas further offshore (Fig. 8.17). The density and secondary production of polychaetes was similar in and outside the PB. The density of bivalves was more than twice as high outside the PB as Inside the PB, which was due to a particularly successful settlement of Nucula nitidosa and Corbula gibba in the deeper waters. Still the densities in the 12 nm zone were much higher, but here several species including Nucula, Tellina, Phaxas, and Abra explained together the high abundance of the bivalves. This is also reflected in the secondary production of bivalves, which was more than twice as high in the 12 nm zone than in the further offshore areas.

Conclusions

The comparison of the present-day diet and the diet at the beginning of the 20th century led some authors to suggest that the preponderance of polychaetes has increased and that of bivalves decreased. These results seemed consistent with the hypothesis that beam trawling has improved the feeding conditions for the two flatfish species by enhancing the abundance of small opportunistic benthic species such as polychaetes in the heavily trawled areas. However, the parallel development of plaice food items in areas of differing fishing intensity over time suggests that the changes in diet and overall food supply are more likely to be related to eutrophication and pollution and/or climate influences.

The PB was never intended to protect benthos/habitats and should not be expected to have such effects. Numerous studies have shown that a moderate disturbance by beam trawling has the largest effect on benthic communities, while further increases in disturbance intensity have less effect. Thus a recovery of benthic communities towards an undisturbed state would rather require areas that are not fished at all, instead of just decreasing the disturbance frequency and intensity. Due to the deficiencies in the available data, which miss a specific monitoring programme designed to evaluate the PB effects, the question is still open as to whether the PB did have any effects on the benthos: especially with respect to its role as fish food.

Chapter 9 Critical appraisal of working hypotheses on key process

Introduction

Quantitative studies of the key processes are essential for assessing the efficacy of the PB as a management measure. The problem at the root is the difficulty we have in separating environmental influences from those of commercial fishing using the observational data available.

It is clear from the data we analysed that plaice abundance in the PB has fallen (Chapter 6) since its instigation due to a migration out of the PB area. After many discussions and explorations of the data we consider the following working hypotheses, outlined in more detail in Chapter 3:

1) Density dependent feed back mechanisms which may reduce the positive effect of a reduction in discarding. [PB instigated → increased density of juveniles → increased competition → decreased growth → increased mortality (or migration from) → low numbers.]
2) A reduction in fishing effort inside the PB. [Decrease in food availability inside the PB relative to that outside → migration from].
3) Environmental changes. [Rise in temperature → fall in benthic production → higher metabolic costs and higher mortality (or migration from).]

In order to address these hypotheses we first compiled an archive of data on commercial fishing and the environment (see Chapters 4-8). Data sets were built from Danish, German and Dutch sources and combined. The hypotheses above were examined using techniques ranging from statistical data-explorations and modeling to more theoretical mathematical approaches. The statistical approaches involved building tri-nation databases and attempting to visualize and model the data along the relevant spatial and temporal trajectories. The modeling approaches described In Chapter 10 were also important. The first is based on the model used during the original ICES WG that resulted in the closure of the PB and permits quantification of the effect of reducing effort and discarding while the second uses the population and bioenergetics of plaice to explore the relative likelihoods of various management scenarios. The empirical data are summarized below and we then discuss the findings in terms of plaice population dynamics.

Synthesis of the available empirical data on the changes in fisheries, environmental conditions and plaice.

Several processes influence the effect of the Plaice Box on the recruitment to the exploitable stock, e.g. the number of a cohort that reaches the marketable size and recruit to the stock (Pastoors et al. 2000). A cohort starts with the influx of plaice larvae that settle on the shallow nursery grounds. Mortality of pre-recruits in the box will be determined by the natural and fishing mortality in the box in combination with the duration of the discard phase and the proportion of the discards size class that inhabits the Plaice Box area.

Larval supply to the continental nursery grounds in general and the Plaice Box in particular, as reflected in the abundance of 0- and 1-group, shows a multiannual pattern with relatively high recruitment in the 1980s. Larval supply will be determined by the egg production of the adult population and the mortality and transport success of the pelagic stages from the offshore spawning areas to the coastal nursery grounds. Egg and larval mortality decrease with increasing water temperatures (Fox et al., 2000), which can partly explain the observed decrease. Since no effect of egg production on recruitment could be detected (ICES 2009; Rijnsdorp et al., in prep), the dome-shaped pattern in recruitment suggest that the mortality and transport success of the pelagic stages varied on a multi-annual scale. Transport success appears to be rather variable as suggested by simulations using hydrodynamic models (van der Veer et al., 1998; Bolle et al., 2009).

The observed decrease in growth rate and change in distribution of undersized plaice resulted in a reduced level of protection by the plaice box as compared to the original conditions. The reduction in the level of protection is determined by the combined effect of the increase in the duration of the discard phase, the decrease in the proportion inhabiting the plaice box and the level of fishing mortality generated by the fleets that were allowed to fish in the plaice box. The strength of the density-dependent response is less than 1% for a 10% change in population density and only marginally affects the recruitment from the box. The reduction in the proportion of the discards in the plaice box will have a much larger impact on the level of protection. Hence, the decrease in the proportion of the discard size class inhabiting the plaice box since the early 1990s, implies that the level of protection has decreased by about 70%.

An important question is whether the observed changes in growth and distribution are caused by the establishment of the Plaice box or due to autonomous changes in the environment. There are two main fisheries-dependent mechanisms that could have caused the observed changes in growth and distribution: a density-dependent reduction in growth due to the reduced level of discard mortality and a reduction in benthic food due to reduced bottom disturbance. Alternatively, the changes could be due to changes in the environmental condition such as temperature or eutrophication that are unrelated to fishing or to the establishment of the plaice box. These mechanisms are not mutually exclusive and the observed changes may be due to a combination of effects. In the following paragraphs, the various hypothesis will be discussed.

The present analysis provide compelling evidence that stock size negatively affect growth rate in the first years of life when plaice is concentrated in the localized nursery areas (Beverton, 1995). The density-dependence decrease with age and coincides with the spreading out of the population over deeper waters (Rijnsdorp and Van Beek, 1991). The establishment of the Plaice Box with the subsequent reduction in discard mortality has likely resulted in a decrease in growth. Because the strength of the density-dependence was small (less than 10% per unit change in density), the effect on the recruitment is negligible. The second mechanism that may lead to a fishery-induced response is the effect of trawling on the food of plaice. The question whether trawling has affected growth rate of plaice remains controversial. There is compelling evidence that bottom trawling leads to a reduction of biomass and a change in the species composition of benthic invertebrates (Jennings et al., 2001; Jennings et al., 2002; Kaiser et al., 2000). Whether trawling may improve conditions for small opportunistic species that provide the food for plaice remains a controversial topic (Hiddink et al., 2008; Reiss et al., 2009; Rijnsdorp and Vingerhoed, 2001). A size-structured benthos production model, parameterized for North Sea offshore sites (Duplisea et al., 2002), suggested that the production of benthos in the size class preferred by plaice actually decreased in the Plaice Box due to competition with larger size classes that could survive at the reduced trawling disturbance within the box, whereas the plaice food was relatively more abundant in the more heavily trawled areas outside of the Plaice Box (Hiddink et al., 2008). Nevertheless, the benthos data series analysed within the Plaice Box evaluation project did not provide support for a relative increase of small opportunistic benthic species. Also, the analysis of the growth rate in relation with trawling disturbance did not provide support for the hypothesis. However, the benthos data suggested that around 1995 a decrease in the abundance of macrobenthos occurred in the southeastern North Sea, both within and outside of the Plaice Box. The changes in benthos are most likely dominated by changes in the ocean climate, in particular the occurrence of the strong winter of 1996, and the decrease in nutrients since the 1980s. However, since the variation in the benthos data is large, the data set does not allow us to entirely refute the trawling disturbance hypothesis.

With regard to the fisheries, unrelated environmental factors, the statistical analysis of plaice growth revealed a significant positive contribution of eutrophication for juvenile age groups. The effect of temperature was only apparent for the growth rate of 0-groups corroborating earlier results (Teal et al., 2008). The fact that no significant temperature effect was detected for the growth of older ages, while a positive temperature effect was detected for the length of older age groups, may suggest that temperature induced variations in length of 0-group plaice propagate later in life. However, it cannot be excluded that temperature also affects the growth rate of older age groups, but that this effect is confounded by the effect of other covariables retained in the selected models. The results of the present analysis corroborates the results of a similar analysis using data upto the early 1990s with regard to eutrophication and population abundance, but not for trawling disturbance (Rijnsdorp and van Leeuwen, 1996). The increase in nutrients in the 1960s and 1970s has likely resulted in an increase in the productivity of the coastal waters as suggested by several modeling studies, as well as long-term monitoring studies (Beukema and Cadée, 1988);(Colijn et al., 2002). Although the effects of the nutrient reductions in the recent decades remained controversial (Boddeke and Hagel, 1995), a recent analysis concluded that the available evidence showed effects of the reduction in nutrients at higher trophic levels (Philippart et al., 2007). The observed reduction in growth and in macro-benthos abundance / biomass in the southeastern North Sea (Chapters 5 and 8) are consistent with the reduction in nutrients.

The change in distribution in juvenile plaice did not coincide with the increase in temperature in the late 1980s. Therefore, the shift to deeper water cannot be interpreted as an avoidance response to the high summer temperatures observed since 1989. The change in distribution occurred at the end of the 1990s and coincided with the decrease in macro-benthos. Also in other ecological time series, a sudden change has been suggested to occur around this time (Weijerman et al., 2005). The change in distribution thus seems to occur at the time when the benthic biomass was reduced to a lower level and at higher temperatures. Could the combined effect of a potential decrease in food and an increase in metabolic costs due to higher temperatures explain the observed shift to deeper and cooler waters? From a bio-energetic perspective, one would indeed predict that fish prefer lower water temperatures when food availability is reduced. If food conditions do not allow the fish to acquire sufficient energy resources for maintenance, a change to lower temperature will reduce maintenance cost making a relatively larger part of the acquired energy available for growth or reproduction. Therefore, the temperature at which the scope for growth (difference between energy acquisition and maintenance cost) is maximal decreases with a decrease in the food availability. This mechanism offers at least a qualitative explanation of the observed movement towards deeper and cooler waters. It remains to be studied whether the mechanism can quantitatively explain the observed changes.

Conclusion

Beam trawl fishing effort (kW days at sea) in the plaice box area has decreased stepwise since the establishment of the box in 1989 and the full closure since 1994 to 35% and 10% respectively of the estimated pre-closure level. The plaice box remains an important fishing area for the fleet of smaller vessel (kW<=221 kW, see table). Especially beam trawlers fishing for shrimps (BEAM.16-31) and the mixed flatfish fisheries (BEAM.<100) are most active and are earning more than 70% inside the PB (see Table 9.1). Nevertheless effort and landings by the exemption beam trawl fleet (BEAM.80-99) fishing for finfish have fallen since the establishment of the PB. Fishing effort by shrimpers is concentrated within the 12 nm zone. Only 14, 4, and 2 % for The Netherlands, Germany and Denmark (mean of 2005 to 2008), respectively, of monetary yield was earned outside the 12 nm zone but within the plaice box area. Fishing mortality of plaice has decreased since 1997, but due to a change in the distribution of the main fishing fleets towards the sole fishing grounds in the south has resulted in an increase in plaice discarding rate. Discarding in the shrimp fishery occurs and mainly applies to 0-group plaice whereas in the flatfish fishery it applies mainly to age groups 1 – 3.

Winter sea surface temperature has increased stepwise in 1988-1989 by about 1oC. Summer temperatures have increased more gradually by 1 oC since 1989. Nutrient concentrations peaked in the early 1980s (phosphates) and early 1990s (nitrate) and decreased subsequently (see Chapter 5). The scientific literature provide ample evidence for a regime shift to have occurred in the North Sea around 1989 and 1998 (Weijerman et al, 2005).

Plaice have moved to deeper water and the proportion of undersized plaice in the box has decreased since 1995 (see Chapter 6). The growth rate of juvenile plaice is lower than in the pre-box period resulting in an extension of the period during which they are exposed to discard mortality. Discarding has increased due to the distributional shift and decrease in growth. Plaice biomass in the North Sea as a whole has increased since 2004 due to a reduction in fishing mortality.

Benthic biomass / abundance has decreased since the 1980s both within and outside the plaice box, with a decrease in the main food items of plaice (polychaetes and small bivalves). The decline in polychaetes is similar within and outside the PB, but the decline in bivalve species seems less pronounced in offshore areas. It should be noted, however, that this observation is based on relatively weak evidence with the existing data. Changes in benthos species composition showed temporal changes in time that were similar between the plaice box and the reference areas. The long term development, with decreasing dominance of polychaetes, seems not related to the PB; but rather to large scale phenomena like the decreasing eutrophication and climate influences. Benthic biodiversity clearly varied in response to climate (cold winters) but no relation with the establishment of the plaice box was apparent (see Chapter 8).

Changes in the fish assemblage were investigated in Chapter 7. We show that, overall, biodiversity increased in the late 1980s while the total mean catch rates of demersal fish decreased inside the PB. This decline, inside the PB, was due to a decline of the dominating flatfish species plaice, dab and sole. The fall in total fish abundance that we observed inside the PB was not mirrored by an increase outside the PB.There was no indication that the closure of the PB had any effect on the fish diversity or fish assemblages.

To summarise it is clear that the PB has resulted in a decrease in the discard mortality rate because of the reduction in fishing effort (Chapter 4). Although the observational data did not support the trawling impact hypothesis, the data do not allow its refutation. The problem here is that we cannot easily quantify its effect. The best information we have on the abundance of plaice comes from the survey data. We could perhaps assume that fishing effort is directly proportional to benthic disturbance and use it as a predictor or explanatory variable in an analysis. The problem is that fishing effort causes removal of the plaice themselves from our survey data, and hence the two variables (fishing effort and plaice abundance) tend, obviously, to be negatively related (see Chapters 4 and 6). The negative relationship itself cannot clearly then either be used to refute the trawling disturbance hypothesis. An experimental approach is thus required to conclusively test whether fishing disturbance has a positive effect of the growth and mortality in plaice. In our opinion the data and models available suggest more strongly that trends in the abundance of juvenile plaice are much more likely due to global environmental influences than fishing. In particular the offshore movement of plaice that is so clear in the data (Chapter 6) is much more likely due to behavioural responses to the combined effect of a decrease in food availability and an increase in temperature.

Chapter 10 Quantitative evaluation of the Plaice box

Introduction

In this chapter, we will use a two different models to study the impact of the PB on the yield and spawning stock biomass of plaice. The first model explores how density-dependent feedback processes influence the effect of a closed area on the yield and biomass of plaice. We apply a cutting-edge modeling technique (de Roos *et al.*, 2007, 2008) to model a fully size-structured population as a fixed number of size-based stages, without sacrificing the ecological realism of the complex model. The transition from each life stage to the next, and the production of offspring from the adult stage, depend on the availability of resources and the abundance in the stage. We use this model to test if and how such density-dependence affects the population-level outcome of the indirect temperature hypothesis set forth in chapter 3. It has recently been shown (van Kooten *et al.*, 2007, de Roos *et al.*, 2007) that such density-dependence can lead to counterintuitive and complex population responses to size-dependent mortality.

The second model , resembling the model approach used in the original plaice box advice (ICES, 1987), is a spatially explicit simulation model that estimates fishing mortality by age group from a given distribution of plaice and fishing effort. With the simulated fishing mortality rate of landings and discards, a yield per recruit analysis is carried out to compare the different plaice box scenarios with regard to the yield per recruit, spawning stock biomass per recruit as well as the proportion of discarded plaice. In contrast to the 1st model, the 2nd model ignores density-dependent feedback. The plaice box scenarios comprise a base line run representing the current situation, and three alternative scenarios representing an extended plaice box, and a re-opening of the plaice box, as well as an experimental design (zig-zag scenario). The latter reflects the experimental approach suggested by the North Sea Regional Advisory Council (see Chapter 2, and appendix to Chapter 2). The three alternative PB-scenario's were agreed upon during the October Workshop with the stakeholders.

Stage structured model (model 1)

The analysis of plaice growth shows that density is an important factor determining plaice growth (Chapter 6). This density-dependence in individual growth is strongest in young and small individuals, and becomes weaker throughout individual life history. Density- or food-dependence in individual body growth is often not taken into account in predictive models of exploited populations. This is curious, because such food-dependent growth forms the ecological rationale behind the influential Schaefer model (Ricker, 1975; Schaefer, 1954). Both recent and classical ecological work shows that such food-dependent individual growth has profound effects on population dynamics (Nicholson, 1957; Persson *et al.*, 1998; Yodzis & Innes, 1992) and on how populations respond to size-dependent mortality (de Roos *et al.*, 2007; van Kooten, Persson & de Roos, 2007). Here we develop two models to study the effects of the PB which do take into account food-dependent individual growth in a simplified form. We divide the plaice population into a number of size-based stages, and assume that the development between stages depends on food availability. Our stages reflect both important distinctions in the life-history of plaice and differences in sensitivity to exploitation.

The first model is the very simplest way in which we can represent the North sea plaice population. We use this model merely to test how much of the effect of turning the plaice box on and off is embedded simply in the life history of plaice. Predictions from this simple model diverge strongly from modeling exercises performed before the plaice box was installed, and we discuss the discrepancies.

A more elaborate model is then developed, based on the simpler model, to examine the 'indirect temperature' hypothesis developed in Chapter 6. This hypothesis explains the shift of large juvenile plaice to locations outside the PB as a response of juvenile plaice to a general decrease in productivity in the entire area, both inside and outside the plaice box. When food becomes relatively scarce, large juvenile plaice prefer cold areas, because metabolic costs are lower there, and even though maximum growth rate may be lower, positive net energy (energy left over after metabolism has been 'paid for') is possible at relatively low food density in colder water.

A simple stage-based plaice model

To study the plaice population in the North Sea, we use a recently developed modeling framework for the study of size-structured populations(de Roos *et al.*, 2007; de Roos *et al.*, 2008). This class of models simplifies the continuous size structure present in the population into a given number of stages, and models the distribution of biomass over these stages. The rate at which biomass is transferred through these stages depends on the food available to these stages, using a simple energy budget within the stages. The spatial ecology and the exploitation of plaice in the North Sea creates to some extent a natural division into stages. Closely inshore are the small juvenile plaice, which occupy very shallow water where beam trawl activity is close to zero. Even when it does not, these fish are small enough to pass through the 80mm mesh size used in the sole fisheries. They hence suffer very little discard mortality. The second stage are the immature individuals which are caught in 80mm mesh size trawls, but which are below the minimum landing size of 270mm. This size class starts at an approximate 130mm, which appears to be the lower length limit of the size range susceptible to discarding inside the PB (Grift *et al.*, 2004, chapter 4). The third stage are all individuals >270mm in length, which suffer fishing mortality. We assume that these individuals are constrained to areas which fall outside the current PB. For simplicity, we assume that maturation of plaice coincides with the minimum landing size of 27cm. Each of these stages is assumed to have its own resource population, which leads to a simple 3-stage model with 3 resource populations (Figure 10.1).

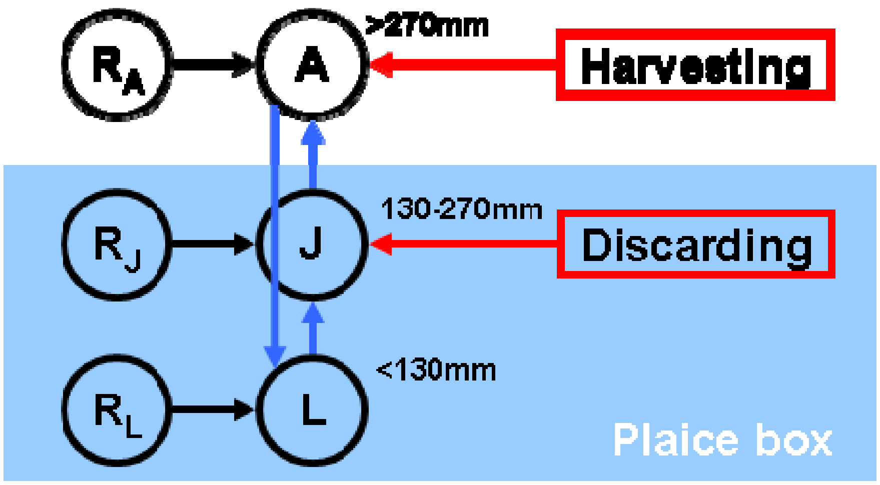


Figure 10.1: Schematic representation of simplest-case North Sea Plaice model. See text for details.

This model consists of 6 ordinary differential equations, listed in Table 10.1. Equations (1), (2) and (3) govern the dynamics of the resource populations R, subscripted by the plaice stage which feeds on them. The resources have semi-chemostat dynamics. Each plaice stage feeds on its resource population following a type II functional response. Equations (4),(5) and (6) describe the dynamics of the 3 plaice stages, small juveniles (L, size at settling to 130 mm), large juveniles (J, 130 to 270 mm) and adults (A, larger than 270 mm).

Table10.1: Equations of simple 3-stage plaice model with 3 resources

$$\frac{dR_L}{dt} = \delta_L (R_{L\max} - R_L) - I_{\max,L} L \frac{R_L}{H_L + R_L} \quad (1)$$

$$\frac{dR_J}{dt} = \delta_J (R_{J\max} - R_J) - I_{\max,J} J \frac{R_J}{H_J + R_J} \quad (2)$$

$$\frac{dR_A}{dt} = \delta_A (R_{A\max} - R_A) - I_{\max,A} A \frac{R_A}{H_A + R_A} \quad (3)$$

$$\frac{dL}{dt} = b \cdot A \cdot v_A^+(R_A) + L \cdot (v_L(R_L) - \gamma_L(v_L^+(R_L)) - \mu_L) \quad (4)$$

$$\frac{dJ}{dt} = L \cdot \gamma_L(v_L^+(R_L)) + J \cdot (v_J(R_J) - \gamma_J(v_J^+(R_J)) - \mu_J) \quad (5)$$

$$\frac{dA}{dt} = J \cdot \gamma_J(v_J^+(R_J)) + A \cdot (v_A(R_A) - v_A^+(R_A) - \mu_A) \quad (6)$$

$$v_i(R_i) = \sigma I_{\max,i} \frac{R_i}{H_i + R_i} - C \quad \text{and} \quad v_i^+(R_i) = \max[v_i(R_i), 0] \quad (7)$$

where $i \in \{L, J, A\}$

$$\gamma_j(v_j^+(R_j)) = \frac{v_j^+(R_j) - \mu_j}{1 - z_j^{\,1 - \frac{\mu_j}{v_j^+(R_j)}}} \text{ Where } j \in \{L, J\}. \quad (8)$$

The accumulation of biomass for growth, development and reproduction follows a simple energy budget (equation (7)), assuming that energy from resource intake is first used to pay maintenance costs, and the remainder (net available biomass) is available for other uses. Adults direct all net available biomass to the production of offspring, and are not assumed to grow. This is a necessary simplification for the correspondence between this model and a fully size-structured equivalent (de Roos *et al.*, 2008). The biomass which adults devote to reproduction, $A \cdot v_A(R_A)$, is added to the small juvenile population, modified by a factor b which represents biomass loss through the non-egg gonad mass (including male gonadal investment), mortality in the pre-settlement egg- and larval stages but also biomass gain through feeding in these early life stages. Small juvenile biomass is gained through feeding $L \cdot v_L(R_L)$, and biomass is lost through mortality $L \cdot \mu_L$. Development of small juveniles into the large juvenile stage is governed by the function $L \cdot \gamma_L(v_L(R_L))$. This equation, together with its counterpart for the maturation of large juveniles into the adult stage (equation (8) in Table 10.1), forms the unique aspect of this model and is derived to guarantee correspondence, in equilibrium, between this model and a fully size-structured counterpart (de Roos *et al.*, 2008). The equation for the dynamics of the large juveniles, equation (5) in Table, is formulated analogously to that of the small juveniles, except that the inflow of biomass from reproduction is replaced by the inflow of small juveniles reaching the size threshold of the large juvenile stage. The superscripted +-signs on the reproduction and the stage transition processes indicate that these terms can become 0 but never negative (equation (7) in Table 10.1). This ensures consistency in periods of food shortage, and facilitates the use of the model to explore non-equilibrium situations (de Roos, 2008).

The adult dynamics (equation (6) in Table) depend on the inflow of maturing individuals from the large juvenile stage, and adult biomass is lost through mortality. As long as adult resources are sufficiently abundant, the terms $\nu_A(R_A)$ and $\nu_A^+(R_A)$ cancel each other out. However, when resources are insufficient to cover metabolic costs, $\nu_A(R_A)$ becomes negative, while $\nu_A^+(R_A)$ becomes 0. Hence, when adults have insufficient food, metabolic costs exceed intake, reproduction stops and the adult stage begins to lose biomass through starvation at a rate proportional to the magnitude of the energy deficit.

Two compartments for the juveniles

One of the features in the data which we aim to study here is the shift in the distribution of juvenile plaice individuals outside the plaice box, which is documented in (Grift *et al.*, 2004). Studying this shift requires an extension of the above model, as we need to explicitly take into account the juvenile plaice living outside the plaice box area. We introduce a second juvenile stage, J2, which feeds on resource population RJ2 (Figure 10.1, Table 10.2). We assume that a fraction p of developing small juveniles (L) enters stage J, while the rest (1-p) leaves the plaice box and enters stage J2. We assume that juveniles migrate between stages J and J2 proportional to the difference in scope for growth in the two habitats. Scope for growth equals $\nu_i(R_i)$, the biomass channeled to growth after metabolic costs have been subtracted. We use the rates E and M for emigration out of and immigration into the plaice box, respectively (equations 11 and 12 in Table). This formulation ensures that migration only occurs in the direction of the highest scope for growth, and acts to equalize scope for growth. This assumption about migration tends to lead to a situation where biomasses are distributed such that scope for growth is equal for juveniles in- and outside the plaice box. The parameter s is a measure of the intrinsic rate at which biomass moves between habitats.

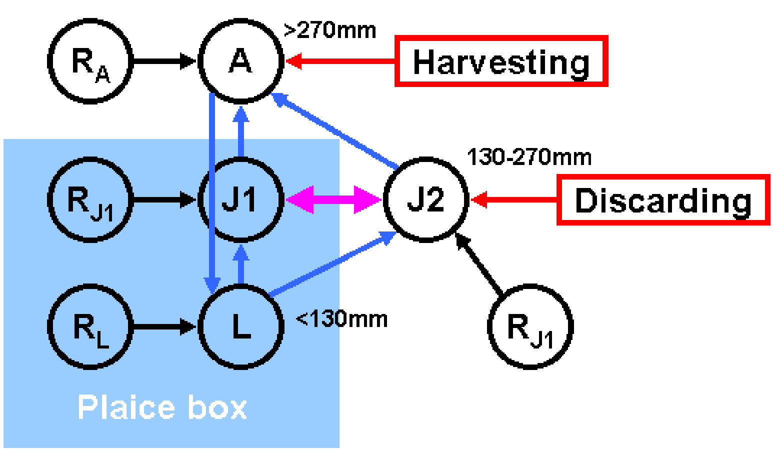


Figure 10.2: Schematic representation of the plaice model extended with a second juvenile stage, J2, which exists outside the plaice box and feeds on its own resource population, RJ2.

Table 10.2: Equations of the extended model with a second large juvenile stage which lives outside the plaice box.

$$\frac{dR_L}{dt} = \delta_L (R_{L\max} - R_L) - I_{\max,L} L \frac{R_L}{H_L + R_L} \quad (1)$$

$$\frac{dR_{J1}}{dt} = \delta_{J1} (R_{J1\max} - R_{J1}) - I_{\max,J1} J2 \frac{R_{J1}}{H_{J1} + R_{J1}} \quad (2)$$

$$\frac{dR_{J2}}{dt} = \delta_{J2} (R_{J2\max} - R_{J2}) - I_{\max,J2} J2 \frac{R_J}{H_J + R_J} \quad (3)$$

$$\frac{dR_A}{dt} = \delta_A (R_{A\max} - R_A) - I_{\max,A} A \frac{R_A}{H_A + R_A} \quad (4)$$

$$\frac{dL}{dt} = b \cdot A \cdot v_A^+(R_A) + L \cdot (v_L(R_L) - \gamma_L(v_L^+(R_L)) - \mu_L) \quad (5)$$

$$\frac{dJ1}{dt} = p \cdot L \cdot \gamma_L(v_L^+(R_L)) + J1 \cdot (v_{J1}(R_{J1}) - \gamma_{J1}(v_{J1}^+(R_{J1})) - \mu_{J1}) - E \cdot J1 + M \cdot J2 \quad (6)$$

$$\frac{dJ2}{dt} = (1-p) \cdot L \cdot \gamma_L(v_L^+(R_L)) + J2 \cdot (v_{J2}(R_{J2}) - \gamma_{J2}(v_{J2}^+(R_{J2})) - \mu_{J2}) + E \cdot J1 - M \cdot J2 \quad (7)$$

$$\frac{dA}{dt} = J1 \cdot \gamma_{J1}(v_{J1}^+(R_{J1})) + J2 \cdot \gamma_{J2}(v_{J2}^+(R_{J2})) + A \cdot (v_A(R_A) - v_A^+(R_A) - \mu_A) \quad (8)$$

$$v_i(R_i) = \sigma I_{\max,i} \frac{R_i}{H_i + R_i} - C \quad \text{and} \quad v_i^+(R_i) = \max[v_i(R_i), 0] \quad (9)$$

where $i \in \{L, J1, J2, A\}$

$$\gamma_j(v_j^+(R_j)) = \frac{v_j^+(R_j) - \mu_j}{1 - z_j^{1 - \frac{\mu_j}{v_j^+(R_j)}}} \text{ Where } j \in \{L, J1, J2\}. \quad (10)$$

$$E = \max\left(0, s \cdot (v_{J2}(R_{J2}) - (v_{J1}(R_{J1})\right) \quad (11)$$

$$M = \max\left(0, s \cdot (v_{J1}(R_{J1}) - (v_{J2}(R_{J2})\right) \quad (12)$$

Parameters

The parameters used in this modeling exercise have been recalculated from various sources. Below we give a short overview for each parameter.

Maximum resource abundance The maximum resource abundance reflects the relative productivity and mediates the strength of density dependence. With body size, an individual's diet generally broadens as its gape size increases and it is able to ingest larger prey items. Consequently, we have assumed values of $R_{\max,L} = 1$, $R_{\max,J1} = 2$, $R_{\max,J2} = 2$ and $R_{\max,A} = 4$. These values reflect the relative productivities of resource for the different plaice population stages. This arrangement also correspond to the pattern that the density-dependent effects on individual growth are strongest early in plaice life history, and decrease later (chapter 6).

Resource growth rate We have assumed the resource growth rate to be equal for all resource populations, so that $\delta_L = \delta_{J1} = \delta_{J2} = \delta_A = 0.1 \cdot day^{-1}$.

Stage transition size ratios The ratio of the size at which individuals enter the small juvenile stage L and at which they develop into large adults, J or J2, (the parameter z1) and the transition size ratio from the large juvenile stages to the adult stage (z2) can be calculated from the lengths at which we assume these transitions to take place. We used the length-weight relationship for plaice published in Fishbase (2007), $W = 7.88 \cdot L^{3.053}$. For the immature stages, it is possible to calculate the expected average weight of individuals in each stage (Van Leeuwen, De Roos & Persson, 2008). Because the model assumes that adults do not grow in body size, we cannot calculate the adult average weight in the same way. We have assumed an adult average length of 300 mm, which results in an average body weight of ~288g. Furthermore, we have taken the length at which individuals enter the small juvenile class equal to 14mm, the length at which the larvae settle in the benthic habitat.

Table 10.3

Stage	Length in (mm)	Length out (mm)	Weight in (g)	Weight out (g)	Average weight (g)
L	14	130	0.025	22.40	7.57
J, J2	130	270	22.40	208.61	192.15
A	270	-	208.61	-	287.7671

Using these numbers, we can calculate the parameters z1 and z2 as $z1 = 0.025/22.40 \approx 0.0011$ and $z2 = 22.40/208.61 \approx 0.11$.

Maximum feeding rate $I_{\max}$ is a biomass-specific daily rate. Intake rate generally scales with surface area, i.e. weight to the power 2/3 (Kooijman, 2000). To calculate the appropriate values for our model, we use the average body weight for each stage (Table) and a published relationship between body weight and $I_{\max}$ for plaice (van der Veer, Kooijman & van der Meer, 2001). This leads to the values $I_{\max,L} = 0.077$, $I_{\max,J} = I_{\max,J2} = 0.026$ and $I_{\max,A} = 0.023$.

Half saturation constant There is no empirical measurement of this parameter for plaice. The resource abundance at which the consumer reaches half its maximum intake rate fixates the size of the environment that the consumer lives in. We account for differences in habitat size and productivity by assuming different values for the maximum resource density, and hence we use the same half saturation constant for all stages in the model, $H = 0.5$.

Metabolic rate We assume that mass-specific metabolic rate C is independent of body weight and hence is the same for all stages in the model (Kooijman, 2000).. Following published values for plaice, we set $T = 0.006 \cdot day^{-1}$ (van der Veer *et al.*, 2009; van der Veer *et al.*, 2001)..

Assimilation efficiency The fraction of biomass intake which can be used by the consumer (σ), equals 0.8 for plaice (van der Veer *et al.*, 2009; van der Veer *et al.*, 2001).

Reproductive efficiency For simplicity, our models assume that recruitment to the pelagic larval stage is instantaneous. In reality, there is an egg stage and a pelagic larval stage in which feeding occurs. There is also high mortality in this early life stage. This parameter translates reproductive output by adults into a biomass inflow into the small juvenile stage. It captures the biomass loss through mortality and biomass gain through feeding. Beverton & Iles (1992) found that approximately 0.03% of fertilized eggs survive to become pelagic settlers. A single gram of female reproductive tissue contains approximately 1500 eggs (van der Veer *et al.*, 2001) while according to the length-weight relationship presented above, a 14 mm settler weighs ~0.025 g. Hence, each settling juvenile is a factor ~37 heavier than when it was released as an egg. Because only 1 out of 3300 eggs survive to settlement, we arrive at a reproductive efficiency of ~0.01. Because only female reproductive tissue contains eggs, we divide this efficiency by 2, arriving at a parameter value $b = 0.005$.

Migration sensitivity There is no data on this parameter, the intrinsic sensitivity of migrating plaice to gradients in growth potential. We have assumed a value of $s = 100$, meaning that plaice respond strongly even when the difference in growth potential is limited.

Fraction of small juveniles which stays in the plaice box The area which the plaice box encompasses has been considered to protect approximately 90% of undersized plaice (Grift *et al.*, 2004). We therefore assume $p = 0.9$.

Mortality Each groups in the model has a single mortality rate, which is the sum of all sources of mortality. For the small juveniles L, we assume a rate of 0.2 per year, for the large juveniles inside the plaice box (J) we assume 0.1 per year. Large juveniles living outside the plaice box (J2) have a high mortality rate of 0.6 per year, as do the harvested adults (A).

Temperature dependence

In order to incorporate temperature-dependence into the plaice model, we use the framework developed in Van Der Veer et. al. (2009). A simple Arrhenius function is used to model the temperature-dependence of the metabolic rate C:

$$C = C_{ref} \cdot e^{\left(\frac{T_A}{T_{ref}} - \frac{T_A}{T}\right)}$$

Here, T is temperature, in K, TA is the species-specific Arrhenius temperature. Following Van der Veer et. al. (2009), we use TA=7000K. The reference temperature Tref equals 283K. For the intake rate, a more complex temperature dependence is used, including not only the Arrhenius function for enzymatic reaction rates, but also a cutoff at low and high temperature, reflecting other physiological limitations of the organism (van der Veer *et al.*, 2009). The temperature dependence of the maximum intake rate is given by

$$I_{\max,i} = I_{\max,i,ref} \cdot e^{\left(\frac{T_A}{T_{ref}} - \frac{T_A}{T}\right)} \left(\frac{1 + e^{\left(\frac{T_{AL}}{T_{ref}} - \frac{T_{AL}}{T_L}\right)} + e^{\left(\frac{T_{AH}}{T_H} - \frac{T_{AH}}{T_{ref}}\right)}}{1 + e^{\left(\frac{T_{AL}}{T} - \frac{T_{AL}}{T_L}\right)} + e^{\left(\frac{T_{AH}}{T} - \frac{T_{AH}}{T_H}\right)}} \right).$$

Here, i represents any plaice stage in the model (L, J, J2, A). When the temperature is between approximately TL (277K) and TH (297K), the relationship between temperature T and maximum intake rate is determined by the Arrhenius relationship. The rates of decrease at high temperature TAH (1.0E5K) and at low temperature TAL (5.0E4K) determine how fast the intake rate declines when the temperature moves outside the tolerance range.

We use the following temperature estimates for the habitats in which the different plaice stages live: Small juveniles (L): 285K, Large juveniles inside the plaice box area (J): 284K, large juveniles outside the plaice box area (J2): 283K, and adults (A): 280K.

Results

Using the simple model, in absence of the plaice box (Figure 10.1, T<2000), assuming that all juvenile plaice are inside the plaice box, leads to a population biomass distribution strongly dominated by juvenile individuals (Figure 10.3. In this model, a strong reduction in the mortality of large juveniles, which represents the effects of reduced discard mortality of these individuals in the plaice box, leads to an initial spike in the abundance of adult plaice, quickly followed by a decline to very low levels. The dominance of large juveniles becomes even stronger, and the abundance of small juveniles is somewhat reduced.

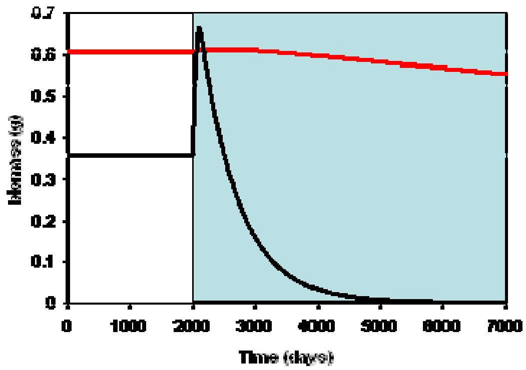


Figure 10.2: A time series calculated with the simple model (Table). Left panel: Adult biomass (A, black line) and small juvenile biomass (L, red line). Right panel: Juvenile (J) biomass. At T<2000 days, we assume there is no plaice box, and large juveniles J suffer the same mortality as adults A, 0.6 per year. At T=2000 days, we 'switch on' the plaice box, reducing the mortality of stage J from 0.6 to 0.1 per year.

The changes in population stage distribution are a result of shifts in the life stage where most competition occurs. The high mortality in stage J when there is no plaice box, means that resources per unit plaice biomass are relatively high, resulting in relatively fast maturation. When the plaice box is implemented, biomass in stage J increases, and food becomes more scarce. The result is that individuals have a longer residence time in this stage, and less biomass advances to the adult stage per unit time. The discard mortality reduces resource competition in stage J and promotes the advance of biomass to the mature stage. In an open system such as the North sea, and the plaice box area within it, large juveniles are not physically constrained to the protected area, and when reduced mortality leads to crowding, it can be expected that fish will move out of the protected area in search of food. We have therefore developed a more complex model (Figure 10.2, which takes into account that large juveniles can in principle live outside the plaice box area.

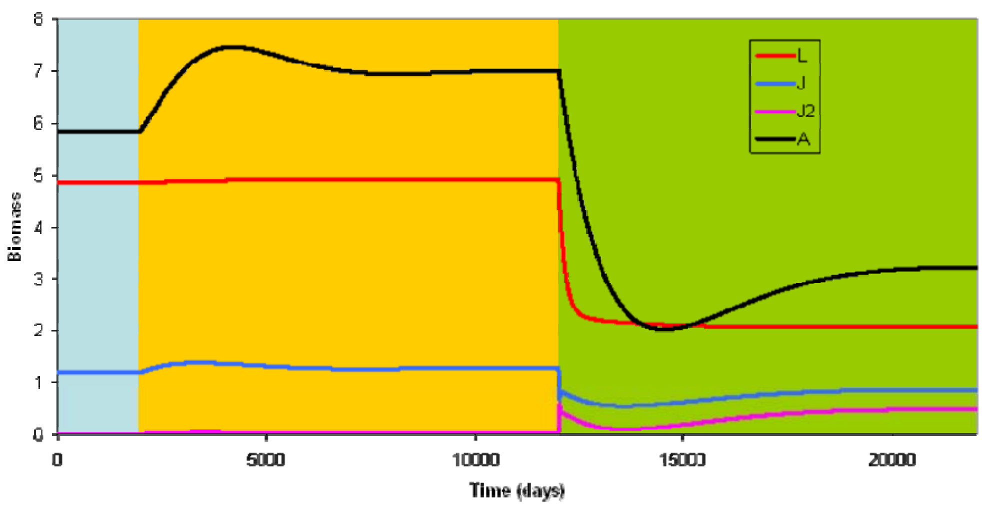


Figure 10.4 Time series computed for the complex model (Figure). At T<2000, discard mortality is high for large juveniles both inside (J) and outside the plaice box (J2) area (0.3 per year in both areas). At T=2000, the discard mortality is reduced to 0.1 per year for J, but not for J2, reflecting the ban on large beam trawlers using small mesh sizes in the plaice box area. At T=12000, productivity (Rmax) in all habitats is reduced by 50%.

Repeating the same simulation in the complex model leads to quite different results (Figure). Initially, the population is dominated by adult biomass rather than large juveniles (Figure 10.2). This discrepancy is a result of the higher total productivity available to large juveniles (RmaxJ + RmaxJ2) in the complex model. When the mortality of large juveniles in the plaice box area (J) is reduced, at T=2000, this results in a substantial increase in adult biomass, while other stages are relatively unaffected. When, at T=12000, the overall productivity is reduced, this leads to a strong reduction in the biomass of small juveniles and adults, a reduction in biomass of large juveniles inside the plaice box, and an increase in large juveniles outside the plaice box.

In order to test the possible effects of changing the size of the plaice box, we have calculated the equilibrium plaice distribution as a function of the fraction of the large juvenile habitat in which these plaice are protected from discard mortality. We have done this both for normal (Figure 10.3), and for reduced productivity (Figure 10.4), and the results are similar. They show clearly the habitat switch in the large juveniles. When the majority of the large juvenile habitat is unprotected, all large juveniles live in this unprotected habitat. When the majority of the large juvenile habitat is protected, all large juveniles develop in the protected habitat. Between these two is a range where the large juveniles are distributed among both habitats. In both cases, increased adult plaice abundance co-occurs with the large juveniles' preference for the protected area (right hand sides of Figure 10.3 and Figure 10.4).

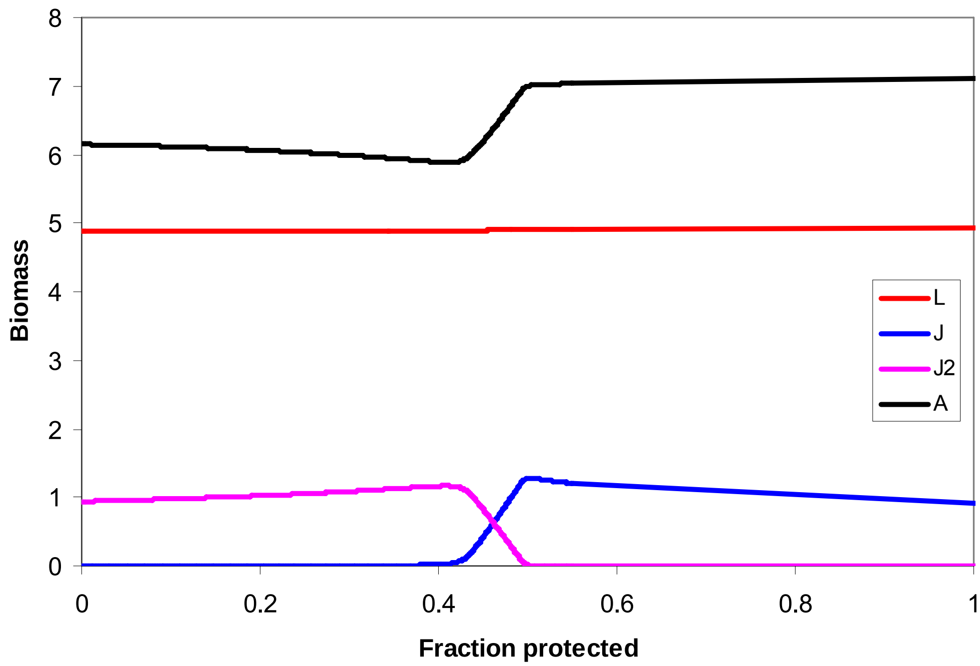


Figure 10.3: Effects of changing the proportion of large juvenile plaice habitat in which discard mortality is low (0 means no protection, 1 means total protection). This calculation is done at normal productivity.

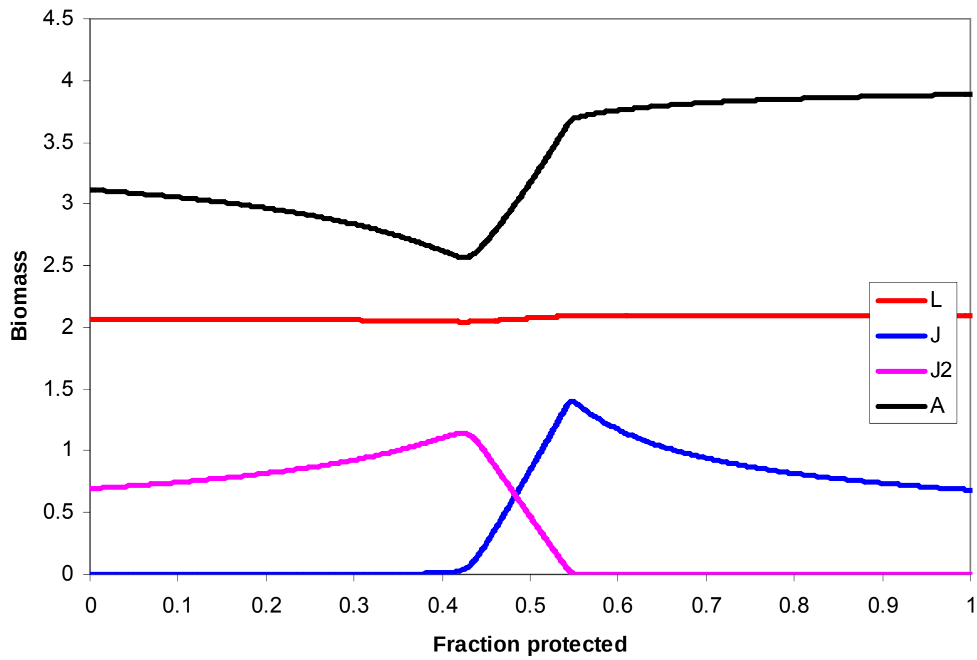


Figure 10.4: Effects of changing the proportion of large juvenile plaice habitat in which discard mortality is low (0 means no protection, 1 means total protection). This calculation is done at 50% reduced productivity in all habitats (as in the right hand side of Figure).

The results varying the percentage of the large juvenile habitat in which no discard mortality occurs (Figure 10.3 and Figure 10.4) shows that in general, when the bulk of the large juvenile biomass resides outside the protected area, increasing the protected fraction sufficiently, leads to increased adult biomass abundance. This result is independent of overall productivity. However, given the 'dip' in the adult abundance curve, a reduction in the extent of the protected fraction can also lead to an increase in adult abundance, but of a lesser magnitude. When the bulk of the large juvenile individuals reside inside the protected area, a reduction in its size always leads to a reduction in adult biomass.

Discussion

The simple model (Table 10.1) predicts that the plaice population in terms of biomass should be strongly dominated by large immature individuals. This does not seem to be the case in the North sea plaice population. A strong reduction in the mortality of this size class, representing the reduced discard mortality brought about by the establishment of the plaice box, leads to a strong reduction in the adult biomass. This decrease is seen in the North sea population as well, and is one of the reasons for the current study. In the model, the decrease is caused by a strong increase of resource competition in the large juvenile stage. This means that the growth of individuals slows down, so that individuals spend a much longer time in the large juvenile stage, and only very few survive to advance to maturity. Although this may occur in small, closed systems, where individuals have no alternative resources or possibility for migration available, we consider it unlikely that this mechanism is responsible for the decline of the plaice SSB in the North sea following the closure of the plaice box. The North sea is an open system, and while the large juvenile plaice may prefer the area covered by the plaice box, they are not restricted to it. The more complex model (Table 10.2) has an 'escape route' for these large juveniles, in the sense that they have a choice between staying in the plaice box, where mortality is low, temperature is high, but food availability is also potentially low, and moving to colder, deeper waters, where mortality is high but competition may also be lower. In this model, the strongest effect of the establishment of the plaice box is a ~15% increase in adult abundance. Despite that densities of large juveniles hardly change in response to the establishment of the plaice box, there is a significant change in the life history of juvenile plaice. Most individuals are now born as small juveniles (L), then advance to be large juveniles inside the plaice box (J), from where they migrate to deeper waters (J2). In this stage the density is low because both mortality and maturation rate are high, leading to very short residence times of individuals in this stage. The 'escape route' created by the habitat for large juveniles outside the plaice box has shifted the effects of the plaice box from the large juvenile to the adult life stage. Although the prediction that the plaice box increases adult biomass is in line with the original arguments used to establish the plaice box, it is doubtful that overall discards would be reduced in the model, because the re-routing of plaice through compartment J2 –which lets them escape intense resource competition- crucially requires high (discard) mortality in that compartment.

In the years following the establishment of the plaice box, a substantial reduction in both dissolved inorganic nutrients and phosphate has been observed (see Chapter 5). The effects of such a reduction on the plaice population in our model, qualitatively fit the observed changes in the plaice population. The reduced productivity induces a decrease in small juvenile and adult abundance, and a shift of large juvenile individuals out of the plaice box area, into colder water.

The effects of changing the size of the plaice box are qualitatively identical, independent of productivity. Adult abundance is always highest when all large juvenile plaice are protected from harvesting. Going from very little protection to a higher fraction, the adult biomass first decreases, suggesting that a small area in which discard mortality is reduced may be worse than no protection at all in relation to SSB.

Spatial explicit model (model 2)

Introduction

In order to explore the effects of alternative plaice box scenarios, a model was developed that simulated the partial fishing mortalities by age-group and métiers based on the spatial distribution pattern of plaice and fishing effort. The model is conceptually similar to the models applied by the ICES Working Group that provided the calculations on which the original plaice box advice was based (ICES 1987). The model estimates the partial fishing mortality of plaice landings and discards by age group for different métiers taking account of the mesh selectivity by métier and an average growth rate of plaice. Effort and plaice distribution patterns are estimated for the most recent 5-year period, and the catchabilities are calibrated against the mean fishing mortality over the study period as available from the most recent ICES stock assessment (ICES, 2009). With the simulated fishing mortality rate of landings and discards, a yield per recruit analysis is carried out to compare the different plaice box scenarios with regard to the yield per recruit, spawning stock biomass per recruit as well as the proportion of discarded plaice. The plaice box scenarios comprise a base line run representing the current situation, and two scenarios in addition to the scenarios of extending the plaice box, removing the box and an experimental design (zig-zag scenario) which has previously been proposed in the North Sea Regional Advisory Council (Appendix to Chapter 2: NSRAC advice).

Method

The model works at the resolution of ICES statistical rectangle (1o longitude and 0.5o latitude) and a time step of 6 months. The study area selected comprised of the southern and eastern North Sea between 51oN to 58oN and 1oE to 9oE. The period 2004-2008 was chosen as a reference period to obtain the average distribution patterns of effort and plaice. The winter and summer distribution of each age groups (1 to 10 years) was estimated from the IBTS and BTS surveys, respectively. IBTS distribution was applied to the first half of the year and the BTS distribution to the second half. Fish densities were expressed as a relative density summing up to 1 over the study area. Fishing effort data were analysed for the dominant métiers for each quarter and then pooled to 6-month periods. Because 8 of the 87 ICES rectangles of the study area were not sampled during the 1st and 3rd quarter surveys between 2004-2009, the relative plaice density was estimated from the surrounding rectangles. Rectangle 44F6 was assigned the value of 44F5. Rectangle 36F8 was assigned the mean value of 36F7 and 37F8. Rectangle 35F6 was assigned the value of 35F5. Finally, the missing F7 (41F7 and 42F7) and F8 (40F8 – 42F8) rectangles in the northern part of the plaice box were assigned a value factor*mean, where mean was the mean value of 37-39F7 and 37-39F8, respectively and factor is the value of rectangles 40F6, 41F6 or 42F6 relative to that of the mean value of 37-39F6.

The proportion of each age group that will be caught is a function of the growth rate, the retention by the gear and the minimum landing size. Length was modeled using the von Bertalanffy growth equation for the 1st and 3rd quarter of the year and setting t0=0. The latter is appropriate since peak spawning of plaice occurs in January and February.

$$L_t = L_\infty (1 - e^{(Kt - t0)}) \qquad [1]$$

The size distribution of the plaice population was modeled assuming a normal distribution N(Lt,□). The proportion p of each size class that is retained in the net is a function of the size of the fish (L), the mesh size used (mesh) and the selection factor (sf = length at 50% retention / mesh size) and selection range (sr = length interval between 25% and 75% retention) of the gear:

$$\ln\frac{p}{1-p} = \frac{\ln(\frac{1}{3}) * sf * mesh}{sr} - \frac{\ln(\frac{1}{3})}{sr} L \qquad [2]$$

Assuming a knife edge sorting ogive, all fish below the minimum landings size that are retained are considered to be discarded and those that are above the minimum landings size are considered to be landed.

For each age group (t), the partial fishing mortalities were estimated for the landings (fl) and discards (fd) at each rectangle (i), time step (j) and métier (k) taking account of the catchability of the gear and of the proportion of the age group retained in the gear:

$$fl_{ijkt} = \sum_{ijkt} p_{kt} q_k e_{ijk} \qquad [3]$$

Table 10.4 Parameter values used in the base-run simulation

Parameter	Value	Unit
K	0.299	cm/year
Linf	41.7	cm
T0	0	year
Cv	0.20	cm
Sf	2.2	
Sr	1.0	cm
Lmin	27.0	cm

Table 10.5. Fishing hours, engine power and mesh size used in the métiers. The catchability is estimated in the base-run simulation and tuned to the mean fishing mortality of age groups 2 to 6 (F2-6) in the reference period as given by the latest ICES stock assessment.

Métier	Engine power kW	Mesh size (cm)	Fishing effort kWhours.year-1 (10^6)	Catchability (q)
OTB-Euro-100	<=221	10	9.0	1.665E-07
OTB-Euro-80	<=221	8	24.3	7.890E-08
OTB-large-100	>221	10	74.4	3.138E-08

OTB-large-80	>221	8	41.7	3.512E-08
Other-large	>221	12	188.0	2.650E-09
Other-small	<=221	12	16.5	7.284E-08
Shrimpers	<=221	3	106.4	3.388E-11
TBB-Euro-100	<=221	10	1.4	1.478E-07
TBB-Euro-80	<=221	8	27.6	3.531E-08
TBB-large-100	>221	10	37.7	6.591E-08
TBB-large-80	>221	8	678.6	2.628E-08
Trammel-large	>221	12	11.3	5.818E-08
Trammel-small	<=221	12	21.2	7.745E-08

Model parameters are given in Table 10.4. Von Bertalanffy growth parameters were based on the mean parameters of the VBG curves fitted through the mean length at age of individual cohorts 1993-2002 (females) as observed in the surveys and market samples. These cohorts are representative of growth in the reference period 2004-2008. Mesh selection parameters were obtained from experiments carried out in the early 1980s on board of commercial vessels (Rijnsdorp and van Beek, 1982).

The estimated catchability q for the various métiers is given in Table 10.5. This table also show the dominant gears in terms of fishing hours. Because, fishing power is affected by the engine power of the vessel, fishing effort is corrected for engine power and expressed as kwhours. Although the fleet of shrimpers use small meshed trawls, the plaice caught mainly refer to 0-group plaice as they fish predominantly in the very shallow waters within the 12 mile zone. Hence, the discarding by this métier was set to zero. No specific information is available on the mesh selection characteristics of the métiers 'trammel' and 'other' and a mesh size of 12cm was assumed at which discarding will be negligible.

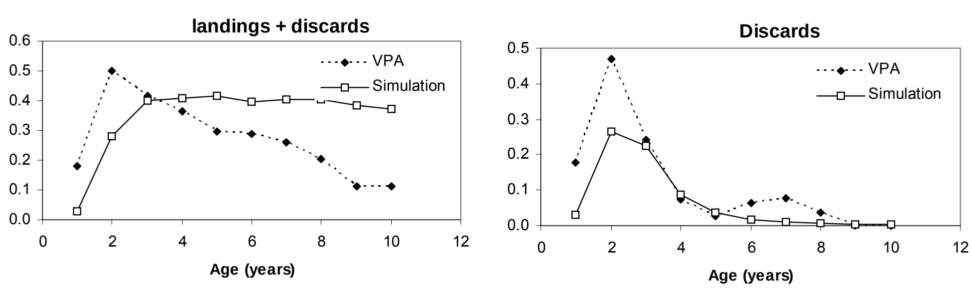


Figure 10.5 Comparison of the simulated fishing mortality of age group 1 to 10 and the VPA estimates by ICES for the total catch (landings and discards: panel left) and discards (panel right).

Model validation and sensitivity

Model performance was evaluated by comparing the simulated fishing mortality rates at age in the reference period and the simulated proportions of discards and landings. Figure 10.5 shows that the simulated exploitation pattern is rather flat, while the VPA estimates an exploitation pattern with a clear peak on the age groups 2 and 3.

Table 10.6 presents the results of the sensitivity analysis. The simulated yield and SSB per recruit are most sensitive to a change in the catchability (Fvpa). A 10% change in catchability results in a 15% change in the yield and a 18% change in the SSB. The simulated discard rate changes by 15% (discard in numbers) and 18% (discards in weight). A 10% change in gear selectivity parameters has a proportional 10% effect on the yield and discard estimates, whereas the SSB changes by only 5%. The coefficient of variation of the length distribution of each cohort has a minor effect on the simulation results. Sensitivities are generally less than 3%.

Table 10.6 Change in Yield per recruit (landings, discards), Spawning Stock Biomass per recruit, Discard percentage (numbers, weight) for a 10% decrease (min) or increase (plus) in the model parameters CV, SF, SR and Fvpa.

	CV		SF		SR		Fvpa	
	min	plus	min	plus	min	plus	min	plus
Yield (landings)	0.976	1.051	1.115	0.894	1.116	0.893	1.149	0.851
Yield (discards)	1.004	0.990	0.958	1.026	0.960	1.024	0.896	1.079
SSB	0.994	1.003	1.049	0.942	1.050	0.941	1.184	0.827
Discards (%num)	1.004	0.995	0.889	1.107	0.888	1.107	0.850	1.147
Discards (%weight)	1.022	0.978	0.892	1.105	0.893	1.104	0.828	1.184

Plaice box scenarios

The plaice box scenarios are shown in Table 10.7. Scenario #1 is the base-line run representing the current situation with the plaice box closed for métiers with engine powers over 221kW during the whole year. Scenario #2 presents the extended scenario in which the plaice box regulation is extended to the ICES rectangles along the Dutch coast and the rectangles neighbouring the current box. This area encompassed 70% and 54% of 1- and 2-year old plaice, respectively. Fishing effort of the métiers expelled from the box was allocated in proportion to their effort in the remaining area. Effort by métiers <221kW is not changed. Scenario #3 presents the situation before the plaice box was established and all métiers >=221kW were allowed to fish up to 12 nm from the coast. For these métiers it was assumed that 30% of their total effort was re-allocated to the plaice box. Effort was distributed evenly over the plaice box rectangles. Scenario #4 presents a change in the current plaice box regulation that was proposed by the Flatfish Working Group of the North Sea Regional Advisory Council to study the response of plaice to a change in fishing patterns. In this scenario the location of the offshore border is changed into a zig-zag pattern by extending the plaice box with one ICES rectangle, and closing these rectangles to all trawl fisheries, and lifting the plaice box regulations in the intermediate. Fishing effort of the trawl fisheries was reallocated to the intermediate rectangles where the plaice box regulation was lifted.

Table 10.7. Plaice box scenarios

Runs	Description
1	Base-line run with current management regime and observed distribution of plaice and effort of eight métiers
2	Extended plaice box comprising an additional line of rectangles along the coast of the Netherlands and the Plaice Box for the >221kW métiers with a mesh size <12cm.. This area encompasses xx% of the undersized plaice.
3	No Plaice box. Plaice box opened for all métiers and assuming that 30% of the effort of métiers >221kW is re-allocated to the plaice box.
4	Zig-zag scenario. Modified plaice box keeping the total surface area similar but extending the outside border alternatively offshore and inshore. This scenario represents an experimental approach to address the hypothesis that plaice left the plaice box because of the reduction in trawling disturbance within the box (see NSRAC Advice in Appendix to Chapter 2)

Table 10.8 Results of the plaice box scenario simulations for the current situation (reference period: 2004-2008) and the situation in 1987 (reference period: 1970s and 1980s). Effect of different scenarios are assessed by the yield and spawning stock biomass per recruit and by the discard percentage in numbers and weight.

Scenario	Stock biomass kg	SSB kg	Yield kg	Yield (discards) kg	Yield (numbers)	Yield (discard numbers)	%discards (numbers)	%discards (weight)
A. Current situation: Yield and (spawning) stock biomass per recruit analysis								
Base	0.569	0.385	0.119	0.039	0.638	0.327	51%	32%
Extended	0.626	0.435	0.129	0.035	0.620	0.292	47%	27%
Open-30	0.560	0.379	0.113	0.040	0.640	0.344	54%	35%
Zig-zag	0.603	0.417	0.121	0.037	0.627	0.316	50%	31%
Relative values to open-30								
Extended	10%	13%	8%	-9%	-3%	-11%	-8%	-16%
Open-30	-2%	-1%	-5%	4%	0%	5%	5%	9%
Zig-zag	6%	8%	1%	-3%	-2%	-3%	-2%	-4%
B. Situation of 1987 : Yield and (spawning) stock biomass per recruit analysis								
Baseline	1.460	0.911	0.102	0.0551	0.757	0.511	67%	54%
Plaice Box whole year	2.877	2.052	0.179	0.0336	0.666	0.305	46%	19%
Plaice Box 2nd-3rd quarter	2.529	1.772	0.160	0.0386	0.688	0.355	52%	24%
Relative values to open-30								
Plaice Box whole year	97%	125%	76%	-39%	-12%	-40%	-32%	-65%
Plaice Box 2nd-3rd quarter	73%	94%	57%	-30%	-9%	-30%	-24%	-55%

Results

The discard percentage in the baseline simulation is estimated at 51% in numbers (Table 10.7). Extending the Plaice Box area results in a decrease in the discard numbers by 8%, while opening of the box and a reallocation of 30% of the fishing effort of the large vessels to the plaice box rectangles results in an increase in the discard numbers by 5%. The yield and (spawning) stock biomass per recruit will increase by 8%-13% by extending the plaice box, and decrease by 1%-5% when opening the box. The zig-zag scenario simulates a small decrease in discards and small increase in the yield per recruit and a moderate increase in the (spawning) stock biomass per recruit.

The results of the current simulations cannot be directly compared to the results of the simulation carried out in 1987, because of the difference in the details of the model structure and parameter setting. Therefore, a simulation was carried out with the model developed in this report and parameterized for the situation in the mid 1980s using the plaice distribution information used by ICES (1987) and the effort distribution of the Dutch fleets of beam trawlers (<=221 kW and >221kW). This analysis shows that the establishment of the Plaice Box is expected to have a large positive effect on the yield and (spawning) stock biomass per recruit, and a substantial reduction in the number and weight of the discards. The different results between the two periods in due to three factors: plaice distribution, fishing effort and growth rate. As compared to the 1980s, undersized plaice are much less restricted to the shallow coastal waters and now occur with the marketable sized age groups on the offshore fishing areas of the fishing fleets, ie. the distribution of plaice showed a more coastal distribution in the 1980s as compared to the current period. The exploitation level in the current period is lower than in the 1980s. Finally, the growth rate of plaice is now somewhat lower than in the 1980s.

Discussion

The simulations are qualitatively in line with the results of the previous analysis by ICES (1987) that a fisheries closure in an area where undersized fish are concentrated reduced the discarding of plaice and enhanced the yield and (spawning) stock biomass of the resource. Quantitatively, however, the simulation shows a much smaller positive effect of the PB than the simulation in 1987 (ICES, 1987). A re-analysis given the conditions in the 1980s – a higher growth rate and a shallower distribution of the undersized fish – shows that the expected positive effects of the PB are substantially higher that those presented in ICES (1987). This discrepancy is mainly due to a higher discard mortality caused by the difference in method used to simulate the discards.. In the 1987 model, discards were modeled based on quarterly discard fractions by age-group and ICES rectangle extrapolated from observed discard fractions. In the current model, discards are modeled based on the growth rate and the mesh selection of the fishing gear. Since growth rate determines the duration that plaice are within the discard size range, relatively small changes in growth rate may have a substantial effect on the discard mortality (Rijnsdorp and Pastoors, 1995).

The current baseline scenario reflecting the current situation of a year round closure of the PB for vessels >221 kW, suggests that the plaice box has a small effect and reduces discarding by 5% and increase the yield and spawning stock biomass per recruit by 2% and 5%, respectively, when compared to the scenario where the plaice box is lifted and 30% of the fishing effort of the fleets of larger vessels is re-allocated to the plaice box rectangles. These positive effects, however, are small as compared to the sensitivity of the model results for the input parameters (selectivity and catchability). Compared to the expected effects in 1987 – a 25% increase (ICES, 1987), which was supported by the re-analysis of the 1987 situation with the current simulation model - the effects of the plaice box under the current conditions of growth, distribution and fishing effort, is much less. The simulations show that the plaice box had a positive effect on the exploitation of plaice in the context of the ecological conditions of the 1980s. However, due to the offshore movement of undersized plaice and the decrease in growth in the 1990s, the positive effect of the PB has been reduced substantialy and re-opening of the PB will have only a small negative effect. The suggested effects of the PB under the current conditions is small against the background of the uncertainty in the model formulations (no feed-back mechanisms such as density-dependence ofr fishery-dependence in growth or distribution).

Extending the PB with an extra line of rectangles from the Belgian coast up to the Skagerrak will reduce the discarding of plaice more substantially and is expected to increase the yield and SSB per recruit. However, even these improvements are less than estimated by ICES (1987), mainly due to the offshore movement of undersized plaice, which reduced the clear spatial separation of undersized and marketable sized plaice, taking away the possibility to reduce discarding by spatial management.

Synthesis

The stage-based model shows clearly that if undersized plaice have the option to migrate outside the plaice box, then reducing discard mortality inside the plaice box leads to increased spawning stock. Growth retardation as a result of reduced discarding mortality can lead to a reduction in the production of harvestable plaice. However, this reduction is smaller than the increased production through reduced discard mortality, so that the net effect of the plaice box is an increase in spawning stock biomass. Only under the (unrealistic) assumption that undersized plaice are completely restricted to the plaice box area do we see that the density-dependent growth retardation of undersized plaice, which is the result of reduced mortality, leads to a reduction in spawning stock biomass. Our stage-structured models represents an extreme case in that density dependence is strongly regulating the growth of individuals. Given that the data suggests that the effect of density on growth of individuals is relatively small (chapter 6), we consider it unlikely that density-induced growth retardation is the primary cause for the decline of the spawning stock biomass following the installation of the plaice box.

Although the two modeling studies approach the problem from different sides, the conclusions are largely aligned. Both approaches show an increase of SSB in response to the establishment of the plaice box, indicating that the original arguments for installing the plaice box are valid. While no conclusions about discarding can be drawn from the stage-structured model, the spatial simulation clearly shows that the plaice box leads to reduced discarding. The response of the stage-structured plaice model to a decrease in productivity shows remarkable similarity to the changes in the plaice population following the establishment of the plaice box. The period since the establishment of the plaice box is characterized by a substantial reduction in eutrophication (chapter 5). Although the link between eutrophication and productivity is complex, we consider the overall reduction in the productivity of benthic resources a valid alternative explanation to the observed changes in plaice in the last decades. Density-dependence is a crucial factor determining the response to reduced productivity, and hence the spatial model can not be used to add support to this scenario.

The spatial explicit model clearly showed that the change in distribution of undersized plaice in conjunction with a decrease in growth rate has substantialy reduced the positive effects of the PB. The results of the simulations suggest that the PB under the current conditions has a positive effect on yield and spawning stock biomass. However, these positive effects are small relative to the uncertainties in the model formulation and the parameter settings.

At the October stakeholder meeting, real time closures were discussed as a potential tool to reduce discarding of undersized plaice. In this scenario, the fisheries avoids fishing areas where discard rates are particularly high due to local aggregations of undersized fish. Because there is no data available that describes the spatial scale at which these local concentrations may occur, nor data on the duration of these local aggregations or the response of the fisheries, it is impossible to quantitatively evaluate how real time closures may contribute to the reduction in plaice discarding. Nevertheless, it is evident that avoiding areas with a high catch rate of discards will certainly contribute to the objective of discard reduction.

Finally, the alternative PB-scenarios not only affect the exploitation of plaice, but will also affect the exploitation of other target species such as sole (Rijnsdorp and van Beek, 1991). Since sole is the most important species for the 80mm beamtrawl fishery, the implications for the economic performance cannot be assessed without taking account of the effects on the sole landings.

Chapter 11 Socio-economic effects

Introduction

This Chapter aims at evaluating potential economic impacts of modifications of the PB (PB) regulation. In Chapter 4 it was shown that the establishment of the PB, its technical implications and the associated licensing system have had a clear effect on the evolution of capacity of certain metiers in the area, in particular BEAM.<=221kW, as compared to fleets outside the Plaice Box, and on the allocation of catches, in particular between beam trawlers <=221 kW and > 221kW.
Thus, any change or prolongation of the regulation will affect regional fleets, their economic settings as well as the future prospects of the fin and shellfish stocks. First, we will analyse the likelihood of the metiers reacting to new modifications of the PB given their present distributional patterns. This includes specific spatial and seasonal analyses. The PB modifications taken into account have been briefly outlined in Chapter 9. They include the 'full' opening of the PB to the 12 nm zone, a Zig-Zag design, an extended scenario, the status quo and two closure scenarios. Second, we will model the catch opportunities under possible different spatial modifications of the future PB and the status quo assuming three competition models for the fleets. Third we will address aspects of nature conservation in relation to the different possible modifications.

Fleet specific spatial analysis of competitive effects

The question is: How might fleets react to potential new management measures for the PB area? This will be inferred from two different spatial analyses of present fleet characteristics and reconciled with the trend we see in overall fleet capacities (Chapter 4.5).

Overlap

Overlap is a measure of resource competition between fleets. The analysis was carried out for those national fleet segments that spend more than 20 000 VMS effort hours of fishing effort in the PB. Based on VMS data, the proportions of effort per ICES statistical rectangle from the period 2005 to 2008 are analysed with the Morisita-Horn index of overlap (ecological application in Herr *et al.*, 2009) and ranges between 0 (no overlap) and 1 (full overlap). Overlaps are presented on the background of effort distribution figures in Chapter 4.

BEAM.16-31.<=221kW

For shrimp vessels, the overlap between Dutch and German vessels is intermediate (0.27 in relative units). This is due to the concentration of shrimpers in the German Bight off the island of Sylt. However, due to the subsample bias in the VMS data for Dutch vessels, the overlap with German vessels must be considered stronger than intermediate (see Fig. 4.3.1). The Danish vessels have comparably low overlaps with the other vessels.

BEAM.80-99.<=221kW

For German vessels, relatively strong overlaps appear to German BEAM.80-99.>221kW. For Dutch conspecifics, only intermediate overlaps appear with competing fleets (shrimpers have different target species). This is due to the relatively strong concentration of Dutch vessels <=221kW of the Dutch coast and the West-Frisian islands, whereas vessels > 221kW tend to operate more in the German Bight. Accordingly, for German beamers <=221kW overlap with Dutch >221kW beamers is stronger than Dutch conspecifics.

Table 11.1: Overlaps between metiers. Bold figures indicate high overlaps and are discussed in the text.

Metiers	Ger BEAM.80-99.<=221kW	Ger BEAM.80-99.>221 kW	Ger OTTER.80-99.<=221kw	Ger OTTER.80-99>221kW	NLD BEAM.16-31.<=221kW	NLD BEAM.80-99.<=221kW	NLD BEAM.80-99.>221 kW	NLD OTTER.80-99.<=221kW	NLD OTTER.80-99.>221 kW	DK BEAM.16-31.<=221kW
GER BEAM.16-31.<=221kW	0.19	0.0	0.0	0.0	**0.27**	0.0	0.0	0.0	0.0	0.14
Ger BEAM.80-99.<=221kW		**0.49**	0.17	0.12	0.29	0.12	**0.32**	0.20	0.24	0.05
Ger BEAM.80-99.>221kW			0.35	0.38	0.14	0.13	**0.53**	**0.59**	**0.57**	0.0
Ger OTTER.80-99.<=221kw				**0.86**	0.07	0.0	0.31	**0.67**	**0.71**	0.0
Ger OTTER.80-99>221kW					0.06	0.03	0.29	**0.71**	**0.76**	0.0
NLD BEAM.16-31.<=221kW						**0.50**	0.25	0.05	0.13	0.10
NLD BEAM.80-99.<=221kW							0.29	0.08	0.20	0.0
NLD BEAM.80-99.>221kW								0.24	0.37	0.0
NLD OTTER.80-99.<=221kW									**0.80**	0.0
NLD OTTER.80-99.>221kW										0.0

BEAM.80-99.>221kW

Strong overlaps appear between Dutch and German conspecifics, but also with otter board trawlers with mesh sizes from 80 to 99.

OTTER.80-99.<=221kW and >221kw

This group of metiers is characterized by very strong overlaps, ranging from 0.67 to 0.86. In turn, overlaps with PB specific fisheries (BEAM.<=221 kW) are comparably low.

Within-area separation

Within-area separation is taken as a proxy for competitive exclusion. This analysis indicates whether fleets would occupy areas where new fishing opportunities are provided and other fleets were forced to retreat simultaneously. It may be expected that strong effects occur for groups <=221kW and > 221kW.
This is analysed for ICES statistical rectangles split by the present PB design (split=1) and squares that are not separated by the PB (split=0). If fleets are not competitively exclusive, they should be positively correlated. Results are grouped into high and low effort cases, assuming that economically important ICES statistical rectangles have high effort. Exclusive behaviour should then typically be dependent of the degree of effort in an ICES statistical rectangle and exclusive tendencies should appear the higher effort is. Effort was termed 'high' when more than 100 hours effort per year were exerted in an ICES statistical rectangle.

Table 11.2 BEAM.80-99 Comparsions
Different countries – same size categories

split	Effort GER BEAM.80-99.<=221 kW	Effort NLD BEAM.80-99.<=221kW	correlation
	SMALL-SMALL		
0	low	low	0.08
0	low	high	-0.07
0	high	low	0.07
0	high	high	0.20
1	low	low	-0.18
1	low	high	0.35
1	high	low	-0.02
1	high	high	0.33
	LARGE-LARGE		
	Effort GER BEAM.80-99.>221kW	Effort_NLD BEAM.80-99.>221kW	correlation
0	low	low	0.28
0	low	high	0.25
0	high	high	0.50
1	low	low	0.88
1	low	high	0.56
1	high	low	0.54
1	high	high	0.79

Table 11.2 continued BEAM 80-99 Comparisons
Same countries – between size categories

split	effort NLD BEAM.80-99.<=221kW	effort NLD BEAM.80-99.>221kW	Correlation
0	low	low	0.14
0	low	high	0.06
0	high	low	0.14
0	high	high	-0.05
1	low	low	-0.10
1	low	high	-0.19
1	high	high	-0.40
	Effort GER BEAM.80-99.>221kW	Effort GER BEAM.80-99.<=221kW	Correlation
0	Low	low	0.14
0	Low	high	0.20
0	high	low	0.22
0	high	high	0.21
1	Low	low	0.04
1	Low	high	-0.12
1	high	low	-0.19
1	high	high	-0.19

Correlations were calculated on 3x3 nm squares. Analyses were carried out for metiers with mesh sizes BEAM 80-99. Pairwise comparisons are presented for large and small, Dutch and German beam trawlers.

Table 11.2 continued BEAM.80-99 Comparisons
Between countries – between size categories

split	effort GER BEAM.80-99.<=221 kW	effort NLD BEAM.80-99.>221kW	Correlation
0	low	low	0.12
0	low	high	0.08
0	high	low	0.21
0	high	high	0.09
1	low	low	0.03
1	low	high	-0.04
1	high	low	-0.12
1	high	high	-0.20
	effort GER BEAM.80-99.>221kW	effort NLD BEAM.80-99.<=221kW	
0	low	low	0.12
0	low	high	0.03
0	high	low	0.06
0	high	high	-0.06
1	low	low	-0.13
1	high	low	-0.02
1	high	high	-0.36

Different countries – same size categories

In both high-high combinations for <=221kW trawlers, distributions are positively correlated (Table 11.2). In all cases, German and Dutch beamers >221 kW are spatially correlated. Correlations for >221 kW are considerably stronger than for <=221 KW. This rather indicates a stronger dependence on habitat and fishing grounds within an ICES statistical rectangle than for beamers <=221 kW.

Different size categories
As expected, correlations are negative for ICES squares split by the PB. The effect increases with effort, i.e. from low/low to high/high. This result may be due to competitive processes between fleets, which may even lead to competitive exclusion, but could also be due to the fleets selecting the most profitable grounds under different management regime.

Summary of fleet competition effects

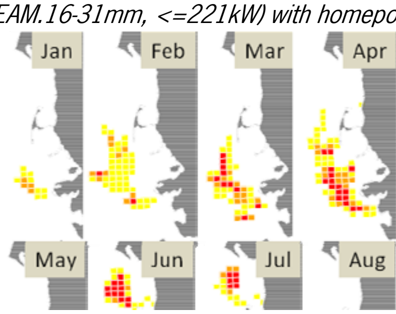
It appears from the overlap analysis, that three relatively distinct groups are present, i.e. shrimp fishing vessels, beam trawlers 80-99 and otter trawlers 80-99. Competition effects are most likely to occur within these groups rather than between these groups, which can be explained through different target species in the fisheries. Although interference competition among fishing vessels is generally assumed, empirical support is scarce (Gillis, 2003; Ulrich et al., 2001). One of the few studies that has provided evidence for competition is the study of the Dutch beam trawl fleet (Rijnsdorp et al., 2000; Poos and Rijnsdorp, 2007). The interference competition is believed to work through change in the behaviour of the fish towards the fishing gear. For this fleet it is also suggested that large vessels are better competitors because of the higher towing speed. Disturbed fish will have a lower chance of escaping for a trawl that is towed at a high speed (Rijnsdorp et al., 2008).
Assuming that the negative correlations between the fishing patterns of different fleet will be (partly) due to competitive processes (worst case scenario), we will assess which metiers are most likely affected by any change of the PB design except for closures aiming at all metiers, are beam trawlers 80-99. Here, negative spatial correlations indicate competitive effects between the two different size categories <=221 kW and > 221kW, so that any change in PB design will lead to significant shifts in effort allocation by either fleet. It was

shown in Chapter 4.5 that the development of fleet capacity by BEAM.<=221 KW was linked to the presence of the PB and the associated licensing system. Competition can also be expected between active gear and static gear, where static gear excludes trawlers and trawlers may damage static gear.
There is no clear country effect in the overlap. Small-small and large-large combinations of beam trawlers show no sign of spatial separation by ICES statistical rectangle, and further, large-large beam trawlers overlap considerably. Notwithstanding the only intermediate overlap for small Dutch beam trawlers 80-99.<=221 kW with other countries' fleets, no country effects are considered further in the spatial model (Chapter 11.3).

Seasonal patterns

To analyze seasonal patterns of activities inside and outside the PB, seven vessels of different métiers (small: 3 x BEAM16-31, SDN>=120, OTTER.100-119; large: 2 x BEAM80-99) with registered home ports in Germany were analyzed individually on daily, monthly and yearly bases. Results for two vessels, BEAM.16-31mm <=221kW and BEAM.80-99mm >221kW are presented in detail to illustrate the patterns.
As shown already by the métier wise analysis in Chapter 4, small beamers fishing for shrimps use the coastal regions and the Waddenzee. For the three ships of this métier analyzed, the main fishing activity was found close to their homeport, but they did undertake trips to the north (Sylter reef and Fanö bay) which lasted about one or two months before they returned to their homeport in Germany (Fig.11.1). Landings to Danish ports were also found regularly.
A future analysis of this relationship with individual data of several countries might lead to a better understanding of fishing behavior. Individual data for vessels with full economic data were only available for the German fleet, limiting the applicability of this approach. Also, the present temporal resolution of VMS data , i.e. mainly 1 – 2 hours between two registrations, is not yet sufficient to analyze competitive fishing patterns between métiers and fleets. .

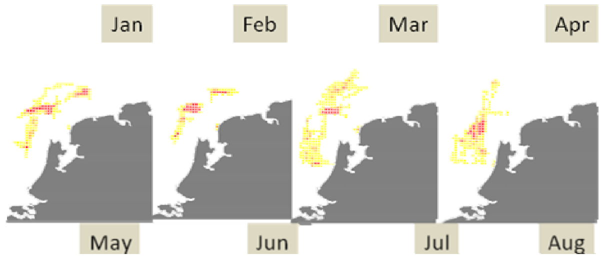
Figure 11.1: Seasonal patterns of effort (hours fishing per month) in 2006 for a small Beam trawler (BEAM.16-31mm, <=221kW) with homeport in Germany fishing along the German and Danish coast.



The analysis reveals that small beamers fishing for shrimp are dependent on the areas of the PB the whole year round. Even part time closures are likely to influence the yields by this métier.

The two large beam trawlers (BEAM.80-90mm, >221 kW, fishing for sole) analyzed were registered to the same home port, like the small ones, but used a Dutch port for landing their catch. So, their fishing grounds were situated off the Dutch coast with minor tendencies to fish westwards in August (Fig. 11.2). Also trips to the Northwest (off the Danish coast) were found in other years in late summer and autumn. As shown in the métierwise analyses, the fishing grounds for this métier are outside the PB, but close to the border of the PB.
This métier uses the fishing grounds just outside the PB the whole year round. Changes in PB design, even if only part time, is likely to influence, positively or negatively (see below) the fishing behavior and yields by this métier.

Figure 11.2: Seasonal patterns of effort (hours fishing per month) in 2006 of a large Beam trawler (BEAM.80-99mm, >221kW, registered to a German homeport and landing in The Netherlands) fishing along the Dutch coast.



Socio-economic model

The aim of this chapter is the calculation of potential monetary gains and/or losses of main métiers in case of changed PB management strategies, i.e.

- Opening of the PB to vessels of all power categories according to the national entitlements to fishing grounds under (EEC) 3760/92 (no PB). This opens coastal waters until the 3-nm zone for Danish, German and Dutch vessels for specified metiers.
- Reducing PB to 12 mile zone, i.e. the situation before the establishment of the PB (12 miles zone)
- Total closure of present PB design (closure PB)
- Extending the PB so that 90% of 1+ Plaice is inside the new PB (PB extension)
- Total closure of extended PB design (closure extended PB)
- Installing a scientific design to evaluate PB effects (zigzag design)

Model building

To model the distribution of earnings after altered PB design, first the monetary yields gained in different areas (Fig. 11.3.) of the present situation (2005 to 2008) were calculated:

- Inside PB (PB)
- Between the border of 12 mile zone and the border of the PB (btwn)
- Inside the extended PB (extPB)
- Inside the scientific zigzag PB design (zigzag)

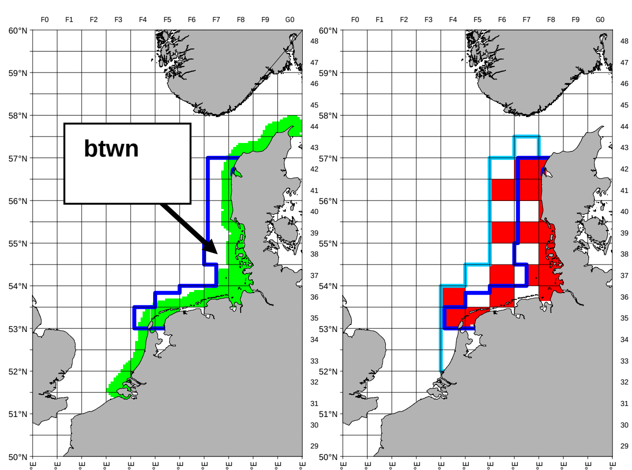


Fig. 11.3:.Spatial setting of the different potential PB management designs. Left: PB (dark blue line), 12 miles zone (green). Right: Extended PB (bright blue line), PB (dark blue line), zig-zag design (red). Please note that the zone between (btwn) the border of the 12 miles zone and the border of the PB is the area which small vessels would have to share with large vessels (>221kW) in case of (local) re-opening of the PB (12 mile zone PB design).

The monetary yields in different areas of the present situation are presented for the Dutch, German and Danish fleet in Tables 11.3., 11.4, 11.5, respectively. The percentages gained in the different zones show that small vessels fishing for shrimps are earning their main yields inside the PB and especially inside the 12 mile zone (indicated by high percentages in PB, but low percentages in the 'between' area, e.g. small German and Danish beam trawler, BEAM16-32, BEAM80-99 and BEAM>100, Tab. 11.6). Please note, that the yield gained in the 'between' area is the yield which has to be shared by the small vessels in case of an opening of the PB down to the 12 miles zone. The same is true for the revenues gained inside the PB in case of a no PB design. On the other hand, in case of a PB extension, yields gained by large vessels just outside the PB (well described by the area of the extended PB) will fall to the small métiers extending their fishing grounds off the coast. This effect will be most severe in the BEAM.80-99 mm >221kW métier which gains 32% and 42% in the area just outside the PB for the Dutch and German fleet, respectively (i.e. the percentages form the extended area minus the percentages of the PB).

Table 11.3: Mean of the years 2005 to 2008 for total earnings (total), the area of the plaice box (PB), the area between the border of the 12miles zone and the border of the plaice box (btwn), the extended PB (ext) area and the area of the PB in zigzag design (ZigZag) of the Dutch fleet. Please note that values of 0.00 indicate earnings below 0.01 Mio. Euro. CSH: common shrimp. PLE: plaice. SOL: sole.

Metier	Power class	species	total	btwn	PB	ext	ZigZag
BEAM.16-31	<=221kW	CSH	52.29	8.13	32.71	47.36	24.96
BEAM.16-31	<=221kW	PLE	0.00	0.00	0.00	0.00	0.00
BEAM.16-31	<=221kW	SOL	0.06	0.01	0.03	0.05	0.03
BEAM.16-31	>221kW	CSH	0.07	0.00	0.00	0.06	0.00
BEAM.80-99	<=221kW	PLE	1.47	0.08	0.20	1.12	0.14

Table 11.4: Mean of the years 2005 to 2008 for total earnings (total), the area of the plaice box (PB), the area between the border of the 12miles zone and the border of the plaice box (btwn), the extended PB (ext) area and the area of the PB in zigzag design (ZigZag) of the German fleet. Please note that values of 0.00 indicate earnings below 0.01 Mio. Euro. CSH: common shrimp. PLE: plaice. SOL: sole.

Metier	Power class	species	total	btwn	PB	ext	ZigZag
BEAM.16-31	<=221kW	CSH	46.80	2.27	46.60	46.79	38.27
BEAM.16-31	<=221kW	PLE	0.00	0.00	0.00	0.00	0.00
BEAM.16-31	<=221kW	SOL	0.03	0.00	0.03	0.03	0.03
BEAM.16-31	>221kW	PLE	0.00	0.00	0.00	0.00	0.00
BEAM.16-31	>221kW	SOL	0.03	0.00	0.00	0.02	0.02

Table 11.5: Mean of the years 2005 to 2008 for total earnings (total), the area of the plaice box (PB), the area between the border of the 12miles zone and the border of the plaice box (btwn), the extended PB (ext) area and the area of the PB in zigzag design (ZigZag) of the Danish fleet. Please note that values of 0.00 indicate earnings below 0.01 Mio. Euro. CSH: common shrimp. PLE: plaice. SOL: sole.

Metier	Power class	species	total	btwn	PB	ext	ZigZag
BEAM.16-31	<=221kW	CSH	12.67	0.30	12.66	12.66	10.18
BEAM.16-31	>221kW	PLE	0.00	0.00	0.00	0.00	0.00
BEAM.16-31	>221kW	SOL	0.00	0.00	0.00	0.00	0.00
BEAM.80-99	<=221kW	CSH	0.02	0.00	0.02	0.02	0.02
BEAM.80-99	<=221kW	PLE	0.01	0.01	0.01	0.01	0.00

Table 11.6: Mean percentage (2005 to 2008) of earnings of total earnings in different zones per main métier, power category and species of the Duch (NLD), German (GER) and Danish (DEN) fleet. For labels of zones please see text. CSH: common shrimp. PLE: plaice. SOL: sole.

	btwn			**PB**			**Ext**			**ZigZag**		
	NLD	GER	DEN	NLD	GER	DEN	NLD	GER	DEN	NLD	GER	DEN
BEAM.>100	13	60	12	19	92	50	49	80	68	17	58	35
<=221kW	22	60	21	34	92	100	77	96	100	31	58	68
CSH		44	3		95	100		98	100		70	79
PLE	28	68	34	38	92	100	79	96	100	37	58	60
SOL	17	59	35	30	90	100	75	95	100	25	52	58
>221kW	4		5	5		6	21	0	40	4		6
PLE	5		4	6		5	21	0	38	4		5
SOL	2		5	4		7	20	0	41	3		7
BEAM.16-31	14	4	2	60	86	100	89	94	100	46	72	88
<=221kW	14	5	2	60	100	100	90	99	100	46	81	80
CSH	15	5	2	62	100	100	90	99	100	47	82	80
PLE	17	6		63	100		91	99		47	80	
SOL	9	4		55	100		88	99		45	81	
>221kW		0			3	100	78	64	100		15	97
CSH							78					
PLE		0			3	100		64	100		28	96
SOL		0			3	100		64	100		3	100
BEAM.80-99	4	20	52	10	42	100	57	69	100	7	21	50
<=221kW	5	31	52	13	67	100	77	83	100	8	33	50
CSH		24	2		58	100		78	100		34	71
PLE	6	35	64	13	71	100	77	87	100	8	32	45
SOL	5	35	65	13	72	100	78	86	100	8	33	45
>221kW	3	3		7	4		36	46		5	3	
PLE	3	3		7	4		36	46		5	3	
SOL	3	3		7	4		36	46		5	3	
GILL-TRAMMEL	7	10	25	13	20	39	96	33	64	13	14	32
<=221kW	7	12	26	13	26	42	96	38	66	13	18	39
CSH	10			18			99			18		
PLE	2	12	26	7	27	37	88	40	65	7	20	34
SOL	10	12	25	15	25	48	99	36	67	15	15	45
>221kW		8	24		11	36		25	61		9	24
PLE		14	24		16	29		37	60		16	16
SOL		1	24		6	44		13	61		2	33

Table 11.6: continued.

	btwn			**PB**			**Ext**			**ZigZag**		
	NLD	GER	DEN	NLD	GER	DEN	NLD	GER	DEN	NLD	GER	DEN
OTTER.>100	1	12	9	4	17	13	21	37	23	3	16	12
<=221kW	2	16	15	5	19	21	32	34	30	3	17	18
CSH	3			5			57			4		
PLE	2	16	14	4	19	23	16	30	34	1	17	18
SOL	0	16	16	6	20	20	27	38	27	4	18	19
>221kW	1	8	4	3	14	5	7	39	15	3	14	5
PLE	2	8	3	4	9	5	9	33	13	3	9	4
SOL	0	9	4	2	19	6	5	45	17	2	19	6
OTTER.80-99	2	4	0	4	5	0	37	40	9	2	2	0
<=221kW	3	4	0	4	5	0	37	39	8	2	2	0
CSH	6			9			43			3		
PLE	1	4	0	2	6	1	34	38	12	1	2	0
SOL	1	4	0	2	5	0	32	40	5	1	3	0
>221kW	0	4	0	3	4	0	39	41	10	2	1	0
PLE	1	4	0	3	4	0	39	39	11	3	1	0
SOL	0	3	0	2	4	0	38	43	9	2	1	0
OTHER	31	32	16	43	41	23	77	74	36	22	41	21
<=221kW		41	6		58	15		94	30		58	14
PLE		43	5		52	12		95	28		52	11
SOL		36	8		70	17		91	32		70	17
>221kW	31	25	26	43	28	31	77	59	42	22	28	29
PLE	31	32	14	43	36	20	77	66	33	22	36	17
SOL		18	38		20	42		51	51		20	40

From the distribution of effort and monetary yield described in Chapter 4 and the potential effects of competition between the métiers in Chapter 11, the following impacts of changes in the PB design on the main métiers can be expected.

Metier	Power	expected effect of changes in PB design	PB extension	PB reduction
Beam100	large	Yes	negative	positive
		Effort is close to border outside the PB. The metier is likely follow the PB border in case of an opening of the PB and accordingly will be deprived from using fishing gounds in case of a PB extension.		
Beam100	small	Yes	positive	negative
		Effort is mostly inside the PB, large vessels with same metier fish close the border outside the PB. An increase in competition for resources is likely if large vessels use same fishing grounds.		

Metier	Power	expected effect of changes in PB design	PB extension	PB reduction
Beam80-99mm	large	Yes	negative	positive
		Effort is close to border outside the PB. The metier is likely follow the PB border in case of an opening of the PB and accordingly will be deprived from using fishing gounds in case of a PB extension.		
Beam80-99mm	small	Yes	positive	negative
		Effort is mostly inside the PB, large vessels with same metier fish close the border outside the PB. An increase in competition for resources is likely if large vessels use same fishing ground.		
Beam16-31mm	large	Yes	no effect	positive
		It is likely that the shrimp fisheries of large vessels will evolve if this resource becomes available. No effort in Danish and German fleet in 2008, only small fishing activity in Dutch fleet in 2008 and in German fleet in 2007. In the present situation fishing grounds for shrimps were only available for this metier off the Belgium coast. A use of fishing grounds inside PB seems likely since on average 111 MIO Euro are earned per year with shrimps from inside the PB (time period 2005-08, see Tables 11.3.1-.3 Only restriction might be shallow waters and tidal gullies.		
Beam16-31mm	small	Yes	no effect	negative
		See large vessels same gear. This effect depends on the competitiveness for fishing shrimps in the coastal areas. It is likely that the shrimp fisheries of large vessels will evolve if this resource becomes available. Small vessels (especially small German vessels smaller than the Eurocutter) might be restricted to shallow waters and tidal gullies.		
Otter >100 mm	large	No		
		This metier fishes mostly outside the box and not close to the PB border. A change in fishing behaviour cannot be expected.		
Otter >100 mm	small	No		
		This metier fishes mostly outside the box and not close to the PB border. A change in fishing behaviour can not be expected.		
Otter 80-99 mm	large	No		
		This metier fishes mostly outside the box and not close to the PB border. A change in fishing behaviour can not be expected.		
Otter 80-99 mm	small	No		
		This metier fishes mostly outside the box and not close to the PB border. A change in fishing behaviour can not be expected.		
Gill-Trammel	large	No		
		This metier fishes mostly outside the box and not close to the PB border. A change in fishing behaviour due to PB modifications can not be expected. However, it is likely that this métier will increase in the future due to conversions of bottom trawlers to gill netters.		

From these expectations, the following rules and equations can be derived to describe the possible changes in yields for different power categories and PB designs:

Power	no PB	12 miles zone	PB extension
large (>221kW)	=larg_tot+f*sml_PB	=larg_tot+f*sml_btw	=larg_tot-f*lrg_ext
small (<=221kW)	=sml_tot-f*sml_PB	=sml_tot-f*sml_btw	=sml_tot+f*larg_ext

With:
f: competition factor (see below)
larg_tot: total earnings of large vessels
sml_tot: total earnings of small vessels
sml_PB: earnings of small vessels inside the PB
sml_btw: earnings of small vessels inside the zone between the border of the 12 miles zone and the border of the PB
lrg_ext: earnings of large vessels in the areas which are to become extended PB
lrg_zigzag: earnings of large vessels in the areas which are to become part of the zigzag designed PB
sml_zigzag: earnings of small vessels in the areas which are not part of the zigzag designed PB anymore

In the zigzag design, the distribution of earning is dependent on the situation of each area before and after the change in management (see Fig. 11.4). Therefore there are four classes to differentiate.

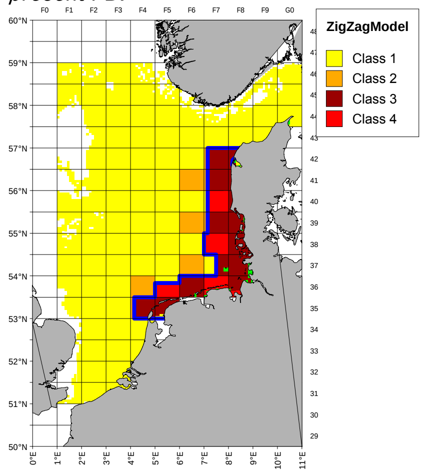
Class	Protected by present PB	Protected by zigzag design
1	0	0
2	0	1
3	1	1
4	1	0

This translates to the following formula for calculating the redistributed earnings for large and small vessels:

Sml = sml1 + (1-f) * sml2 + sml3 + sml4 + lrg4
Lrg = lrg1 + f * sml2 + lrg2 + lrg3

Sml1: yield of small vessels in areas of class1 of zigzag design.
Sml2: yield of small vessels in areas of class2 of zigzag design.
Sml3: yield of small vessels in areas of class3 of zigzag design.
Sml4: yield of small vessels in areas of class4 of zigzag design.
Lrg1: yield of large vessels in areas of class1 of zigzag design.
Lrg2: yield of large vessels in areas of class2 of zigzag design.
Lrg3: yield of large vessels in areas of class3 of zigzag design.
Lrg4: yield of large vessels in areas of class4 of zigzag design.

Fig. 11.4:. Areas of different classes of zigzag design (see text). Dark blue line indicates the border of the present PB.



Implications of various PB management scenarios

Economic implications

From the amounts gained in the last years in certain areas (Chapter 11) the amount of gains and losses of main métiers for different management strategies (resulting in different PB designs) are compared to the present PB design for three different competition situations between large (>221kW) and small (<=221kW) vessels:

- 'all to large': Large vessels are the more competitive.
- '50:50': Small vessels and large are equal in the ability to exploit the marine resources. The monetary yield is split equal between both power categories.
- 'all to small': Small vessels are the more competitive vessels in the traditional fishing grounds.

From this three values for factor f, which is defined as 'share of large vessels', are used:

all to large:	f=1.0	large vessels get all the yield from a shared area
50:50	f=0.5	equal competitive strength
all to small	f=0.0	large vessels get no yield from a shared area

no PB design

In this management design the small beam trawlers (BEAM.16-31mm) fishing for shrimp can lose up to 82 % (18% remaining) of their earnings in case of severe competition with large vessels (Tab. 11.8). However, this is strongly dependent on the evolution of the fleet segment BEAM.16-31mm >221kW. But as shown in Chapter 4, this métier already exists and fishing was performed in 2008 in the Dutch, 2007 in the German, and in 2005 and 2006 in the Danish fleet. **This design might be the end of a large proportion of the shrimp fisheries in the North Sea.**

Also, beam trawlers fishing for flatfish (BEAM.89-99 and BEAM.>100) can lose up to 59% fishing if competition with large vessels is strong after an opening of the plaice box. Since large vessels are already operating near the border of the PB they are very likely to extend their fishing grounds towards the coast if no restrictions exist any longer, if not for the available plaice as for the sole, which is known to migrate into the coastal waters each spring for spawning (ICES 1965).

12 mile zone design

In the 12 miles zone design the catch and earnings which are to be shared are much smaller than in the no PB design (Tab. 11.9). In this management design the small beam trawlers (BEAM.16-32mm) fishing for shrimp can lose up to 9 % of their earnings in case of severe competition with large vessels. This due to the fact that most shrimps are caught within the 12 miles zone.

Small beam trawlers fishing for flatfish (BEAM.89-99 and BEAM.>100) can lose still up to 41% fishing if competition with large vessels is strong after an opening of the plaice box.
From this design the shrimp fisheries are mostly unaffected whereas the mixed flatfish fisheries with small vessels are likely to lose a large quantity of their yields.

Extended PB design

In contrast to the designs of PB reductions, in this design the large vessels are the métiers which are most likely to loose monetary yields. Whereas small beamers fishing for plaice have the potential to increase their earnings by over 1000%, the large beamers will lose 44 % of their earnings (about 15 Mio €, Tab. 11.3.7). Please note that losses by large vessels in the shrimp fisheries account to up to 100% but the total amount is small since the yields are low at present.
This design is of advantage for the mixed flatfish fisheries with small vessels and disadvantageous for the mixed flatfish fisheries with large vessels.

Zigzag design

In the outcome of the zigzag design no severe redistributions of yield were found (Tab. 11.11.). The few high percentages of losses in some métiers (e.g. OTTER.80-99, <=221kW) are due to very low earnings at present and the total amount which is redistributed is low.
This design is mostly neutral in its impact.

Total closure of the PB

The effects of a closed PB are most severe for the small vessels (<=221kW) and especially for the shrimp fishery (Tab. 11.12) which is similar to the situation after a potentially total closure of the extended PB (see below) or the opening of the PB for highly competitive large vessels (see above). **This design might be the end of a large proportion of the shrimp fisheries in the North Sea.** Large vessels are not effected as severely as the small ones since they are not allowed inside the PB at present anyway. The high percentages are results of low yield inside the box at present which again are results of inaccuracies in the allocations by the VMS data.

Total closure of the extended PB

This design has the potential for the most severe impacts on small and on large vessels since productive fishing grounds cannot be used any more. The small shrimpers will lose about 95% (ca. 105 Mio €) of their income in this PB design (Tab. 11.12). That catches and landings can be gained elsewhere is especially unlikely for shrimpers since these animals are only abundant in the coastal and shallow areas. **This design would lead to the end a large proportion of the shrimp fisheries in the North Sea.**

Discussion

The effect of the different changes in the management regimes (PB-scenario's) on the socio-economy of the different métiers was based on the known yields taken from the different areas, assuming that the observed yield had to be shared among vessels that were forced to re-allocate their effort into these areas due to the change in management. This is a necessarily crude approach. In reality, a larger yield may be taken from a fishing ground since it is unlikely that the fishery will fully deplete the local resource. Also, rather strong assumptions were made on the allocation ratio's of the yield over the different competing fleets. Nevertheless, the results will give an overview of the potential effects of modification of the PB management regime.

Conclusions

With the exception of the zigzag design, all other potential changes to the areal extent of the PB will lead to a redistribution of yields between the métiers (especially between small and large vessels, <= and >221kW). This, however, is highly dependent on the competition between large and small vessel of all métiers and the temporal evolution by each métier. Therefore any potential changes in the PB implementation will need sufficient time for enterprises to adjust their fleets and to evolve their equipment and fishing behavior.

Implications on discarding: assessing inside-outside proportions of discard from flatfish and shrimp fisheries in relation to different spatial settings of the Plaice Box (based on discard observations).

The proportions are assessed according to the present boundary of the plaice box, and two newly developed spatial setups termed 'zigzag' and 'extended'. The 'extended PBOX is shown in Figure 11.6. For closures scenarios (closing present Plaice Box design and the extended Plaice Box) discards from flatfish fisheries will mount to zero. Potential differential distributions of junvenile plaice in response to changes of the PB design are not considered.

Discards in the shrimp fisheries <=221kW appear mostly inside the present plaice box. When extending the plaice box , almost all discards will be obtained inside the box (< 100 t outside). Inter-annual variability is small, the slight discrepancy to the discard figures given in Appendix Table AppChpt4.3.3 is due to the use of different data sources, logbooks as compared to ICES WGCRAN reported data for all countries.
The largest portion of bycatch is due to large beam trawlers in the flatfish fisheries, i.e. BEAM.80-99.>221kW. Dutch vessels have a high share in this metier. At present, some 40-50000 t of by-catch of juvenile plaice are obtained in this fisheries, of which almost 100 % is attributed to outside the PB. Accounts for discards inside the

PB for this metier are likely subject to misreporting in logbooks and calculation constraints of the VMS method. A further source of error is the composition of the Dutch VMS subsample available for analysis. It was assumed, that the VMS subsample is evenly distributed according the the activity of the Dutch fleet. However, this assumption does not necessarily hold. In the case of derogations from EC 850/98 and the issueing of special permits to vessels > 221 kW, a >221kW-vessel fishing inside the plaice box would necessarily behave more like <=221kW vessel so that discrads then would belong to the other category..

Substituting metiers as a means to reduce by-catch

It appears from Table 11.7, that designating a new extended plaice box would cut discards from the large beamers by almost half. Offering these fishing opportunities to a metier with lower discard rates would lead to an increase in stock, even at the same level of catches, since the level of discarding in this metier would be lower. For the plaice stock, for instance the > 20000 t of discard calculated for large beam trawlers inside the extended PB would then be subject to discarding from small beam trawlers or even otter trawlers. This is exemplified in Figure 11.5. Blue squares indicate areas in which small beam trawlers (<=221kW) perform better than large beam trawlers (>221kW). Designating a new extended PB would encompass 13 areas with better performance as compared to 5 areas with the opposite tendency. In turn, opening the PB to large vessels (>221kW) again would have negative effects on the total level of discarding, since in only a few inshore ICES squares do large

Table 11.7. Plaice discards (t) by metier and year and potential discards for different spatial settings of the plaice box under the present utilization pattern. * Figures for beam trawlers >221kW discussed in text.

year	metier	power	Age group	Pbox outside	Pbox inside	Zigzag outside	Zigzag inside	Extended PBOX outside	Extended PBOX inside
2005	BEAM.16-31	<=221kW	age0	274.9	1301.54	514.07	1062.37	99.67	1476.77
2006	BEAM.16-31	<=221kW	age0	328.28	1149.47	525.44	952.32	51.31	1426.45
2007	BEAM.16-31	<=221kW	age0	233.57	1111.1	516.39	828.28	63.95	1280.72
2008	BEAM.16-31	<=221kW	age0	215.84	1058.96	404.1	870.7	60.3	1214.51
2005	BEAM.16-31	>221kW	age0	0		0	0		0
2006	BEAM.16-31	>221kW	age0		0		0		0
2007	BEAM.16-31	>221kW	age0	0	0	0	0	0	0
2008	BEAM.16-31	>221kW	age0	0.83		0.83		0.18	0.65
2005	BEAM.80-99	<=221kW	age1+	9482.54	2106.34	10396.26	1192.63	185.73	11403.15
2006	BEAM.80-99	<=221kW	age1+	6040.03	1714.26	6794.38	959.91	147.32	7606.97
2007	BEAM.80-99	<=221kW	age1+	7694.08	702.47	7931.67	464.88	46.01	8350.54
2008	BEAM.80-99	<=221kW	age1+	5599.77	555.34	5833.81	321.3	40.84	6114.28
2005	BEAM.80-99 *	>221kW	age1+	48285.3	4731.9	41901	11116.2	23693.1	29324.1
2006	BEAM.80-99 *	>221kW	age1+	42963.4	2958.1	35024.9	10896.6	20446.5	25474.9
2007	BEAM.80-99 *	>221kW	age1+	46815.9	3077.6	38152.7	11740.8	22067	27826.5
2008	BEAM.80-99 *	>221kW	age1+	39030.9	3905.7	32436.4	10500.2	15418	27518.6
2005	OTTER.80-99	<=221kW	age1+	1989.62	219.24	2091.22	117.64	680.08	1528.77
2006	OTTER.80-99	<=221kW	age1+	1506.51	188.28	1559.5	135.29	495.29	1199.5
2007	OTTER.80-99	<=221kW	age1+	949.5	70.94	989.92	30.52	337.45	682.99
2008	OTTER.80-99	<=221kW	age1+	987.4	48.83	1001.08	35.15	335.87	700.36

beamers perform better than smaller ones.

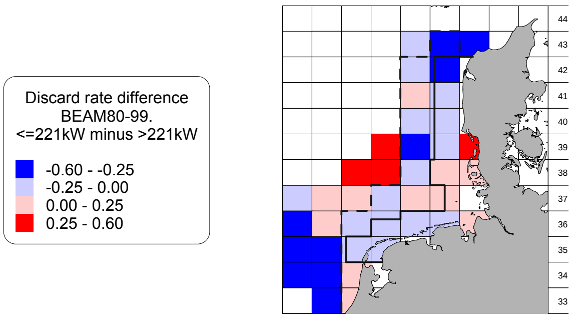


Fig 11.5 Difference in modelled discard rates for BEAM.80-99.<=221kW and .>221kW, respectively

Table 11.8: Results of the economic model for the no PB design. Shown are mean earnings and mean percentages of calculated earnings of present earnings of the years 2005 to 2008 of the sum of Dutch, German and Danish fleet for three competition scenarios: 1. all to large, all yields of shared areas to large vessels; 2. 50:50, yields of shared areas equally shared; 3. all to small, all yields of shared areas to small vessels. CSH: common shrimp. PLE: plaice. SOL: sole.

		present earnings			calculated earnings by economic model - no PB design											
		mio €			small (<=221kW)						large vessels (>221kW)					
		small	small	large	all to large		50:50		all to small		all to large		50:50		all to small	
metier	species	total	in PB	total	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%
BEAM.16-31	CSH	111.76	91.97	0.02	19.79	18	107.16	96	111.76	100	91.99	147888	4.62	7489	0.02	100
BEAM.16-31	PLE	0.01	0.00	0.00	0.00	20	0.01	96	0.01	100	0.01	483	0.00	119	0.00	100
BEAM.16-31	SOL	0.09	0.06	0.01	0.03	28	0.09	96	0.09	100	0.07	33757	0.01	1783	0.01	100
BEAM.80-99	CSH	0.04	0.04	0.00	0.01	31	0.04	97	0.04	100	0.04	0	0.00	0	0.00	0
BEAM.80-99	PLE	2.04	0.60	36.16	1.44	74	2.01	99	2.04	100	36.77	102	36.19	100	36.16	100
BEAM.80-99	SOL	14.29	2.45	106.19	11.85	83	14.17	99	14.29	100	108.63	102	106.31	100	106.19	100
BEAM.>100	CSH	0.07	0.07	0.00	0.00	1	0.06	95	0.07	100	0.07	0	0.00	0	0.00	0
BEAM.>100	PLE	0.79	0.57	9.98	0.22	41	0.76	97	0.79	100	10.55	105	10.01	100	9.98	100
BEAM.>100	SOL	0.09	0.04	0.56	0.05	64	0.09	98	0.09	100	0.60	106	0.56	100	0.56	100
GILL-TRAMMEL	CSH	0.02	0.00	0.00	0.01	91	0.02	100	0.02	100	0.00	0	0.00	0	0.00	0
GILL-TRAMMEL	PLE	2.10	0.72	1.14	1.37	63	2.06	98	2.10	100	1.87	173	1.18	104	1.14	100
GILL-TRAMMEL	SOL	1.97	0.66	0.78	1.31	65	1.93	98	1.97	100	1.44	197	0.81	105	0.78	100
OTTER.80-99	CSH	0.01	0.00	0.00	0.01	91	0.01	100	0.01	100	0.00	0	0.00	0	0.00	0
OTTER.80-99	PLE	4.08	0.16	3.38	3.92	96	4.08	100	4.08	100	3.54	105	3.39	100	3.38	100
OTTER.80-99	SOL	0.55	0.01	0.74	0.54	98	0.55	100	0.55	100	0.75	102	0.74	100	0.74	100
OTTER.>100	CSH	0.03	0.00	0.00	0.03	97	0.03	100	0.03	100	0.00	0	0.00	0	0.00	0
OTTER.>100	PLE	3.39	0.68	6.26	2.71	80	3.35	99	3.39	100	6.93	110	6.29	101	6.26	100

Table 11.9: Results of the economic model for the 12 mile zone design. Shown are mean earnings and mean percentages of calculated earnings of present earnings of the years 2005 to 2008 of the sum of Dutch, German and Danish fleet for three competition scenarios: 1. all to large, all yields of shared areas to large vessels; 2. 50:50, yields of shared areas equally shared; 3. all to small, all yields of shared areas to small vessels. CSH: common shrimp. PLE: plaice. SOL: sole.

		present earnings			calculated earnings by economic model - 12 miles zone design									
		mio €			small (<=221kW)						large vessels (>221kW)			
		small	small	large	all to large		50:50		all to small		all to large		50:50	
metier	species	total	in btw	total	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%
BEAM.16-31	CSH	111.76	10.70	0.02	101.06	91	111.22	100	111.76	100	10.71	17974	0.55	994
BEAM.16-31	PLE	0.01	0.00	0.00	0.01	90	0.01	100	0.01	100	0.00	153	0.00	103
BEAM.16-31	SOL	0.09	0.01	0.01	0.08	93	0.09	100	0.09	100	0.01	2198	0.01	205
BEAM.80-99	CSH	0.04	0.02	0.00	0.02	80	0.04	99	0.04	100	0.02	0	0.00	0
BEAM.80-99	PLE	2.04	0.31	36.16	1.73	87	2.02	99	2.04	100	36.48	101	36.18	100
BEAM.80-99	SOL	14.29	1.07	106.19	13.23	93	14.24	100	14.29	100	107.25	101	106.24	100
BEAM.>100	CSH	0.07	0.01	0.00	0.05	86	0.07	99	0.07	100	0.01	0	0.00	0
BEAM.>100	PLE	0.79	0.38	9.98	0.41	59	0.77	98	0.79	100	10.36	103	10.00	100
BEAM.>100	SOL	0.09	0.02	0.56	0.07	81	0.09	99	0.09	100	0.58	103	0.56	100
GILL-TRAMMEL	CSH	0.02	0.00	0.00	0.01	95	0.02	100	0.02	100	0.00	0	0.00	0
GILL-TRAMMEL	PLE	2.10	0.52	1.14	1.58	74	2.07	99	2.10	100	1.67	150	1.17	103
GILL-TRAMMEL	SOL	1.97	0.34	0.78	1.63	82	1.95	99	1.97	100	1.11	148	0.79	102
OTTER.80-99	CSH	0.01	0.00	0.00	0.01	94	0.01	100	0.01	100	0.00	0	0.00	0
OTTER.80-99	PLE	4.08	0.11	3.38	3.97	97	4.08	100	4.08	100	3.49	103	3.38	100
OTTER.80-99	SOL	0.55	0.01	0.74	0.54	99	0.55	100	0.55	100	0.75	101	0.74	100
OTTER.>100	CSH	0.03	0.00	0.00	0.03	98	0.03	100	0.03	100	0.00	0	0.00	0
OTTER.>100	PLE	3.39	0.46	6.26	2.93	86	3.36	99	3.39	100	6.71	107	6.28	100
OTTER.>100	SOL	0.06	0.01	0.17	0.05	85	0.06	99	0.06	100	0.18	106	0.17	100
OTHER	PLE	5.93	0.37	1.47	5.57	94	5.91	100	5.93	100	1.83	128	1.48	101
OTHER	SOL	0.01	0.00	0.00	0.01	92	0.01	100	0.01	100	0.00	129	0.00	101

Table 11.10: Results of the economic model for the extended PB design. Shown are mean earnings and mean percentages of calculated earnings of present earnings of the years 2005 to 2008 of the sum of Dutch, German and Danish fleet for three competition scenarios: 1. all to large, all yields of shared areas to large vessels; 2. 50:50, yields of shared areas equally shared; 3. all to small, all yields of shared areas to small vessels. CSH: common shrimp. PLE: plaice. SOL: sole. Please note that large vessels are not allowed inside the extended PB and with that no completion takes place with this design.

		present earnings			calculated earnings by economic model - extended PB design											
		mio €			small (<=221kW)						large vessels (>221kW)					
		small	large	large	all to large		50:50		all to small		all to large		50:50		all to small	
metier	species	total	ext. PB	total	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%
BEAM.16-31	CSH	111.76	0.01	0.02					111.77	100					0.00	22
BEAM.16-31	PLE	0.01	0.00	0.00					0.01	126					0.00	11
BEAM.16-31	SOL	0.09	0.00	0.01					0.09	106					0.00	11
BEAM.80-99	CSH	0.04	0.00	0.00					0.04	100					0.00	0
BEAM.80-99	PLE	2.04	15.84	36.16					17.88	1002					20.33	56
BEAM.80-99	SOL	14.29	47.01	106.19					61.30	437					59.17	55
BEAM.>100	CSH	0.07	0.00	0.00					0.07	100					0.00	0
BEAM.>100	PLE	0.79	3.20	9.98					3.99	1015					6.78	67
BEAM.>100	SOL	0.09	0.16	0.56					0.25	401					0.40	71
GILL-TRAMMEL	CSH	0.02	0.00	0.00					0.02	100					0.00	0
GILL-TRAMMEL	PLE	2.10	0.81	1.14					2.91	140					0.33	28
GILL-TRAMMEL	SOL	1.97	0.47	0.78					2.44	126					0.31	38
OTTER.80-99	CSH	0.01	0.00	0.00					0.01	100					0.00	0
OTTER.80-99	PLE	4.08	0.71	3.38					4.79	118					2.67	79

Table 11.11: Results of the economic model for the zigzag design. Shown are mean earnings and mean percentages of calculated earnings of present earnings of the years 2005 to 2008 of the sum of Dutch, German and Danish fleet for three competition scenarios: 1. all to large, all yields of shared areas to large vessels; 2. 50:50, yields of shared areas equally shared; 3. all to small, all yields of shared areas to small vessels. CSH: common shrimp. PLE: plaice. SOL: sole.

				calculated earning by economic model - ZigZag scenario											
		present earnings		small (<=221kW)						large vessels (>221kW)					
		mio €		all to large		50:50		all to small		all to large		50:50		all to small	
metier	species	small	large	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%	mio €	%
BEAM.16-31	CSH	111.76	0.07	111.49	100	111.62	100	111.76	100	0.29	792	0.15	446	0.02	100
BEAM.16-31	PLE	0.01	0.00	0.01	100	0.01	100	0.01	100	0.00	100	0.00	100	0.00	100
BEAM.16-31	SOL	0.09	0.01	0.09	100	0.09	100	0.09	100	0.01	404	0.01	252	0.01	100
BEAM.80-99	CSH	0.04	0.00	0.04	84	0.04	92	0.04	100	0.00	0	0.00	0	0.00	0
BEAM.80-99	PLE	2.04	36.16	2.48	126	2.51	128	2.55	129	35.72	99	35.69	99	35.66	99
BEAM.80-99	SOL	14.29	106.19	15.66	110	15.76	111	15.86	111	104.82	99	104.72	99	104.62	98
BEAM.>100	CSH	0.07	0.00	0.07	100	0.07	100	0.07	100	0.00	0	0.00	0	0.00	0
BEAM.>100	PLE	0.79	9.98	0.91	124	0.91	124	0.91	125	9.86	99	9.86	99	9.86	99
BEAM.>100	SOL	0.09	0.56	0.09	107	0.09	107	0.09	107	0.56	99	0.56	99	0.56	99
GILL-TRAMMEL	CSH	0.02	0.00	0.02	100	0.02	100	0.02	100	0.00	0	0.00	0	0.00	0
GILL-TRAMMEL	PLE	2.10	1.14	2.00	99	2.11	103	2.22	108	1.24	104	1.13	96	1.02	87
GILL-TRAMMEL	SOL	1.97	0.78	1.92	98	1.98	101	2.04	104	0.83	107	0.76	98	0.70	89
OTTER.80-99	SOL	0.01	0.00	0.01	78	0.01	89	0.01	100	0.00	0	0.00	0	0.00	0
OTTER.80-99	CSH	4.08	3.38	3.36	82	3.73	91	4.11	101	4.10	122	3.73	111	3.35	99
OTTER.80-99	PLE	0.55	0.74	0.47	85	0.51	93	0.55	101	0.82	112	0.78	106	0.74	100
OTTER.>100	SOL	0.03	0.00	0.03	100	0.03	100	0.03	100	0.00	0	0.00	0	0.00	0
OTTER.>100	PLE	3.39	6.26	3.24	95	3.34	99	3.44	102	6.40	102	6.30	101	6.20	99
OTTER.>100	SOL	0.06	0.17	0.06	97	0.06	99	0.06	101	0.18	101	0.17	100	0.17	100
OTHER	CSH	5.93	1.47	5.95	100	5.98	101	6.01	101	1.45	99	1.42	97	1.39	95
OTHER	PLE	0.01	0.00	0.01	99	0.01	100	0.01	100	0.00	103	0.00	101	0.00	99

Table 11.12: Results of the economic model for the total closure of the PB and the total closure of the extended PB. Shown are mean earnings and mean percentages of calculated earnings of present earnings of the years 2005 to 2008 of the sum of Dutch, German and Danish fleet. CSH: common shrimp. PLE: plaice. SOL: sole.

		present earnings mio €		calculated earnings closure of PB				calculated earnings closure of extended PB			
		small	large	small (<=221kW)		large (>221kW)		small (<=221kW)		large (>221kW)	
metier	species	total	total	mio €	%	mio €	%	mio €	%	mio €	%
BEAM.16-31	CSH	111.76	0.02	19.79	18	0.02	100	4.94	4	0.00	22
BEAM.16-31	PLE	0.01	0.00	0.00	20	0.00	66	0.00	4	0.00	11
BEAM.16-31	SOL	0.09	0.01	0.03	28	0.01	66	0.01	8	0.00	11
BEAM.80-99	CSH	0.04	0.00	0.01	31	0.00	0	0.00	13	0.00	0
BEAM.80-99	PLE	2.04	36.16	1.44	74	33.87	94	0.42	21	20.33	56
BEAM.80-99	SOL	14.29	106.19	11.85	83	99.26	93	2.91	21	59.17	55
BEAM.>100	CSH	0.07	0.00	0.00	1	0.00	0	0.00	0	0.00	0
BEAM.>100	PLE	0.79	9.98	0.22	41	9.35	94	0.15	18	6.78	67
BEAM.>100	SOL	0.09	0.56	0.05	64	0.53	95	0.02	20	0.40	71
GILL-TRAMMEL	CSH	0.02	0.00	0.01	91	0.00	0	0.00	1	0.00	0
GILL-TRAMMEL	PLE	2.10	1.14	1.37	63	0.84	71	0.62	28	0.33	28
GILL-TRAMMEL	SOL	1.97	0.78	1.31	65	0.47	58	0.70	35	0.31	38
OTTER.80-99	CSH	0.01	0.00	0.01	91	0.00	0	0.01	56	0.00	0
OTTER.80-99	PLE	4.08	3.38	3.92	96	3.33	99	2.69	67	2.67	79
OTTER.80-99	SOL	0.55	0.74	0.54	98	0.73	99	0.39	72	0.59	81
OTTER.>100	CSH	0.03	0.00	0.03	97	0.00	0	0.01	43	0.00	0
OTTER.>100	PLE	3.39	6.26	2.71	80	5.95	95	2.29	68	5.35	86
OTTER.>100	SOL	0.06	0.17	0.05	81	0.16	94	0.04	71	0.15	82
OTHER	PLE	5.93	1.47	5.12	87	1.07	75	4.14	70	0.76	55
OTHER	SOL	0.01	0.00	0.01	83	0.00	64	0.01	68	0.00	54

Conservation effects

Conservation aspects of Plaice Box scenarios

With respect to nature conservation, the likely shift in effort allocation between metiers is the most significant effect of the different Plaice Box scenarios, since metiers have different ecosystem impacts. Ecosystem impacts of the fisheries include the bycatch of undersized fish and invertebrates, the trawling impact on the benthos and benthic habitats, as well as the bycatch of marine mammals and birds (Jennings and Kaiser, 1998). For the evaluation of the conservation effects, we assume the bycatch of undersized fish, effects on benthos and habitats, and bycatch of marine mammals as tentative conservation objectives. The bycatch of sea birds are considered to be less of a problem.

The marine mammal bycatch is restricted to the fisheries deploying static gear. Bycatch of harbour porpoises have been recorded from the Dutch coast Camphuysden (2004) An expansion of these fisheries may aggravate the bycatch problem. A change in the distribution or fishing effort of the other metiers is not likely to affect marine mammals.

Any change in fishing effort in the coastal waters will result in a change in the bycatch of undersized fish. Catchability (the fishing mortality imposed by a unit of effort) will differ between gears and fish species. Hence, beam trawl gear will be more efficient for benthic flatfish, while otter trawl gear may be more efficient for demersal roundfish (Piet at al., 2009). Differences in catchability of the metiers considered in this study were estimated for marketable plaice in Chapter 10 and showed that the shrimp metier had a catchability that was about 10^{-3} lower than that of other metiers. However, because of the low mesh size used, the bycatch of small fish will be much higher. It is likely that the bycatch of undersized fish will be mainly influenced by changes in fishing effort of the metiers using small meshed gears (shrimpers, OTB-80, TBB-80) in the areas where the small fish are most abundant (12 nm zone, inside the PB). Extending the PB, therefore will likely result in a decrease in the bycatch of undersized fish, whereas the 12 nm PB scenario allowing larger vessels to fish up to the 12 nm zone will increase the bycatch of undersized fish.

The impact of fishing on the benthos will be most prominent for the metiers using flatfish beam trawls (TBB-80 and TBB-100). The tickler chains used with this gear have been shown to impose substantial mortality on benthic invertebrates (Bergman and Hup, 1992; Bergman and van Santbrink, 2000). Trawling impact differs among benthic habitats and is likely to be more important in deeper water with silty sediments than in shallow areas characterised by sandy grounds (Hall, 1994, Kaiser et al., 2006). In offshore areas of the North Sea, benthic biomass and species composition has been shown to decrease with trawling disturbance (Jennings et al., 2001ab; Duineveld et al., 2007, Reiss et al., 2009). The shrimpers use a light beam trawl without tickler chains. The impact therefore is considered to be much less than that of flatfish beam trawls. Although with a lower intensity, the benthos in the PB was still continuously influenced by the ongoing trawling activities by smaller vessels even after the establishment of the PB in 1989. Since the impact of bottom trawling is non-linear, with the first trawling event having a relatively higher impact that a subsequent event (Kaiser et al. 2006), this may explain why we have not been able to detect a change in the benthos in the PB as compared to the reference areas (see chapter 8). Nevertheless, the reduction in trawling effort since 1989 is expected to have lowered the trawling impact on the benthos and as the fishing intensity even in heavily fished areas has an influence on benthic communities (Reiss et al. 2009), every reduction in effort can be considered positive for benthic communities. However, it is unlikely that the PB led to areas within the PB which had been trawled before, but have been untouched since 1995. In terms of conservation aspects, again, such areas would be a prerequisite for the recovery of the benthic fauna towards an undisturbed state. The PB was never intended to protect benthos/habitats and should not be expected to be an effective measure in this respect. A change in the management scenario will not only influence the fishing effort in the PB, but will also affect the fishing effort and its distribution in the other areas. The effect of a re-allocation of fishing effort will depend on the objective considered. If the fishing effort is re-allocated from a sensitive area to a non-sensitive area, the management will have a positive contribution to the conservation objectives. However, if the effort is re-allocated to a more sensitve area, the effect may be negative (Hiddink et al. 2006). An illustration of the unforeseen implications is given by the closure of the spawning areas of North Sea cod in 2001, aimed to protect spawning cod, which has resulted in an increase in the trawling impact in areas which were previously hardly fished (Rijnsdorp et al., 2001).

Based on the considerations above we come to the following assessment of the implications of the different scenarios on the marine mammals, fish bycatch, benthos (biomass, species composition, benthic habitats).

Based on the considerations above we come to the following assessment of the implications of the different scenarios on the marine mammals, fish bycatch, benthos (biomass, species composition, benthic habitats).

Scenario	Effect	Evaluation
No Plaice Box	The opening of the Plaice Box give large vessels access to coastal waters increasing the bycatch of undersized fish and increasing the trawling impact on benthos but decreasing the impact in offshore areas.	Negative on bycatch of undersized fish. Effects on benthos depends on relative effect of the re-allocation of effort between sensitive and non-sensitive areas. No impact on marine mammals
ZigZag	This scenario would increase the amount of plaice by-catch outside the zigzag box boundaries (Table 4.3.2). It would further open coastal areas to beam trawlers >221 kW increasing the impact on the benthos in coastal waters and reducing the impact in offshore waters	Neutral to light negative on bycatch undersized fish and benthos
Extended Plaice Box	This concept will substitute the impact of beam trawlers >221 kw with the impact of beam trawlers <=221 kW or otter board trawlers. Thus, the overall impact will be a significant reduction of impact on the benthic ecosystem components. Trawling impact in offshore sensitive areas may increase due to re-allocation	Positive on bycatch of benthos. No change in the impact on fish bycatch
Closure scenarios	These management concepts would reduce bycatch and impact from beam trawlers to zero.	Very positive on bycatch of fish, benthos. No trawling will allow recovery of benthos. Possible negative effects on marine mammals if static gear increase

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Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2009 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation, with the last inspection being held on the 5th of October 2007.

Justification

Rapport C002/10
Project Number: 4301100501

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

Approved: Dr. T. Bult
Head Fisheries Department

Signature:

Date: 27 Januari

Approved: Dr. ir T.P.A. Brunel
Fisheries Department

Signature:

Date: 27 Januari

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Appendix to Chapter 2

Plaicebox Workshop Stakeholders 07-10-2009

Attendants: Ben Daalder, Christine Röckmann, Emilie Hugenholtz, Doug Beare, Adriaan Rijnsdorp, Alexander Schröder, Mette Plasbjerg, Torens Schulze, Heino Fock, Henk Offringa, Floor Quirijns, ulrich Damm, Wim de Boer, Geert Meun, Marieke Verweij, Tobias van Kooten

Summary first day (Doug Beare)

Fisheries data

- Effort and landings data from before the instigation of the plaice box: before 1983 and after 1989 data are available. In between, CBS stopped collecting data due to black landings (unreliable data).
- TBB 70-79 mm: might be nephrops fishery. But in the Netherlands only OTB is used for nephrops. If you catch >= 70% nephrops, you are allowed to use these mesh sizes. Maybe it is more common in Denmark and Germany.
- VMS (NL) data from until 2009 will be used (as recent as possible)

Biology of plaice

- Surveys show that age-1 plaice as moved out the plaice box. Other age groups show similar trends over time inside and outside the plaice box. (Reference area 'outside plaice box': show it in a map)
- Plaice growth stops > 20 °C. Sole benefits from higher temperatures. But the shift of plaice offshore was not due to increasing temperatures (changes were out of phase).

Benthos / food

- Benthos: changes are observed in benthic community in the plaice box by fishers and in surveys, but it does not show in the data. Probably the fact you don't see differences between the plaice box and the reference area is due to the choice of reference area.
- Wim de Boer: brown crab (*cancer pagurus*) has increased enormously in the north, outside the plaice box: just on the border on the edge of a rocky area where the ground is very clean.
- Brown crab is landed by beam trawlers. They don't have to be landed alive, although that would improve (and prices) the quality of crab.
- Uli Damm: after the cold winter 1996 brown crab was found dead. Probably brown crab benefits from warm winters.
- Food for plaice: Proportion polychaetes/bivalves has reduced. In 1995 total numbers of individuals have decreased. These trends are seen both inside and outside the plaice box.
- Macrozoobenthos: different community compositions inside and outside the plaice box. Compositions have changed in and outside the box: due to global phenomenon, not a local phenomenon.

Synthesis / conclusions

- no evidence for simplistic causal relationships
- benthos: no evidence that changes are due to the plaice box
- during instigation of the plaice box no clear agreements were made about the evaluation
- can't conclude it has been beneficial
- reduced discards would improve survival
- no evidence for fisheries induced change in distribution of age-1 plaice
- pronounced regime shifts in 1989-1990 and the mid 1990s
- gadoid predators have reduced: overall community changed from roundfish dominated to flatfish dominated
- changes in climate

Views of the Dutch fishing industry (Wim de Boer)

Introduction of Wim:

- 1953: 13 year's old: UK44 (grand father's boat, ~150 hp) → otter trawling
- 1958: UK104 (~200 hp) from Wim's uncle → pair trawling (capsized and lost the crew)
- 1965: UK157 Wim's first vessel as a skipper → beam trawling
- After installation of the 12-miles zone, the fleet of smaller vessels moved offshore from 2 to 12 miles. Border (10-12 mile): best fishing. Like now, along the border of the plaice box. Hypothesis: lack of food inside due to reduced trawling, so more fish along the edge of the area where was being trawled
- UK56 (1980): last vessel, 2000 hp → beam trawling
- Proposal for the plaice box by researchers: Border of the box was shifted inshore, along depth lines, according to advice of fishers

Opinions on the plaice box on behalf of the Dutch fishing industry → see written document by Wim de Boer

Reaction Henk Offringa: so what would be the suggestion of the industry be on how to manage this area. (this discussion will be held later during the day)

Wim de Boer: At the moment there is nothing to protect in the plaice box. Except for an area north of Texel. After partially closing the plaice catches were very good. But now, during complete closure, there are no good catches anymore. UK45 fished in the plaice box (he was there for research purposes) and caught hardly anything in a period when there used to be good catches.

"There is no plaice in the box. So it doesn't protect plaice anymore"

About 7 years ago there was a request from euro cutters to have the large beam trawl vessels back in the box in order to improve catches again (by trawling).

What would have happened if there would have been fishing in the plaice box? Scientists claimed that with fishing the situation for plaice might have been worse right now. Stakeholders want proof for this claim.
Hypothesis (Adriaan Rijnsdorp): plaice still grows up in the area of the plaice box. If there would have been fishing in the box, these juveniles would have had a higher chance of being discarded. However, the fact that juveniles have moved offshore was not induced by the fishery. If the fish have moved out because the fleet wasn't there, then this hypothesis does not hold.

One conclusion from the first day was "no evidence for fisheries induced change in distribution of age-1 plaice"…

Possibilities are:

- If we assume that removal of the fishery from the plaice box <u>has not</u> induced a change in distribution of juvenile plaice, then the plaice box might have had a positive effect on plaice, by preventing the juveniles being discarded.
- If we assume that removal of the fishery from the plaice box <u>has</u> caused the change in distribution of juvenile plaice (by reduction of bottom trawling), then the plaice box had a negative effect on plaice.

This is relevant for understanding the functioning of closed areas.
The industry supports the second assumption.

Wim: "if the box would be opened now, probably the fishers will not go back into the area. Simply because the catches are not good. It needs years of fishing to get the fish back in the area."

Doug Beare: Recruitment: if there is a high recruitment, it doesn't matter that part of that is being discarded, as long as sufficient juveniles recruit to the stock.

View of the NGOs - North Sea Foundation & WWF (Emilie Hugenholtz)

- If actual effort is known, can stronger conclusions be drawn on the effects of fishing in and out the plaice box.
- Is there a plaice box? There is still fishing in plaice box, so that suggests that there is none
- Plaice box is not a real protected area of closed area. The plaice box cannot be used as a proper protected area, because there was/is lack of many features of a protected area (agreements, more elaborate supporting research, etc)
- Benthos: reducing fishing does not protect benthos. Removal of fishing is required for that.
- Required: compare areas with no bottom disturbance. This will help you draw conclusions on whether shifts have an environmental of fisheries cause.
- So rethink the plaice box design, criteria, indicators etc. Reconsider draught board proposal from 2005.
- Another topic to be discussed is: how to reduce discards and how to deal with benthic diversity.
- Sheet on Marine Spatial Planning: shows opinion of NGOs on MPAs. Note: Plaice Box is not an MPA as other MPAs under consideration (N2000). There should be no confusion about that.

Doug Beare: investigated roundfish stocks during & after WOII, in the northern North Sea. WOII resulted in a real protected area, which led to high catches.
Wim de Boer: the first three years after WOII plaice catches were high as well, but after that catches decreased dramatically.
Emilie Hugenholtz: we have to distinguish between different goals. If we want to protect juvenile plaice, maybe for food enhancement it is good to have the fisheries back in. If we want to protect benthic diversity, then maybe we need to close areas completely for fisheries.

In this case we have to protect juvenile plaice. During the past years, protection of the sea bed and benthic diversity has creeped in as an extra objective, but this never was in the original objectives.

Suggestion: look at the proposal from 2005 and reconsider carrying out that experiment.
Wim: why don't we just lift the ban and look at what happens in the next 5 years. After 5 years we can evaluate and decide what to do next.

Perceptions of stakeholders about the plaice box (Marieke Verweij)

Based on:
- 11 interviews with fishers of large beam trawlers (outside PB)
- 5 ENGO staff members from 3 different ENGOs (Environmental NGOs)

Conclusions:
- Fishers emphasize positive effects of fishing (ploughing and food)
- ENGO staff emphasize negative effects of fishing (fishing mortality)
- Difficult to distinguish: no reference areas where no fishing takes place, or where all fishing is allowed
- Scientists should play an active role in facilitating the debate

Adriaan Rijnsdorp: do we know about perceptions of German / Danish representatives?
- Torsten: coastal shrimp fishers were informed about this workshop. The response was that they don't like the plaice box to be opened just like that. Reason: increase in competition for the German fleet. A lot of different opinions between fishers. Difficult to conclude what The Opinion is.
- According to Wim: during the NSRAC Peter Breckling (Germany) was opposed against opening the plaice box (because of the increase in competition).
- Mette Plasbjerg: plaice box is not being viewed in Denmark as being successful. But she doesn't know what the fishers' views are on what should happen to the area.

Side-step: study by Adriaan Rijnsdorp: response of species that are fished and how growth rate and maturation are influenced by fisheries. How much trawling impact can certain species survive?

Suggestion Emilie Hugenholtz: make it clear what we do and do not agree on amongst the different international stakeholders. Other idea: investigate what went wrong last time, i.e. why wasn't the previous proposal wasn't followed up.

Next week there is a NSRAC meeting, where this might be put on the table.

Scenarios

- Completely open the plaice box for 5 years and evaluate what happens
- Reopen patches (experimental design for investigating effects on bottom, zigzag, … already proposed set-ups). Also investigate long term effects. I.o.w. make a structure where the most scientific knowledge will be gained
- Reopen the plaice box and use RTCs to protect patches of juvenile plaice
- Close a larger area in the North Sea where 90 % of the juvenile plaice is

Include in scenario description include practical issues, i.e. management of the measure, enforcement, etc.

Hypotheses

Do we have to find out what exactly happened in the plaice box? Or do we only need a political outcome (based on consensus between stakeholders)?

- temperature
- food (ploughing)
- eutrophication
- effect of discards on benthic communities

How to move on

In report:
- include experiment proposal to investigate effects of bottom trawling on benthic communities (food)
- investigate what the effects of discards are on an area
- make a note on discarding: was the plaice box a good measure to reduce discarding? What might be alternatives?

Socio-economic impacts

- These aspects are mainly relevant for the scenarios: what are the effects on socio-economics?
- Is the number of vessels per port (inside vs. outside the plaice box) informative about the effects of the plaice box on socio-economics?
- Look at fishing areas and yield within the plaice box in specific areas
- Also take into account (positive & negative) effects of scenarios on environment (value of area can change)
- Fishing pattern of beam trawlers < 221 kW over the years
- Patterns in investment: increase in length and/or power in fleet register etc. We have to realize that changes in these parameters do not have to be directly related to the plaice box.

Statement by Willem de Boer about the Plaicebox, Workshop October 2009 –I Jmuiden:

Ladies and Gentlemen,

We would very much like to use this opportunity to express the opinions of the fisheries on the plaice box and developments since its introduction. We are glad that this evaluation of the results is finally taking place and that the European Commission had commissioned this as a result of a request from the North Sea-RAC.

The start of the plaice box is the result of a close partnership between fishery scientists and fishermen specialised in fishing for sole and plaice. The 40,000 km2 fishing area along the Danish, German and Dutch coasts has been of prominent importance for decades, and until 1990, 60 % of all activities of the Dutch demersal fleet took place in this area. The plaice box was first closed for six months of the year in 1989 and for the entire year from 1993 onwards.

Closure occurred at a time when the stocks of sole, plaice and cod were good to very good. The spawning stock of plaice was estimated for a number of years in the mid-eighties at 400,000 tonnes or more, with annual TACs in excess of 150,000 tonnes. The sole situation was in such good condititon that the quota could be raised by 85% in 1990. Bear in mind that at the time, the capacity of the Dutch beamtrawlfleet was approximately 600,000 HP.

The main reason for introducing the plaice box was to give young sole and plaice a chance to take part in the spawning process at least once. Scientists were wildly enthusiastic: they said: “while the stocks are so good, we are taking extra protective measures that will translate into a further stock increase with a quota increase of at least 15 to 20 % per year!” It was persuasive, and the fisheries sector was actually promised this!

We all know what has happened to this protected area: contrary to what everyone (scientists in particular) expected, fish stocks in this area have declined sharply and biodiversity has actually become thinner than when the fleet still fished there. Ask any fisherman who has tried his luck inside the box, and you will hear the same thing: “the place is dead; a desert with nothing more than a layer of starfish, and hardly any fish!”

It will undoubtedly be suggested that the plaice box is not completely closed as the 300 Euro cutters with 300 HP can still fish there. The reality is that the Euro cutters, in view of the above, are also inactive or barely active within the box; check the data of the satellite tracking system.

A few more facts since 1990: In terms of size, less than one third of the fleet remains in relation to 1990 and in recent years we have seen historically the lowest TACs of plaice. Luckily, this downward spiral has been broken.

Since the mid-nineties the fisheries have regularly pointed out the negative effects of closing the plaice box regarding the size of fish stocks. However, scientists have always pointed out that the results of the plaice box are difficult to estimate and the situation of the plaice stocks would possibly be worse still if the plaice box had not been introduced. According to the fisheries sector, this claim is baseless. In any case, in our view these are simply assumptions without scientific proof.

It is over 10 years ago that Dutch scientists were consulted on partially opening the plaice box on an experimental basis and partially closing it; the so-called draughtboard variant. However, this never resulted in a solid proposal and policymakers and politicians were not interested. They did not possess the courage as various member states did not see the plaice box as protecting small fish but as protecting their own coastal fisheries.

We feel that the establishment of the plaice box has been a major flop, and who has the courage to reach this conclusion and say ‘we have to approach this differently’?

Furthermore, we also want to make clear that the call for the establishment of marine reserves – i.e. more closed area’s – cannot be supported on the grounds that they may be good for fishing stocks and will create greater biodiversity. The establishment of the plaice box in this area has led to the exact opposite situation.

Therefore, no one should be surprised that the fisheries are very sceptical regarding further plans for protected areas and closed areas. The first question is what do we hope to achieve, as managers and scientists? Closing and then waiting to see what happens is not an option, of course. Han Lindeboom often mentions combining the interests of science and the fisheries. However, if even a zone that is closed purely on the grounds of fishing stock concerns has already gone so utterly wrong, then we find a combined approach completely undesirable.

Let us mention one aspect. In recent years, the European Union has set the reduction of discards as top priority in its fisheries policy. If we look at the areas that are intended for protection under Natura 2000, such as the Klaverbank and the Dogger Bank, these are regions will little or no discards. How counter-productive can proposals be? And the Dogger Bank consists largely of only a mixure of sand and mud. A fishing track of a trawl is no longer visible even within a few hours.
What so strange is about all these plans is that almost every member state is making a fuss and that the North Sea is in danger of becoming a patchwork of protected areas. For example, on the Dogger Bank there are three member states, but one is looking at bird protection while another is talking about porpoises, and another about sea bed life.
When will we stop this?

It really is high time that we developed a sense of reality, firstly among NGOs and scientists but also among managers. And that we first and foremost ensure that the effects of the plaice box are on the table. For us, as the fisheries sector, there is but one clear and relevant question: what has gone wrong with the area that until 1990 produced massive quantities of fish every year? And what is happening to the sea bed life in this area? As long as clarity on this issue is not forthcoming, we will continue to fight against more protected and closed areas in the North Sea.

Thank you for attention.

Willem de Boer.

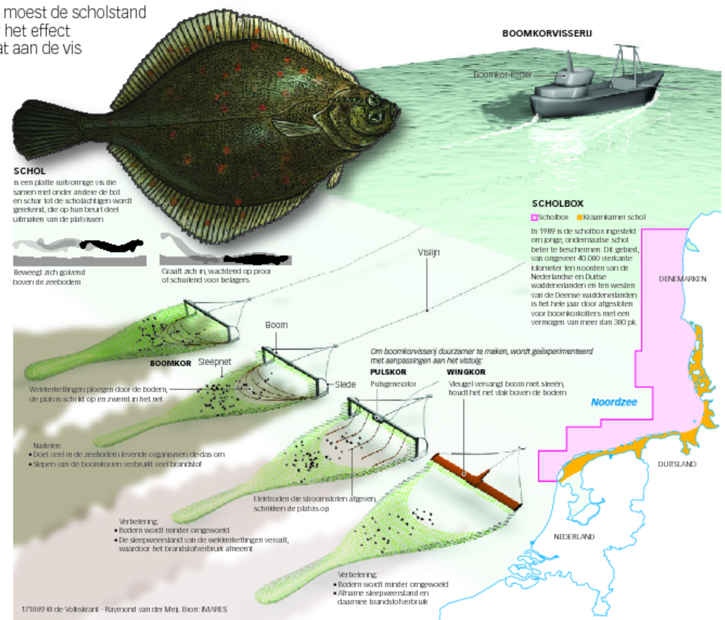
Plaice Box Article in the Volkskrant

Visserij Biologen gaan onderzoek instellen naar onbedoeld effect van rustplaats voor jonge platvis op zee

De schone schijn van schol

Een scholbox op zee moest de scholstand vooruit helpen. Maar het effect is omgekeerd. Ligt dat aan de vis of aan de vissers?

Door **Marcus Werner**



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De militant klinkende stem op het YouTube-filmpje verheft zich tegen een achtergrond van motorlawaai. Twee bolronde netten worden aan boord van een vissersschip gehesen. Ze puilen uit van de vis. 'Scholexplosie! De zee zit barstensvol vis', zegt de stem.

Het filmpje, gemaakt door een Urker visser, is ongewoon voor een tijd waarin wordt gewaarschuwd voor de teloorgang van allerlei wilde vispopulaties. Volgens het blad *Science* van enkele jaren geleden zullen in 2048 wereldwijd zelfs alle populaties commercieel geëxploiteerde vissoorten verdwenen zijn.

Op de Noordzee is daar weinig van te merken. Vissers vingen deze zomer in een week soms 34 ton schol. Zulke vangsten zijn er in 25 jaar niet geweest. Eindelijk een vissoort, zo lijkt het, waar het wél goed mee gaat. Maar dat is schone schijn. De vissersvloot is voor een belangrijk deel gesaneerd, waardoor meer vissen overleven, de scholstand lijkt zich de laatste vijf jaar geleidelijk te herstellen van een lange periode van zware bevissing, maar je kunt niet zeggen dat de schol floreert.

De platvis is dan ook nog steeds onderwerp van verhitte discussies. De EU-vangstlimiet voor schol is op grond van adviezen van visserijbiologen voor dit jaar vastgesteld op 55.500 ton. Volgend jaar gaat deze TAC – Total Allowable Catch, de maximumvangst die de populatie niet in gevaar brengt – weliswaar omhoog, maar slechts met het in visserijafspraken vastgestelde maximum van 15 procent. In de bloeitijd van de Nederlandse scholvisserij tussen 1980 en 1990 lag de TAC rond de 180 duizend ton, bij een volgens de vissers ongeveer even grote scholpopulatie als nu. De biologen hebben verkeerd gerekend, vinden de vissers.

Ook bij natuurorganisaties ligt de schol niet lekker. Zij wijzen erop dat netten van scholvissers een slachting aanrichten onder organismen in de Noordzeebodem, en dat het door zee slepen van deze zogeheten boomkorren brandstof slurpt. Stichting De Noordzee adviseert consumenten niet te kiezen voor met de boomkor gevangen schol of tong.

Visserijbiologen zitten eveneens met de schol in hun maag. In de gloriedagen van de scholvisserij werd al geanticipeerd op mogelijke overbevissing van schol. Omdat schollen in de Waddenzee opgroeien en daarna in de loop van een paar jaar naar dieper water in de Noordzee trekken, werd in 1989 de zogeheten scholbox ingesteld, een beschermd gebied voor de kust tussen Texel en Noord-Denemarken. Achterliggende gedachte: rust voor de halfwasscholletjes, zodat ze pas als ze volwassen waren, de visgronden buiten de scholbox zouden bereiken.

'Quota werken voor haring, maar niet voor gemengde visserij; misschien moeten we naar quota in dagen op zee, minder activiteit dus'

Alleen doet de scholbox niet wat ervan werd verwacht. Visserij-experts evalueerden de scholbox vorige week in IJmuiden. Adriaan Rijnsdorp, hoogleraar duurzaam visserijbeheer in Wageningen en vis-ecoloog bij de IJmuidense vestiging van onderzoeksinstituut Wageningen Imares, was erbij. Al decennialang is hij betrokken bij het scholonderzoek in de Noordzee en bij de visserijbiologische adviezen voor de Nederlandse en Europese overheid. 'De scholbox', zegt hij, 'leek een prima antwoord op het voor de scholstand grootste probleem van boomkorvisserij: de bijvangst van ondermaatse schollen.' Schol en tong leven namelijk door elkaar op de Noordzeebodem. Wie op tong vist, een geliefde prooi voor vissers vanwege de relatief grote marktwaarde, vist onherroepelijk ook grote aantallen kleinere schollen op.

Rijnsdorp: 'Tongnetten, met een maaswijdte van 8 centimeter, vangen tongen van de toegestane minimummaat, terwijl de ondermaatse exemplaren ontsnappen.' Tong – de naam zegt het al – heeft een langwerpige tongvorm. Schollen hebben een ruitvormig lijf. 'Daarvan blijven exemplaren van ver onder de minimummaat achter de mazen hangen. En dat zijn nou juist de vissen die de toekomstige ouderpopulatie uitmaken.'

Discards

De gemengde vangst van schol en tong, en de vangstquoteringen per soort die vissers krijgen toebedeeld, leiden ertoe dat te kleine vissen als ten dode opgeschreven *discards* in zee worden gekieperd. Wanneer het quotum voor een soort is opgevist, gebeurt dat ook met exemplaren die een legale grootte hebben – wat eufemistisch *highgrading* wordt genoemd.

De scholbox, die eerst alleen in de paaiperiode van schol werd gesloten, ging in 1995 het gehele jaar dicht voor vissersschepen met een motorvermogen van boven de 300 pk. Voor kleinere schepen, die moeilijk ver op zee vissen, maakte de politiek een uitzondering.

Over het resultaat, zegt Rijnsdorp, waren hij en zijn collega-visbiologen 'volstrekt verrast': 'De scholstand en -vangst daalden, en ook de aanwas van jonge schol pakte lager uit!'

Experimenteren op volle zee

Boomkorvissers experimenteren met innovatief vangtuig dat de bijvangst moet verminderen. Schipper Klaas-Jelle Koffeman vist met een 2.000 pk-kotter voornamelijk op schol. Hij vangt goed: 1.400 kilo per 'trek' van twee uur. In 2008 en 2009 viste hij enkele maanden met een hydrorig, waarin een aangepaste boom waterwervelingen opwekt om de vis uit de bodem te jagen: 'De vangsten zijn nu nog lager, maar dat is een kwestie van de vistechniek aanpassen.' De natuurorganisaties zijn te drammerig, vindt Koffeman: 'Geef de sector tien jaar om te laten zien dat het veel duurzamer kan, in plaats van steeds te hameren op schade aan het bodemleven.' Christien Absil van Stichting De Noordzee gelooft dat de schade van de boomkorvisserij zich uitbreidt. Ze maakt zich ook zorgen over de bijvangsten. 'Bij de huidige schepen is dat 28 ton per week, inclusief krabben en zeesterren.'

Dat omgekeerde effect van de scholbox intrigeert Rijnsdorp enorm. Hij acht het onwaarschijnlijk dat vissers massaal in de scholbox vissen. Zij worden goed in de gaten gehouden. Klimaatverandering zou volgens Rijnsdorp de boosdoener kunnen zijn, omdat is aangetoond dat jonge scholletjes op het Wad naar dieper water trekken zodra het water warmer wordt dan 20 graden. Dat zou verder van de kust kunnen doorwerken.

Een andere mogelijkheid is dat de – inmiddels sterk verminderde – aanwas van de voedselrijkdom door fosfaten in de Noordzee (eutrofiëring) tot een grote scholpopulatie heeft geleid. De meest plausibele theorie lijkt echter dat de boomkorvisserij een hoge scholstand in de hand werkt. De boomkor van platvisvissers bestaat uit een stalen balk met aan weerszijden een soort slede en waarop de boom over de zeebodem rijdt. Daarachter sleept, als een ware puntzak, het net. 'Wekkers', zware kettingen die aan de sleden hangen, ploegen door de bodem om platvissen het net in te jagen.

Rijnsdorp: 'Het lijkt erop dat het omwoelen van de bodem grotere lang levende bodemdieren de das omdoet. Kleinere zeeorganismen met een snelle levenscyclus, zoals borstelwormen, hebben weinig last van de boomkor, omdat die door snelle groei en voortplanting gemakkelijk de sterfte door bodemomwoeling compenseren. Vooral die wormen worden door schol en tong gegeten.'

Rijnsdorp vermoedt dat jonge scholletjes de scholbox verlaten om op zoek te gaan naar het voedsel dat vrijkomt als gevolg van de boomkorvisserij langs de randen van de scholbox. Met als negatief effect dat er méér ondermaatse schol wordt opgevist.

De theorie van de eutrofiëring als mogelijke verklaring voor het omgekeerde effect van de scholbox is volgens Rijnsdorp statistisch moeilijk aan te tonen. De klimaattheorie is lastig te onderzoeken omdat de watertemperatuur in de scholbox overal gelijk is.

De voedseltheorie daarentegen wordt straks tegen het licht gehouden, als althans de aanvraag van Rijnsdorp, het Texelse zee-instituut NIOZ en de Universiteit van Amsterdam voor een miljoen euro onderzoeksgeld wordt gehonoreerd: 'Daarmee willen we uitzoeken hoe precies de voedselrelaties in de Noordzee liggen, mét en zonder bodemberoering, en wat de effecten zijn op de vispopulaties en het bodemleven.'

De scholbox is mislukt. Hoe valt dan de goede scholvangst te verklaren? Rijnsdorp: 'Vrijwel zeker uit de kleinere vissersvloot, waardoor de spoeling per schip beter wordt. Dat was in de modellen voorzien.

Maar daarmee is niet gezegd dat het visserijbeleid met gewichtsquota voor de boomkorvisserij succesvol is. Quota werken voor haring, maar niet voor gemengde visserij. Misschien moeten we naar quota in dagen op zee, een inspanningsbeperking dus.'

Plaice Box Recommendations: North Sea RAC (October 2005)

Plaice Box Evaluation experiment

Adriaan Rijnsdorp and Rob Grift (RIVO), with contributions of Simnon Jennings (CEFAS), Mike Kaiser (University of Bangor), Thomas Neudecker (Bundesforschungsambt Fisherei) and NSRAC Focus Group on Plaice Box.

Introduction

The plaice box was established in 1989 to enhance the recruitment, yield and spawning stock biomass through a reduction in plaice discarding. As the landings, stock biomass and recruitment declined since the introduction of the Plaice Box, an evaluation of its effectiveness through an experimental setup is urgently needed in order for the European Commission to decide whether to (a) keep the box in place; (b) modify the box; (c) abolish the box[1]. On request of the EU, an expert group assessed the ecological effects of the Plaice Box and concluded that it was impossible to measure the effect of the box on the recruitment of plaice in a direct manner[2]. The North Sea Regional Advisory Council (NSRAC), which was asked for advice by the Commission, recognised that an experimental approach is needed to assess the effectiveness of the plaice box. They also recognised the need for the formulation of clear objectives and criteria to test whether the objectives of the plaice box as technical management measure have been met. This document presents a research proposal to allow an evaluation of the effect of the plaice box. It will describe and explain the questions and hypothesis that need to be answered to find out the mechanism operating in the box; (b) describe the methodology to be used; (c) propose criteria that can be used to evaluate the experimental results in the light of the hypothesis.

Research question

The question at stake is whether the decrease in yield and spawning stock biomass of plaice is caused by the establishment of the plaice box or caused by natural processes, or a combination of the two. There are several processes operating in the box that may affect plaice:

a) settlement of plaice larvae in the box
b) predation (o.a. seals, cormorants)
c) benthic productivity (eutrophication)
d) abiotic factors (temperature, oxygen)
e) fishing mortality (landings and discards)
f) thinning of the population leading to density-dependent growth
g) trawling impact on the benthos may affect growth rate
h) changes trawling disturbance may influence the spatial distribution of plaice

The first four entries (a-d) comprise natural processes, whereas the others (e-h) are related to fishing. It should be noted that the settlement of plaice larvae in the box (a), which is known to show substantial inter-annual variability, will be the most important

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[1] EC DG Fish. Review of access restrictions in the Common Fisheries Policy. Non-paper from the Commission Services. Brussel, 28-05-2005

[2] Grift RE, Tulp I, Clarke L, Damm U, McLay U, Reeves S, Vigneau S, Weber W, 2004. Assessment of ecological effects of the plaice box. Repport of the European Commission Expert Working Group to evaluate the Shetland and Plaice boxes. Brussels, 121 p.

factor determining the recruitment to the fishery, and that the plaice box can only reduce the mortality rate of the plaice that settles in the box.

The hypothesis that the plaice box has no or even a negative influence on plaice bears on the assumption that bottom disturbance by trawlers (in particular beam trawlers) will increase the food availability of plaice. According to this hypothesis, the displacement of fishing effort from the plaice box to the areas just outside the box, will have led to the following chain of events: a reduction in the bottom disturbance in the box, a reduction in the productivity of the benthic food organisms for plaice, a shift in the spatial distribution of pre-recruit plaice to the intensively trawled fishing grounds along the border of the box and beyond. It is also possible that trawling affected the interactions between plaice and other species that would normally be suppressed by trawling. In addition, the possibility of a density-dependent reduction in pre-recruit growth needs to be considered, as better survival in the plaice box may lead to an increased intra- and inter-specific competition for food, a reduction in growth, an increase in the duration of the pre-recruit period and an increase in cumulative mortality.

The alternative hypothesis states that the changes in environmental conditions have had a negative influence by affecting the quality of the demersal habitat through 1) summer temperatures exceeding the physiological acceptable temperature range; 2) a decrease in benthic productivity due to a reduced eutrophication and or changes in temperatures; 3) an increase in the predation mortality by o.a. seals and cormorants. Also, the level of larval plaice settling in the plaice box may have decreased as compared to the years before 1989.

In order to tackle the two competing hypothesis, a study comprising both field experiments and analytical work is necessary. The emphasis of the study needs to be on the fisheries-related processes as these are clearly specified and can be manipulated experimentally. In contrast, the effect of temperature, eutrophication or predation cannot be manipulated in the field, although the response of plaice to temperatures may be studied in tank experiments. It is recognised that if the fisheries dependent hypothesis is true, a closed area may not be an appropriate management measure to protect undersized plaice from discarding as the undersized fish will follow the fishery. If the fisheries dependent hypothesis can be refuted, a closed area is an appropriate management measure.

The two competing hypotheses lead to the following five research questions:

1) What is the effect of trawling intensity on the benthic productivity and the food availability of plaice
2) What is the effect of trawling intensity on the spatial distribution of pre-recruit plaice
3) What is the effect of water temperature on the spatial distribution and growth rate of pre-recruit plaice
4) What is the effect of the density of plaice and other food competitors on the growth rate of pre-recruit plaice
5) What is the effect of the current plaice box on the survival and subsequent recruitment of pre-recruit plaice.

Methodology

1) The effect of trawling intensity on benthic productivity and food availability

This research question can be tackled by conducting a field experiment in which 2 – 3 representative study sites in the plaice box are closed for all trawl fishery for 5 years and are deliberately trawled in an experimental setup. Study sites need to be about 5x5 nm, to allow selection of different sediment types. Within these areas, different levels of controlled trawling can be imposed in sub-areas, reflecting the changes in trawling intensity as observed in the plaice box. Within each sub-area, benthos (epi- and infauna) is sampled to determine the biomass and productivity. Plaice is sampled to determine their main prey species. Subsequently, the effect of trawling on the food availability for plaice can be investigates. A number of replicate sub-areas (~6) will be studied to obtain sufficient statistical power.

2) The effect of trawling intensity on the spatial distribution of plaice

The response of plaice to a change in the trawling disturbance may be studied in a field experiment where the line of intensive trawling along the border of the box will be modified by a change in the location of the border. In this approach, the current fixed relation between trawling intensity and depth/distance from the coast will be un-coupled and allow the study of how the distribution of pre-recruit plaice along the depth gradient responds to changes in trawling intensity. Below, two possible approaches are given. It should be noted that the two options are given as examples. In a later stage, the exact boundaries of the experimental areas need to be determined taking account of the homogeneity of the habitats within the experimental areas.

Ideally, the experimental set up would comprise a number of alternating segments of 10 nm wide that are either *fully closed* or *fully opened* to the trawl fisheries (Figure 1). It is expected that within the open segments, the fishery will create an intensively fished area at a shallower depth than the intensively fished border of the fully closed segments. If pre-recruit plaice favour trawled areas, a change in their spatial distribution is expected during the growing period. In this experimental set up, the access regime of the plaice box will have to be changed for the duration of the experiment and for the experimental area.

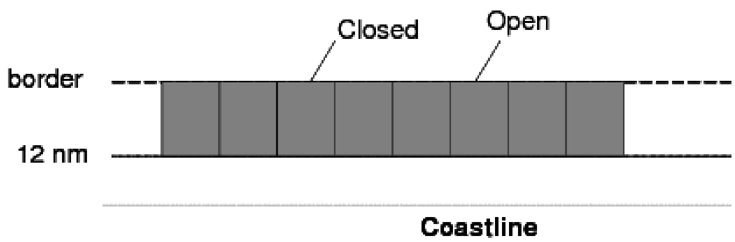

Figure 1. Potential experimental set up to test the change in plaice distribution to a change in the fishing patterns. In the zone within the plaice box between the 12 nm zone and the border of the box, a number of alternating segments of approximately 10 nm wide will be either closed or opened for trawl fisheries.

Although the experimental set up described above is the scientifically preferred option, an alternative set up that is scientifically acceptable is shown in Figure 2. Here the border of the plaice box is shifted alternatingly 10 nm offshore and 10 nm inshore. The surface area that is under the current access regime of the box remains the same. If at half way during the experiment, a clear response of plaice is observed, the border of the box may be swapped by moving the segments in the opposite direction. In this experiment, only the borders of the box will be changed, the access regime of the plaice box and the surface area of the protectd area will remain unchanged.
Trawling intensity will be monitored using VMS data of all relevant fleets operating in the study area. The response of pre-recruit plaice will be determined through research surveys during the main growing period. Plaice will be sampled for stomach contents and growth rate to examine a possible relationship with trawling intensity. The benthos in the experimental areas will be sampled along transects perpendicular to the border to determine biomass, productivity and food availability.

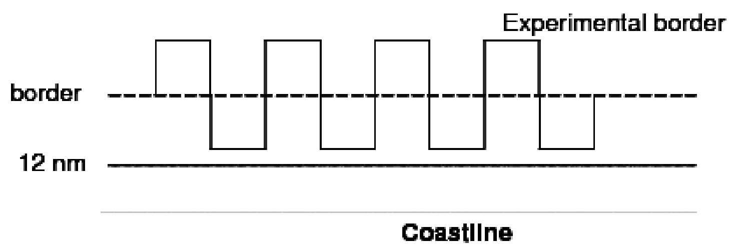

Figure 2. Potential experimental set up to test the change in plaice distribution to a change in the fishing patterns. The border of the plaice box will be shifted either offshore or inshore in part of the box during the experimental period. The total surface area unnder the current access regime of the plaice box will not be changed.

3) The effect of density of plaice and other competitors on growth rate
Density-dependent growth of plaice can be studied by a statistical analysis of the inter-annual changes in growth rate of pre-recruit plaice (length of 1 and 2 year old plaice) in the plaice box in relation to density of plaice, other competitors and environmental factors that may influence growth. These relationships will also be investigated for species that have similar diets as plaice.

4) The effect of temperature on the distribution of plaice
There are several possibilities to study the effect of water temperature on the spatial distribution of plaice. First, tank experiments can be conducted to estimate the

physiological range of temperatures for different size classes of plaice[3]. Second, the variations in distribution of cohorts as observed in research vessel surveys can be analysed in relation to the inter-annual variations in temperature. Third, field experiments can be conducted by tagging pre-recruit plaice in different years, and examining the inter-annual differences in migration and dispersion in relation to the temerature conditions. The latter approach will only yield results if the temperature conditions in the study period will show sufficient inter-annual differences. Fourth, in collaboration with the fishing industry, commercial catch rates of a selection of vessels operating in the southeastern North Sea may be recorded on a haul-haul basis together with fishing position, depth and bottom temperature. If a sufficient number of vessels collaborate, the immediate response of fish to changes in temperature may be quantified at a resolution that is not achievable using research vessels.

5) Evaluation of the effect of the current plaice box on the survival and subsequent recruitment of pre-recruit plaice
The implication of the results of the research questions 1 – 4 need to be evaluated using a spatial explicit modelling approach, for instance those employed in the previous plaice box evaluations[4]. These models allow the calculation of the impact of fishing (intensity and spatial patterns) on the survival and growth of a cohort. The model needs to take account of the influence of trawling and temperature on the spatial distribution and growth of pre-recruit plaice. This approach needs disaggregated input data on the actual distribution of the fishing effort of the relevant fleets and their mesh sizes (VMS and EU-logbook data) and actual data on the distribution of pre-recruit plaice inside the plaice box.

Criteria to evaluate the plaice box as management measure

The two field experiments are expected to provide strong evidence whether or not the processes assumed in hypothesis 1 (a reduction in trawling intensity will have a negative effect of the productivity of pre-recruit plaice and will lead to a change in distribution of pre-recruit plaice to the more intensively fished areas) will take place. If the experiments yield significant results for this hypothesis, we may conclude that an area with restricted trawling is an inappropriate tool to protect pre-recruit plaice for discarding, since the fish follows the fishery.
If the results of the experiments falsify the hypothesis, we may conclude that the plaice box will have reduced the discard mortality of undersized plaice. The level of protection will depend on the proportion of the population of undersized plaice that resides in the plaice box, the duration of their stay in the box, the level of fishing effort in the box and the level of density-dependent reduction that may occur in growth.

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[3] Fonds M, Cronie R, Vethaak AD, Van der Puyl P, 1992. Metabolism, food consumption and growth of plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) in relation to fish size and temperature. Neth J Sea Res 29: 127-143
[4] ICES. 1987. Report of the ad-hoc meeting of the North Sea flatfish working group, IJmuiden, 2-5 February 1987. ICES C.M. 1987/Assess:14.
ICES. 1999. Report of the workshop on the evaluation of the Plaice Box, IJmuiden, 22-25 June 1999. ICES C.M. 1999/D:6.

The influences of many of the natural processes that may have affected the trends in yield and spawning stock biomass of plaice after the establishement of the plaice box cannot be determined. The 4th research task will nevertheless allow an evaluation of the effect of the observed increase in temperature on the effectiveness of the plaice box. If there is support that plaice respond to the warmer temperatures during summer, the offshore shift in distribution as observed in the 1990s will have made the plaice box less effective as a larger proportion of the under-sized plaice will have moved out of the plaice box.

Appendix to Chapter 4

Fishing effort and discards

Tabel AppChpt4.Oo1: Percent of estimated catch allocation on landings.

country	year	species	power	estimated catch (tons)	landings (tons)	Explanation by analysis (%)
DEN	2005	CSH	<=221kW	3855	3855	100.0
DEN	2005	PLE	<=221kW	4786	4787	100.0
DEN	2005	PLE	>221kW	7414	7414	100.0
DEN	2005	SOL	<=221kW	205	205	99.9
DEN	2005	SOL	>221kW	147	147	100.0
DEN	2006	CSH	<=221kW	3853	3853	100.0
DEN	2006	PLE	<=221kW	6009	6009	100.0
DEN	2006	PLE	>221kW	7841	7843	100.0
DEN	2006	SOL	<=221kW	110	110	100.0
DEN	2006	SOL	>221kW	118	118	100.0
DEN	2007	CSH	<=221kW	3700	3700	100.0
DEN	2007	PLE	<=221kW	3541	3563	99.4
DEN	2007	PLE	>221kW	6514	6516	100.0
DEN	2007	SOL	<=221kW	48	49	99.9
DEN	2007	SOL	>221kW	119	119	99.9
DEN	2008	CSH	<=221kW	3239	3239	100.0
DEN	2008	PLE	<=221kW	5131	5135	99.9
DEN	2008	PLE	>221kW	5468	5487	99.6
DEN	2008	SOL	<=221kW	52	52	100.0
DEN	2008	SOL	>221kW	89	89	100.0
GER	2005	CSH	<=221kW	17329	17329	100.0
GER	2005	PLE	<=221kW	1957	1959	99.9
GER	2005	PLE	>221kW	1331	1332	99.9
GER	2005	SOL	<=221kW	311	311	99.9
GER	2005	SOL	>221kW	345	345	100.0
GER	2006	CSH	<=221kW	15498	15506	99.9
GER	2006	PLE	<=221kW	2350	2350	100.0
GER	2006	PLE	>221kW	1229	1229	100.0
GER	2006	SOL	<=221kW	142	142	100.0
GER	2006	SOL	>221kW	291	291	100.0
GER	2007	CSH	<=221kW	12009	12009	100.0
GER	2007	PLE	<=221kW	1353	1355	99.8
GER	2007	PLE	>221kW	1181	1194	98.9
GER	2007	SOL	<=221kW	98	98	99.3
GER	2007	SOL	>221kW	304	304	100.0
GER	2008	CSH	<=221kW	12261	12261	100.0
GER	2008	PLE	<=221kW	1526	1526	100.0
GER	2008	PLE	>221kW	1537	1537	100.0
GER	2008	SOL	<=221kW	170	170	100.0
GER	2008	SOL	>221kW	275	275	100.0

country	year	species	power	estimated catch (tons)	landings (tons)	Explanation by analysis (%)
NLD	2005	CSH	<=221kW	15958	15959	100.0
NLD	2005	CSH	>221kW		2	
NLD	2005	PLE	<=221kW	1580	1638	96.4
NLD	2005	PLE	>221kW	20502	21157	96.9
NLD	2005	SOL	<=221kW	1235	1242	99.5
NLD	2005	SOL	>221kW	9527	9532	99.9
NLD	2006	CSH	<=221kW	15444	15444	100.0
NLD	2006	CSH	>221kW		10	
NLD	2006	PLE	<=221kW	2258	2263	99.8
NLD	2006	PLE	>221kW	20602	20797	99.1
NLD	2006	SOL	<=221kW	830	830	100.0
NLD	2006	SOL	>221kW	7109	7111	100.0
NLD	2007	CSH	<=221kW	16029	16029	100.0
NLD	2007	CSH	>221kW		9	
NLD	2007	PLE	<=221kW	1318	1339	98.4
NLD	2007	PLE	>221kW	21545	21548	100.0
NLD	2007	SOL	<=221kW	1309	1310	99.9
NLD	2007	SOL	>221kW	8888	8889	100.0
NLD	2008	CSH	<=221kW	14555	14558	100.0
NLD	2008	CSH	>221kW	20	20	100.0
NLD	2008	PLE	<=221kW	1608	1614	99.6
NLD	2008	PLE	>221kW	18401	18402	100.0
NLD	2008	SOL	<=221kW	1073	1085	98.9
NLD	2008	SOL	>221kW	7948	7957	99.9

Tabel AppChpt4.Oo1: Quality flag continued

Tabel AppChpt4.Oo2: Dutch landings, earnings and percent of earnings within the plaice box (PB) and the area

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
BEAM.16-31	<=221kW	CSH	2005	15951.27	45.58	28.76	63	26	16
BEAM.16-31	<=221kW	CSH	2006	15432.38	44.16	21.76	49	14	7
BEAM.16-31	<=221kW	CSH	2007	16019.1	58.94	38.31	65	33	21
BEAM.16-31	<=221kW	CSH	2008	14527.12	60.47	41.99	69	22	16
BEAM.16-31	<=221kW	PLE	2005	6.74	0.01	0.01	53	14	8
BEAM.16-31	<=221kW	PLE	2006	0.9	0.00	0	59	31	18
BEAM.16-31	<=221kW	PLE	2007	0.17	0.00	0	69	39	27
BEAM.16-31	<=221kW	PLE	2008	0.27	0.00	0	72	22	16
BEAM.16-31	<=221kW	SOL	2005	10.97	0.12	0.07	58	17	10
BEAM.16-31	<=221kW	SOL	2006	2.48	0.04	0.01	39	4	2
BEAM.16-31	<=221kW	SOL	2007	2.8	0.03	0.02	49	12	6
BEAM.16-31	<=221kW	SOL	2008	3.7	0.04	0.03	75	24	18
BEAM.16-31	>221kW	CSH	2008	19.76	0.07	na	na	na	na
BEAM.80-99	<=221kW	PLE	2005	914.92	1.95	0.24	12	29	4
BEAM.80-99	<=221kW	PLE	2006	774.8	1.69	0.31	19	40	7
BEAM.80-99	<=221kW	PLE	2007	482.71	1.08	0.11	10	51	5
BEAM.80-99	<=221kW	PLE	2008	591.06	1.16	0.15	13	47	6
BEAM.80-99	<=221kW	SOL	2005	1200.33	13.52	1.56	12	24	3
BEAM.80-99	<=221kW	SOL	2006	771.45	10.60	1.69	16	38	6
BEAM.80-99	<=221kW	SOL	2007	1262.67	16.42	1.62	10	49	5
BEAM.80-99	<=221kW	SOL	2008	1041.09	11.74	1.49	13	42	5
BEAM.80-99	>221kW	PLE	2005	19333.03	38.30	2.41	6	42	3
BEAM.80-99	>221kW	PLE	2006	17539.26	35.36	2.3	7	55	4
BEAM.80-99	>221kW	PLE	2007	18807.63	37.41	1.96	5	51	3
BEAM.80-99	>221kW	PLE	2008	15168.68	27.10	2.23	8	48	4
BEAM.80-99	>221kW	SOL	2005	9500.83	109.83	6.9	6	41	3
BEAM.80-99	>221kW	SOL	2006	7083.26	98.79	6.55	7	55	4
BEAM.80-99	>221kW	SOL	2007	8846.07	114.24	6.08	5	51	3
BEAM.80-99	>221kW	SOL	2008	7837.71	87.50	7.56	9	47	4
BEAM.>100	<=221kW	PLE	2005	68.91	0.15	0.03	17	68	11
BEAM.>100	<=221kW	PLE	2006	672.63	1.57	1.09	70	68	47
BEAM.>100	<=221kW	PLE	2007	40.26	0.09	0.01	9	82	7
BEAM.>100	<=221kW	PLE	2008	114.91	0.24	0.14	56	81	46
BEAM.>100	<=221kW	SOL	2005	2.67	0.03	0.01	21	70	14
BEAM.>100	<=221kW	SOL	2006	3.58	0.05	0.02	47	70	33
BEAM.>100	<=221kW	SOL	2007	2.23	0.03	0	14	82	11
BEAM.>100	<=221kW	SOL	2008	16.3	0.19	0.07	37	24	9
BEAM.>100	>221kW	PLE	2005	1571.65	3.71	0.1	3	72	2
BEAM.>100	>221kW	PLE	2006	2974.32	7.59	0.53	7	84	6
BEAM.>100	>221kW	PLE	2007	2241.42	5.43	0.54	10	92	9
BEAM.>100	>221kW	PLE	2008	1276.78	2.66	0.13	5	76	4
BEAM.>100	>221kW	SOL	2005	29.12	0.33	0.01	3	46	1
BEAM.>100	>221kW	SOL	2006	24.16	0.32	0.02	5	65	3
BEAM.>100	>221kW	SOL	2007	15.18	0.23	0.01	4	93	3
BEAM.>100	>221kW	SOL	2008	46.24	0.51	0.02	5	27	1

between the border of the 12 miles zone and the PB border (btw) on the total earnings.

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
GILL-TRAMMEL	<=221kW	CSH	2005	1.98	0.01	na	na	na	na
GILL-TRAMMEL	<=221kW	CSH	2006	10.19	0.03	0	18	57	10
GILL-TRAMMEL	<=221kW	PLE	2006	0.38	0.00	0	10	40	4
GILL-TRAMMEL	<=221kW	PLE	2007	0.21	0.00	0	5	0	0
GILL-TRAMMEL	<=221kW	SOL	2005	6.1	0.07	na	na	na	na
GILL-TRAMMEL	<=221kW	SOL	2006	34.76	0.47	0.04	8	45	4
GILL-TRAMMEL	<=221kW	SOL	2007	29.74	0.41	0	1	0	0
GILL-TRAMMEL	<=221kW	SOL	2008	2.44	0.03	0.01	38	67	25
OTTER.80-99	<=221kW	CSH	2005	3.25	0.01	0	4	19	1
OTTER.80-99	<=221kW	CSH	2006	1.03	0.00	0	2	58	1
OTTER.80-99	<=221kW	CSH	2007	0.84	0.00	0	29	75	22
OTTER.80-99	<=221kW	CSH	2008	9.76	0.03	0	1	33	0
OTTER.80-99	<=221kW	PLE	2005	647.28	1.46	0.02	2	35	1
OTTER.80-99	<=221kW	PLE	2006	750.86	1.69	0.03	2	22	0
OTTER.80-99	<=221kW	PLE	2007	785.64	1.67	0.05	3	69	2
OTTER.80-99	<=221kW	PLE	2008	700.89	1.41	0.02	2	39	1
OTTER.80-99	<=221kW	SOL	2005	21.49	0.26	0	2	33	1
OTTER.80-99	<=221kW	SOL	2006	17.99	0.25	0.01	2	20	0
OTTER.80-99	<=221kW	SOL	2007	12.29	0.15	0	3	72	2
OTTER.80-99	<=221kW	SOL	2008	20.98	0.23	0	1	22	0
OTTER.80-99	>221kW	PLE	2005	102.15	0.22	0.01	4	20	1
OTTER.80-99	>221kW	PLE	2006	171.69	0.37	0.01	2	14	0
OTTER.80-99	>221kW	PLE	2007	284.51	0.61	0.03	4	26	1
OTTER.80-99	>221kW	PLE	2008	794.76	1.58	0.03	2	11	0
OTTER.80-99	>221kW	SOL	2005	1.95	0.02	0	1	19	0
OTTER.80-99	>221kW	SOL	2006	3.35	0.05	0	2	16	0
OTTER.80-99	>221kW	SOL	2007	27.62	0.33	0.01	3	24	1
OTTER.80-99	>221kW	SOL	2008	71.59	0.78	0.02	2	5	0
OTTER.>100	<=221kW	CSH	2005	2.36	0.01	0	9	72	7
OTTER.>100	<=221kW	CSH	2007	9.35	0.05	na	na	na	na
OTTER.>100	<=221kW	CSH	2008	21.18	0.05	0	0	0	0
OTTER.>100	<=221kW	PLE	2005	0.32	0.00	na	na	na	na
OTTER.>100	<=221kW	PLE	2006	62.38	0.14	0	1	0	0
OTTER.>100	<=221kW	PLE	2007	30.01	0.07	na	na	na	na
OTTER.>100	<=221kW	PLE	2008	207.1	0.43	0.03	7	69	5
OTTER.>100	<=221kW	SOL	2006	0.2	0.00	0	1	0	0
OTTER.>100	<=221kW	SOL	2008	0.79	0.01	0	10	0	0
OTTER.>100	>221kW	PLE	2005	150.23	0.36	0.01	4	7	0
OTTER.>100	>221kW	PLE	2006	53.81	0.13	0.01	5	1	0
OTTER.>100	>221kW	PLE	2007	145.52	0.34	0.01	3	58	2
OTTER.>100	>221kW	PLE	2008	946.11	1.99	0.12	6	71	4
OTTER.>100	>221kW	SOL	2005	0.04	0.00	0	1	0	0
OTTER.>100	>221kW	SOL	2007	0.14	0.00	0	1	26	0
OTTER.>100	>221kW	SOL	2008	1.11	0.01	0	2	13	0
OTHER	<=221kW	PLE	2006	1.22	0.00	na	na	na	na
OTHER	>221kW	PLE	2005	0.04	0.00	0	19	0	0
OTHER	>221kW	PLE	2006	57.92	0.14	0.07	49	79	38
OTHER	>221kW	PLE	2007	69.42	0.16	0.08	50	81	40
OTHER	>221kW	PLE	2008	215.27	0.45	0.25	56	84	47

Tabel AppChpt4.Oo2: Dutch landings and earnings continued.

Tabel AppChpt4.Oo3: German landings, earnings and percent of earnings within the plaice box (PB) and the area

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
BEAM.16-31	<=221kW	CSH	2005	17274.8	47.84	47.73	100	3	3
BEAM.16-31	<=221kW	CSH	2006	15499.68	45.22	45.05	100	2	2
BEAM.16-31	<=221kW	CSH	2007	11989.03	44.21	44.1	100	8	8
BEAM.16-31	<=221kW	CSH	2008	12259.85	49.93	49.53	99	7	7
BEAM.16-31	<=221kW	PLE	2005	0.25	0.00	0	99	7	7
BEAM.16-31	<=221kW	PLE	2006	0.53	0.00	0	99	1	1
BEAM.16-31	<=221kW	PLE	2007	2.23	0.00	0	100	11	11
BEAM.16-31	<=221kW	PLE	2008	0.79	0.00	0	100	5	5
BEAM.16-31	<=221kW	SOL	2005	0.7	0.01	0.01	100	2	2
BEAM.16-31	<=221kW	SOL	2006	1.37	0.02	0.02	100	1	1
BEAM.16-31	<=221kW	SOL	2007	3.11	0.04	0.04	100	5	5
BEAM.16-31	<=221kW	SOL	2008	4.88	0.06	0.06	100	7	7
BEAM.16-31	>221kW	PLE	2007	1.88	0.00	0	3	10	0
BEAM.16-31	>221kW	SOL	2007	2.22	0.03	0	3	10	0
BEAM.80-99	<=221kW	CSH	2005	54.5	0.14	0.11	83	66	55
BEAM.80-99	<=221kW	CSH	2006	2.81	0.01	0	42	54	23
BEAM.80-99	<=221kW	CSH	2007	0.7	0.00	0	83	19	15
BEAM.80-99	<=221kW	CSH	2008	1.06	0.00	0	24	5	1
BEAM.80-99	<=221kW	PLE	2005	568.78	1.21	0.81	67	60	40
BEAM.80-99	<=221kW	PLE	2006	354.93	0.78	0.58	74	61	45
BEAM.80-99	<=221kW	PLE	2007	87.57	0.19	0.15	76	52	40
BEAM.80-99	<=221kW	PLE	2008	43.06	0.08	0.05	66	25	17
BEAM.80-99	<=221kW	SOL	2005	232.07	2.67	1.85	69	59	41
BEAM.80-99	<=221kW	SOL	2006	77.46	1.08	0.67	62	58	36
BEAM.80-99	<=221kW	SOL	2007	48.3	0.63	0.54	85	50	42
BEAM.80-99	<=221kW	SOL	2008	44.9	0.50	0.37	73	26	19
BEAM.80-99	>221kW	PLE	2005	977.64	2.04	0.08	4	76	3
BEAM.80-99	>221kW	PLE	2006	773.38	1.62	0.07	4	74	3
BEAM.80-99	>221kW	PLE	2007	722.59	1.45	0.05	3	50	2
BEAM.80-99	>221kW	PLE	2008	764.97	1.37	0.07	5	55	3
BEAM.80-99	>221kW	SOL	2005	331.08	3.85	0.16	4	78	3
BEAM.80-99	>221kW	SOL	2006	279.63	3.88	0.17	4	74	3
BEAM.80-99	>221kW	SOL	2007	287.74	3.67	0.12	3	50	2
BEAM.80-99	>221kW	SOL	2008	268.04	2.99	0.15	5	53	3
BEAM.>100	<=221kW	CSH	2006	3.56	0.01	0.01	91	32	30
BEAM.>100	<=221kW	CSH	2007	19.57	0.07	0.07	100	60	59
BEAM.>100	<=221kW	PLE	2005	0.38	0.00	0	91	97	88
BEAM.>100	<=221kW	PLE	2006	300.05	0.70	0.63	90	60	54
BEAM.>100	<=221kW	PLE	2007	118.02	0.29	0.28	99	69	69
BEAM.>100	<=221kW	PLE	2008	55.73	0.11	0.1	89	69	62
BEAM.>100	<=221kW	SOL	2005	0.02	0.00	0	100	46	46
BEAM.>100	<=221kW	SOL	2006	2.66	0.04	0.03	89	40	35
BEAM.>100	<=221kW	SOL	2007	0.05	0.00	0	100	93	93
BEAM.>100	<=221kW	SOL	2008	1.22	0.01	0.01	73	86	63
BEAM.>100	>221kW	PLE	2006	15.14	0.04	na	na	na	na
BEAM.>100	>221kW	SOL	2006	0.03	0.00	na	na	na	na

between the border of the 12 miles zone and the PB border (btw) on the total earnings.

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
GILL-TRAMMEL	<=221kW	PLE	2005	4.92	0.01	0	20	22	4
GILL-TRAMMEL	<=221kW	PLE	2006	6.75	0.02	0	9	63	5
GILL-TRAMMEL	<=221kW	PLE	2007	7.51	0.02	0.01	44	42	18
GILL-TRAMMEL	<=221kW	PLE	2008	7.93	0.02	0.01	36	54	19
GILL-TRAMMEL	<=221kW	SOL	2005	61.34	0.62	0.08	13	24	3
GILL-TRAMMEL	<=221kW	SOL	2006	50.66	0.68	0.04	6	69	4
GILL-TRAMMEL	<=221kW	SOL	2007	34.42	0.44	0.13	30	51	15
GILL-TRAMMEL	<=221kW	SOL	2008	98.86	1.12	0.57	51	47	24
GILL-TRAMMEL	>221kW	PLE	2005	1.38	0.00	0	17	97	17
GILL-TRAMMEL	>221kW	PLE	2006	1.26	0.00	0	9	99	8
GILL-TRAMMEL	>221kW	PLE	2007	1.25	0.00	0	22	80	17
GILL-TRAMMEL	>221kW	SOL	2005	5.05	0.05	0.01	12	1	0
GILL-TRAMMEL	>221kW	SOL	2006	7.04	0.11	0	0	92	0
GILL-TRAMMEL	>221kW	SOL	2007	6.77	0.08	0.01	6	58	4
OTTER.80-99	<=221kW	PLE	2005	1221.26	2.72	0.27	10	79	8
OTTER.80-99	<=221kW	PLE	2006	900.85	2.11	0.18	9	74	6
OTTER.80-99	<=221kW	PLE	2007	758.65	1.62	0.02	1	83	1
OTTER.80-99	<=221kW	PLE	2008	472.76	0.91	0.02	2	98	2
OTTER.80-99	<=221kW	SOL	2005	16.72	0.19	0.02	12	75	9
OTTER.80-99	<=221kW	SOL	2006	8.4	0.12	0.01	9	75	7
OTTER.80-99	<=221kW	SOL	2007	12.37	0.15	0	1	67	0
OTTER.80-99	<=221kW	SOL	2008	18.91	0.20	0	0	66	0
OTTER.80-99	>221kW	PLE	2005	274.24	0.58	0.04	6	89	6
OTTER.80-99	>221kW	PLE	2006	286	0.67	0.04	6	94	6
OTTER.80-99	>221kW	PLE	2007	261.42	0.55	0.02	3	95	3
OTTER.80-99	>221kW	PLE	2008	339.34	0.65	0	0	6	0
OTTER.80-99	>221kW	SOL	2005	7.74	0.08	0.01	13	94	12
OTTER.80-99	>221kW	SOL	2006	4.43	0.07	0	1	78	1
OTTER.80-99	>221kW	SOL	2007	7.02	0.09	0	1	64	1
OTTER.80-99	>221kW	SOL	2008	6.18	0.07	0	0	8	0
OTTER.>100	<=221kW	PLE	2005	122.52	0.27	0.09	31	89	28
OTTER.>100	<=221kW	PLE	2006	699.78	1.70	0.3	18	89	16
OTTER.>100	<=221kW	PLE	2007	300.75	0.69	0.09	12	62	8
OTTER.>100	<=221kW	PLE	2008	841.64	1.74	0.25	14	92	13
OTTER.>100	<=221kW	SOL	2005	0.19	0.00	0	30	84	25
OTTER.>100	<=221kW	SOL	2006	1.1	0.02	0	21	94	19
OTTER.>100	<=221kW	SOL	2007	0.16	0.00	0	23	70	16
OTTER.>100	<=221kW	SOL	2008	0.75	0.01	0	5	79	4
OTTER.>100	>221kW	PLE	2005	55.45	0.13	0.01	5	87	4
OTTER.>100	>221kW	PLE	2006	69.55	0.16	0.02	10	77	7
OTTER.>100	>221kW	PLE	2007	43.84	0.10	0.02	19	75	14
OTTER.>100	>221kW	PLE	2008	254.15	0.53	0.02	4	97	4
OTTER.>100	>221kW	SOL	2005	0.83	0.01	0	3	79	3
OTTER.>100	>221kW	SOL	2006	0.1	0.00	0	3	72	2
OTTER.>100	>221kW	SOL	2007	0.01	0.00	0	52	29	15
OTTER.>100	>221kW	SOL	2008	0.29	0.00	0	17	99	16

Tabel AppChpt4.Oo3: German landings and earnings continued.

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
OTHER	<=221kW	PLE	2005	41.05	0.10	0.06	59	70	41
OTHER	<=221kW	PLE	2006	87.4	0.21	0.12	57	90	52
OTHER	<=221kW	PLE	2007	80.27	0.19	0.12	61	86	52
OTHER	<=221kW	PLE	2008	104.28	0.22	0.07	30	87	26
OTHER	<=221kW	SOL	2005	0	0.00	0	94	30	29
OTHER	<=221kW	SOL	2008	0	0.00	0	45	97	44
OTHER	>221kW	PLE	2005	23.44	0.06	0.02	45	92	41
OTHER	>221kW	PLE	2006	84.03	0.20	0.08	40	90	36
OTHER	>221kW	PLE	2007	162.83	0.37	0.12	31	88	27
OTHER	>221kW	PLE	2008	178.39	0.38	0.11	28	87	24
OTHER	>221kW	SOL	2005	0	0.00	0	52	95	49
OTHER	>221kW	SOL	2006	0	0.00	0	1	0	0
OTHER	>221kW	SOL	2007	0.03	0.00	0	1	73	0
OTHER	>221kW	SOL	2008	0.01	0.00	0	26	92	24

Tabel AppChpt4.Oo3: German landings and earnings continued.

Tabel AppChpt4.Oo4: Danish landings, earnings and percent of earnings within the plaice box (PB) and the area between the border of the 12 miles zone and the PB border (btw) on the total earnings.

				landings	earnings total	earnings in PB	PB on total	btw on PB	btwn on total
Metier	Power	Species	Year	(tons)	Mio €	Mio €	%	%	%
BEAM.16-31	<=221kW	CSH	2005	3855.43	11.41	11.41	100	3	3
BEAM.16-31	<=221kW	CSH	2006	3838.23	11.11	11.11	100	2	2
BEAM.16-31	<=221kW	CSH	2007	3672.22	12.99	12.99	100	3	3
BEAM.16-31	<=221kW	CSH	2008	3233.49	15.15	15.14	100	1	1
BEAM.16-31	>221kW	PLE	2005	0.76	0.00				
BEAM.16-31	>221kW	PLE	2006	1.09	0.00	0	100		
BEAM.16-31	>221kW	SOL	2005	0.02	0.00				
BEAM.16-31	>221kW	SOL	2006	0.00	0.00	0	100		
BEAM.80-99	<=221kW	CSH	2006	8.15	0.02	0.02	100	2	2
BEAM.80-99	<=221kW	PLE	2005	0.55	0.00	0	100	76	76
BEAM.80-99	<=221kW	PLE	2006	7.58	0.02	0.02	100	52	52
BEAM.80-99	<=221kW	SOL	2005	0.01	0.00	0	100	76	76
BEAM.80-99	<=221kW	SOL	2006	0.05	0.00	0	100	54	54
BEAM.>100	<=221kW	CSH	2006	6.48	0.02	0.02	100	8	8
BEAM.>100	<=221kW	CSH	2007	28.02	0.09	0.09	100	0	0
BEAM.>100	<=221kW	CSH	2008	5.39	0.02	0.02	100	0	0
BEAM.>100	<=221kW	PLE	2005	0.73	0.00	0	100	27	27
BEAM.>100	<=221kW	PLE	2006	3.10	0.01	0.01	100	41	41
BEAM.>100	<=221kW	SOL	2005	0.02	0.00	0	100	32	32
BEAM.>100	<=221kW	SOL	2006	0.00	0.00	0	100	37	37
BEAM.>100	>221kW	PLE	2005	2833.81	6.22	0.53	8	78	7
BEAM.>100	>221kW	PLE	2006	3159.48	7.27	0.35	5	73	4
BEAM.>100	>221kW	PLE	2007	2289.87	4.93	0.25	5	85	4
BEAM.>100	>221kW	PLE	2008	1053.74	2.05	0.06	3	62	2
BEAM.>100	>221kW	SOL	2005	18.83	0.22	0.02	9	71	6
BEAM.>100	>221kW	SOL	2006	16.65	0.22	0.02	8	78	6
BEAM.>100	>221kW	SOL	2007	19.29	0.28	0.01	4	77	3
BEAM.>100	>221kW	SOL	2008	11.34	0.13	0.01	8	57	4
GILL-TRAMMEL	<=221kW	PLE	2005	1431.78	2.73	0.85	31	80	25
GILL-TRAMMEL	<=221kW	PLE	2006	1663.27	3.26	1.05	32	70	22
GILL-TRAMMEL	<=221kW	PLE	2007	575.37	1.14	0.51	44	75	33
GILL-TRAMMEL	<=221kW	PLE	2008	651.48	1.20	0.48	40	62	25
GILL-TRAMMEL	<=221kW	SOL	2005	182.93	1.93	0.74	39	54	21
GILL-TRAMMEL	<=221kW	SOL	2006	90.35	1.19	0.56	47	50	23
GILL-TRAMMEL	<=221kW	SOL	2007	39.16	0.55	0.25	46	67	31
GILL-TRAMMEL	<=221kW	SOL	2008	33.31	0.37	0.22	60	44	27
GILL-TRAMMEL	>221kW	PLE	2005	853.98	1.57	0.32	20	79	16
GILL-TRAMMEL	>221kW	PLE	2006	891.62	1.65	0.41	25	83	21
GILL-TRAMMEL	>221kW	PLE	2007	497.53	0.94	0.33	35	87	31
GILL-TRAMMEL	>221kW	PLE	2008	233.36	0.41	0.14	34	88	30
GILL-TRAMMEL	>221kW	SOL	2005	69.93	0.74	0.29	40	57	23
GILL-TRAMMEL	>221kW	SOL	2006	54.49	0.72	0.32	44	48	21
GILL-TRAMMEL	>221kW	SOL	2007	69.99	0.92	0.32	35	56	20
GILL-TRAMMEL	>221kW	SOL	2008	43.19	0.48	0.28	58	58	34
OTTER.80-99	<=221kW	PLE	2005	359.60	0.78	0.02	2	35	1
OTTER.80-99	<=221kW	PLE	2006	369.65	0.87	0	0	33	0
OTTER.80-99	<=221kW	PLE	2007	284.18	0.62	0	0	0	0
OTTER.80-99	<=221kW	PLE	2008	244.73	0.49	0	0	0	0
OTTER.80-99	<=221kW	SOL	2005	16.96	0.20	0	1	37	0
OTTER.80-99	<=221kW	SOL	2006	15.73	0.22	0	0	62	0
OTTER.80-99	<=221kW	SOL	2007	5.76	0.08	0	0	0	0
OTTER.80-99	<=221kW	SOL	2008	13.59	0.14	0	0	0	0
OTTER.80-99	>221kW	PLE	2005	1263.60	2.60	0.01	0	45	0
OTTER.80-99	>221kW	PLE	2006	1060.84	2.32	0	0	22	0
OTTER.80-99	>221kW	PLE	2007	857.84	1.78	0	0	10	0
OTTER.80-99	>221kW	PLE	2008	820.47	1.56	0	0	11	0
OTTER.80-99	>221kW	SOL	2005	50.21	0.60	0	0	29	0
OTTER.80-99	>221kW	SOL	2006	30.43	0.43	0	0	21	0
OTTER.80-99	>221kW	SOL	2007	14.99	0.20	0	0	9	0
OTTER.80-99	>221kW	SOL	2008	22.33	0.24	0	0	6	0

AppChpt4.Oo4: Danish landings and earnings continued.

Metier	Power	Species	Year	landings (tons)	earnings total Mio €	earnings in PB Mio €	PB on total %	btw on PB %	btwn on total %
OTTER.>100	<=221kW	PLE	2005	759.09	1.73	0.34	20	75	15
OTTER.>100	<=221kW	PLE	2006	707.67	1.72	0.55	32	63	20
OTTER.>100	<=221kW	PLE	2007	765.14	1.72	0.28	17	68	11
OTTER.>100	<=221kW	PLE	2008	1636.36	3.34	0.78	23	49	11
OTTER.>100	<=221kW	SOL	2005	4.30	0.05	0.01	20	83	17
OTTER.>100	<=221kW	SOL	2006	3.31	0.05	0.01	20	70	14
OTTER.>100	<=221kW	SOL	2007	3.24	0.04	0.01	16	90	14
OTTER.>100	<=221kW	SOL	2008	4.40	0.05	0.01	25	73	18
OTTER.>100	>221kW	PLE	2005	2123.85	4.84	0.31	6	64	4
OTTER.>100	>221kW	PLE	2006	2390.98	5.68	0.32	6	63	4
OTTER.>100	>221kW	PLE	2007	2407.61	5.26	0.13	2	74	2
OTTER.>100	>221kW	PLE	2008	2708.33	5.49	0.25	5	73	3
OTTER.>100	>221kW	SOL	2005	7.70	0.09	0.01	9	62	6
OTTER.>100	>221kW	SOL	2006	16.64	0.24	0.01	5	62	3
OTTER.>100	>221kW	SOL	2007	14.87	0.20	0.01	4	83	3
OTTER.>100	>221kW	SOL	2008	12.05	0.13	0.01	7	92	6
OTHER	<=221kW	PLE	2005	2235.09	5.22	0.62	12	44	5
OTHER	<=221kW	PLE	2006	3257.75	7.89	1.21	15	25	4
OTHER	<=221kW	PLE	2007	1938.76	4.44	0.55	12	54	7
OTHER	<=221kW	PLE	2008	2602.23	5.47	0.5	9	56	5
OTHER	<=221kW	SOL	2005	0.51	0.01	0	16	20	3
OTHER	<=221kW	SOL	2006	0.81	0.01	0	15	23	3
OTHER	<=221kW	SOL	2007	0.37	0.00	0	16	39	6
OTHER	<=221kW	SOL	2008	0.78	0.01	0	22	80	18
OTHER	>221kW	PLE	2005	338.06	0.79	0.13	16	61	10
OTHER	>221kW	PLE	2006	338.66	0.83	0.09	11	74	8
OTHER	>221kW	PLE	2007	462.76	1.06	0.26	24	75	18
OTHER	>221kW	PLE	2008	671.35	1.42	0.38	27	75	20
OTHER	>221kW	SOL	2005	0.09	0.00	0	24	61	14
OTHER	>221kW	SOL	2006	0.08	0.00	0	8	83	7
OTHER	>221kW	SOL	2007	0.07	0.00	0	78	97	76
OTHER	>221kW	SOL	2008	0.32	0.00	0	58	93	54

Table AppChpt4.3.1 German EU DCR plaice by-catch data in shrimp fisheries (Beam, 16-31 mm) and derivation of annual by-catch rates for Dutch and German shrimpers. * Few high rates cause leverage.

Month	Number of samples	Plaice by-catch rate in shrimp catch (%)	Extrapolated	German seasonal split factor of shrimp catch	Dutch seasonal split factor of shrimp catch	German annual by-catch factor (%)	Dutch annual by-catch factor (%)
Jan			0.5	0.014	0.051	0.007	0.026
Feb			0.36	0.018	0.055	0.006	0.020
Mar			0.36	0.050	0.064	0.018	0.023
Apr	9	0.36		0.118	0.112	0.043	0.040
May			0.06	0.093	0.090	0.006	0.005
Jun	7	0.79		0.090	0.067	0.071	0.053
Jul*	9	48.50		0.072	0.071	3.477	3.425
Aug	4	3.60		0.093	0.091	0.335	0.329
Sep	9	0.92		0.143	0.103	0.132	0.095
Oct			0.7	0.136	0.128	0.095	0.090
Nov			0.6	0.122	0.109	0.073	0.065
Dec			0.5	0.050	0.058	0.025	0.029
Annual rate %						4.29	4.20

Table AppChpt4.3.2 Standardised catch rates for 0-group plaice in DYFS autumn samples by area. Standardised to maximum=1. All depth strata. Affiliation : HUSUM, BUESUM – northeastern Wadden Sea, CUXHAVEN – Elbe/Weser estuaries, OSTFRIESLAND – western Wadden Sea

Area	Number of samples analysed	Relative catch rate 0-group plaice Sept/Oct
HUSUM	1746	0.23
BUESUM	1249	0.33
CUXHAVEN	1229	0.74
OSTFRIESLAND	1889	1

Tabble AppChpt4.3.3 Plaice discards in shrimp fisheries. Shrimp catches based on ICES WGCRANGON.

Year *y*	Shrimp catch (landings in t)				Year class factor	Plaice by-catch estimate (t)		Year class	Numbers at age by year class (*10^6)		Efficiency f
	Denmark	Germany	The Netherlands	Belgium		GER+B+DK	The Netherlands		Age 0 discarded	VPA Age1 from *y+1*	
1980	2140	11694	5617	929				1980			
1981	2821	10713	5036	807				1981			
1982	3107	14151	7311	1407				1982			
1983	1972	8828	6853	644	5.1	1995	1169	1983	703	1258	0.8
1984	770	8283	3998	641	5.4	1793	724	1984	559	1846	0.8
1985	744	12246	6886	588	5.1	2395	1189	1985	796	4750	0.8
1986	956	10909	7004	490	2.8	1200	666	1986	415	1950	0.8
1987	1439	11699	7705	533	3.8	1791	988	1987	618	1769	0.8
1988	1292	10501	6271	497	4.8	2038	1018	1988	679	1187	0.8
1989	1286	8895	6983	748	4.8	1787	1117	1989	645	1036	0.8
1990	581	4694	4736	446	3.7	821	665	1990	330	913	0.9
1991	805	8950	6894	454	4.4	1750	1157	1991	646	776	0.9
1992	2391	7708	7193	578	3.9	1624	1071	1992	599	531	0.9
1993	1452	9089	8500	519	1.5	627	472	1993	244	442	0.9
1994	1574	11444	8764	660	1.2	653	410	1994	236	1162	0.9
1995	1904	8649	14599	512	1.7	737	952	1995	375	1290	0.9
1996	1983	11426	12446	400	6.7	3580	3159	1996	1498	2148	0.9
1997	2899	14618	13367	345	2.9	1975	1447	1997	760	776	0.9
1998	2307	11120	11995	189	0.8	437	376	1998	181	844	0.9
1999	2907	12838	14064	590	1.0	630	531	1999	258	983	0.9
2000	2322	13009	11587	324	1.0	652	472	2000	250	540	1
2001	1824	9333	14296	392	3.8	1877	2275	2001	923	1712	1
2002	3195	12002	11461	266	0.5	323	235	2002	124	546	1
2003	3687	11900	15354	458	1.1	761	713	2003	328	1261	1
2004	3337	13754	14312	340	1.4	1069	859	2004	428	789	1
2005	4191	16484	16141	436	0.8	691	517	2005	269	947	1
2006	4235	14350	15512	406	1	815	652	2006	326	1031	1
2007	3957	12172	16109	203	1	701	677	2007	306	890	1
2008	3388	12956	14548	263	1	713	611	2008	294		1

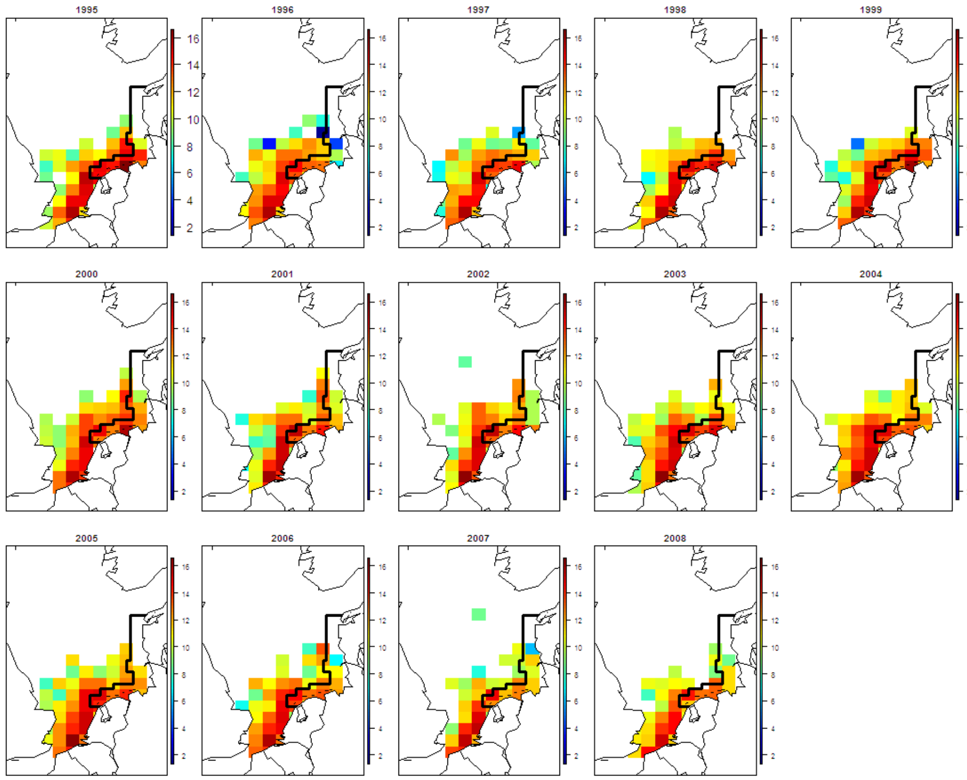
Table AppChpt4.3.4 Discard rates for plaice in flatfish and mixed fisheries, country The Netherlands, by month , year and ICES square.

Country	metier	powercat	Effect	N	Mean discard rate landings %	Level of month	Level of statsq	Level of year
NLD	BEAM80-89	=<221kW	year	5	1.36			2000
NLD	BEAM80-89	=<221kW	year	2	195.79			2001
NLD	BEAM80-89	=<221kW	year	4	4.38			2003
NLD	BEAM80-89	=<221kW	month	2	195.79	4		
NLD	BEAM80-89	=<221kW	month	2	2.46	5		
NLD	BEAM80-89	=<221kW	month	7	1.64	6		
NLD	BEAM80-89	=<221kW	statsq	1	4.19		32F3	
NLD	BEAM80-89	=<221kW	statsq	1	0.30		33F3	
NLD	BEAM80-89	=<221kW	statsq	1	24.22		33F4	
NLD	BEAM80-89	=<221kW	statsq	3	37.23		34F4	
NLD	BEAM80-89	=<221kW	statsq	3	2.94		35F4	
NLD	BEAM80-89	=<221kW	statsq	1	12.17		35F5	
NLD	BEAM80-89	=<221kW	statsq	1	25.19		36F5	
NLD	BEAM80-89	>221kW	year	19	0.44			1999
NLD	BEAM80-89	>221kW	year	22	2.34			2000
NLD	BEAM80-89	>221kW	year	11	1.47			2001
NLD	BEAM80-89	>221kW	year	26	1.29			2002
NLD	BEAM80-89	>221kW	year	34	4.41			2003
NLD	BEAM80-89	>221kW	month	9	2.33	1		
NLD	BEAM80-89	>221kW	month	4	0.39	2		
NLD	BEAM80-89	>221kW	month	18	0.88	3		
NLD	BEAM80-89	>221kW	month	14	2.46	4		
NLD	BEAM80-89	>221kW	month	16	2.03	5		
NLD	BEAM80-89	>221kW	month	11	19.47	6		
NLD	BEAM80-89	>221kW	month	8	2.80	7		
NLD	BEAM80-89	>221kW	month	8	2.56	8		
NLD	BEAM80-89	>221kW	month	10	0.74	9		
NLD	BEAM80-89	>221kW	month	3	11.85	10		
NLD	BEAM80-89	>221kW	month	11	0.80	11		
NLD	BEAM80-89	>221kW	statsq	2	1.70		32F2	
NLD	BEAM80-89	>221kW	statsq	4	2.71		32F3	
NLD	BEAM80-89	>221kW	statsq	3	2.43		33F2	
NLD	BEAM80-89	>221kW	statsq	11	2.76		33F3	
NLD	BEAM80-89	>221kW	statsq	2	2.17		33F4	
NLD	BEAM80-89	>221kW	statsq	5	3.24		34F2	
NLD	BEAM80-89	>221kW	statsq	7	3.32		34F3	
NLD	BEAM80-89	>221kW	statsq	4	4.29		34F4	
NLD	BEAM80-89	>221kW	statsq	1	2.71		35F1	
NLD	BEAM80-89	>221kW	statsq	5	1.74		35F2	
NLD	BEAM80-89	>221kW	statsq	7	5.40		35F3	
NLD	BEAM80-89	>221kW	statsq	4	3.77		35F4	
NLD	BEAM80-89	>221kW	statsq	3	0.85		36F1	
NLD	BEAM80-89	>221kW	statsq	4	0.38		36F2	
NLD	BEAM80-89	>221kW	statsq	1	0.67		36F3	
NLD	BEAM80-89	>221kW	statsq	5	10.83		36F4	
NLD	BEAM80-89	>221kW	statsq	3	9.26		36F5	
NLD	BEAM80-89	>221kW	statsq	1	183.29		36F6	
NLD	BEAM80-89	>221kW	statsq	1	62.84		36F7	
NLD	BEAM80-89	>221kW	statsq	3	0.49		37F1	
NLD	BEAM80-89	>221kW	statsq	4	0.09		37F2	
NLD	BEAM80-89	>221kW	statsq	2	3.34		37F5	
NLD	BEAM80-89	>221kW	statsq	3	13.72		37F6	
NLD	BEAM80-89	>221kW	statsq	1	862.29		37F7	
NLD	BEAM80-89	>221kW	statsq	1	0.77		38F1	
NLD	BEAM80-89	>221kW	statsq	2	0.11		38F2	
NLD	BEAM80-89	>221kW	statsq	2	0.45		38F3	
NLD	BEAM80-89	>221kW	statsq	4	2.93		38F6	
NLD	BEAM80-89	>221kW	statsq	2	1.22		38F7	
NLD	BEAM80-89	>221kW	statsq	3	0.15		39F3	
NLD	BEAM80-89	>221kW	statsq	3	1.55		39F6	
NLD	BEAM80-89	>221kW	statsq	3	1.98		39F7	
NLD	BEAM80-89	>221kW	statsq	1	0.08		40F3	
NLD	BEAM80-89	>221kW	statsq	1	0.25		40F4	
NLD	BEAM80-89	>221kW	statsq	1	0.15		40F5	
NLD	BEAM80-89	>221kW	statsq	2	0.62		40F6	
NLD	BEAM80-89	>221kW	statsq	1	1.90		40F7	
NLD	OTTER100-119	=<221kW	year	2	3.90			2003
NLD	OTTER100-119	=<221kW	month	2	3.90	7		
NLD	OTTER100-119	=<221kW	statsq	1	3.55		38F5	
NLD	OTTER100-119	=<221kW	statsq	1	6.14		38F6	
NLD	OTTER100-119	>221kW	year	4	2.21			2003
NLD	OTTER100-119	>221kW	month	4	2.21	9		
NLD	OTTER100-119	>221kW	statsq	1	2.05		38F4	
NLD	OTTER100-119	>221kW	statsq	1	0.98		39F4	
NLD	OTTER100-119	>221kW	statsq	1	3.71		39F5	
NLD	OTTER100-119	>221kW	statsq	1	1.98		40F5	
NLD	OTTER80-89	>221kW	year	3	1.53			2001
NLD	OTTER80-89	>221kW	month	3	1.53	3		
NLD	OTTER80-89	>221kW	statsq	1	3.47		37F3	
NLD	OTTER80-89	>221kW	statsq	1	1.13		37F4	
NLD	OTTER80-89	>221kW	statsq	1	0.92		38F3	

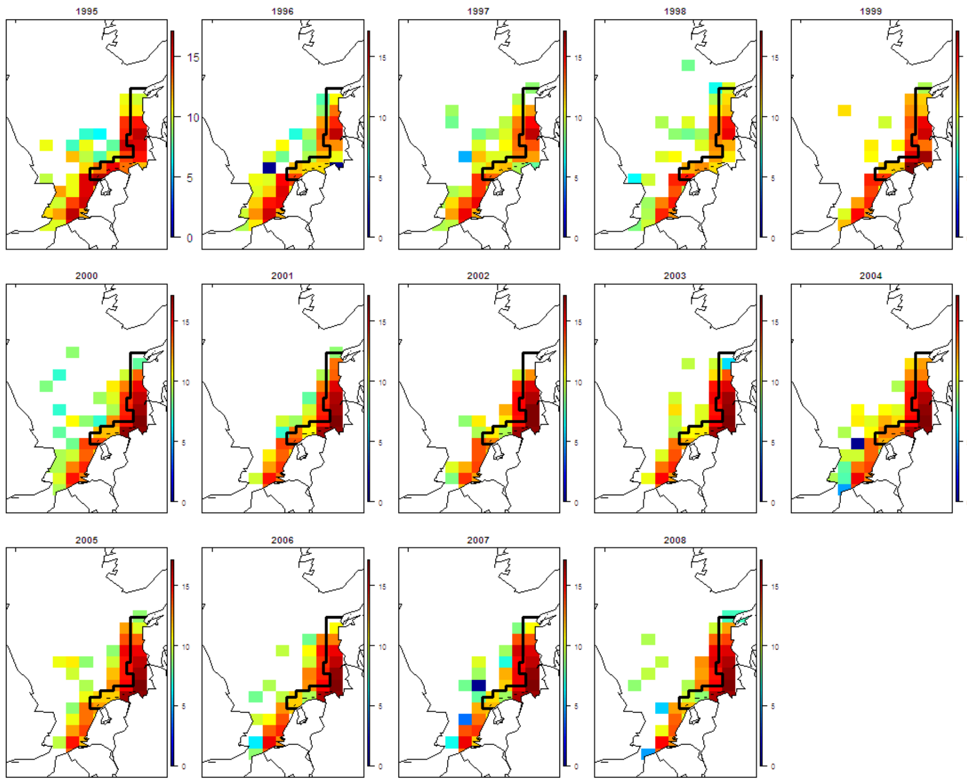
Table AppChpt4.3.5 Slope-slope regressions for the conversion of the Dutch VMS sub-sample to full VMS effort by year, metier and ICES square.

year	metier	power	ICES square	kWhours-VMS slope GER	Adjusted r-squared	kWhours-VMS slope NLD	Adjusted r-squared	Slope-slope ratio = conversion factor
2005	BEAM.16-31	<=221kW	34F4	350.56	0.89658	666.37	0.86103	1.901
2005	BEAM.16-31	<=221kW	35F4	339.59	0.9315	3435.24	0.66778	10.116
2005	BEAM.16-31	<=221kW	37F7	285.37	0.85112	8153.17	0.98712	28.57
2005	BEAM.16-31	<=221kW	38F7	183.38	0.96804	4044.3	0.39274	22.055
2005	BEAM.16-31	<=221kW	38F8	387.85	0.96618	373.38	0.90797	0.963
2005	BEAM.16-31	<=221kW	39F7	400.47	0.9482	782.91	0.53963	1.955
2005	BEAM.16-31	<=221kW	40F7	300.08	0.98754	1338.42	0.59364	4.46
2006	BEAM.16-31	<=221kW	34F4	258.09	0.99847	933.13	0.68818	3.616
2006	BEAM.16-31	<=221kW	35F4	599.85	0.72398	1530.76	0.95238	2.552
2006	BEAM.16-31	<=221kW	38F7	274.59	0.88606	560.58	-0.21733	2.042
2007	BEAM.16-31	<=221kW	35F4	242.97	0.9249	2061.24	0.67189	8.484
2007	BEAM.16-31	<=221kW	38F7	207.84	0.89919	451.82	0.92179	2.174
2007	BEAM.16-31	<=221kW	39F7	271.18	0.93353	734.78	0.64576	2.71
2008	BEAM.16-31	<=221kW	34F4	189.42	0.93482	1281.78	0.58627	6.767
2008	BEAM.16-31	<=221kW	35F4	249.81	0.99395	833.78	0.6777	3.338
2005	BEAM.80-99	<=221kW	32F2	1069.39	0.43298	8037.14	0.70232	7.516
2005	BEAM.80-99	<=221kW	33F3	703.51	0.72067	1238.83	0.79013	1.761
2005	BEAM.80-99	<=221kW	35F3	224.79	0.95965	4625.52	0.23811	20.577
2005	BEAM.80-99	<=221kW	35F4	108.03	0.72918	297.47	0.74423	2.753
2005	BEAM.80-99	<=221kW	36F3	79.83	0.76102	158.32	0.46818	1.983
2005	BEAM.80-99	<=221kW	36F4	406.02	0.72277	488.18	0.23487	1.202
2005	BEAM.80-99	<=221kW	36F5	286.68	0.95074	484.61	0.55584	1.69
2005	BEAM.80-99	<=221kW	36F7	486.88	0.97534	3717.76	0.33884	7.636
2005	BEAM.80-99	<=221kW	37F4	230.68	0.80478	958.58	0.43168	4.155
2005	BEAM.80-99	<=221kW	37F5	166.26	0.91102	312.17	0.0294	1.878
2005	BEAM.80-99	<=221kW	38F4	212.02	0.84545	3273.26	0.92545	15.439
2006	BEAM.80-99	<=221kW	34F3	926.88	0.9553	4039.34	0.87001	4.358
2006	BEAM.80-99	<=221kW	34F4	534.65	0.04826	396.82	0.83501	0.742
2006	BEAM.80-99	<=221kW	35F4	319.28	0.87351	302.66	0.45845	0.948
2006	BEAM.80-99	<=221kW	36F3	369.95	0.81131	1199.9	0.7941	3.243
2006	BEAM.80-99	<=221kW	36F4	420.13	0.75134	1206.83	0.68386	2.873
2006	BEAM.80-99	<=221kW	36F5	242.71	0.78588	415.01	0.49506	1.71
2006	BEAM.80-99	<=221kW	36F7	461.79	0.96953	193.68	0.30395	0.419
2006	BEAM.80-99	<=221kW	37F4	191.03	0.60959	1129.29	0.85159	5.912
2006	BEAM.80-99	<=221kW	37F5	523.92	0.84382	348.83	0.21838	0.666
2006	BEAM.80-99	<=221kW	37F7	298.92	0.93945	16570.39	0.80868	55.434
2006	BEAM.80-99	<=221kW	38F6	203.75	0.89087	358.31	0.75763	1.759
2006	BEAM.80-99	<=221kW	39F7	230.7	0.97131	833.38	0.34515	3.612
2007	BEAM.80-99	<=221kW	35F4	454.03	0.96981	200.62	0.76777	0.442
2007	BEAM.80-99	<=221kW	36F4	479.1	0.77389	1298.09	0.60259	2.709
2007	BEAM.80-99	<=221kW	36F5	409.8	0.8321	985.39	0.83568	2.405
2007	BEAM.80-99	<=221kW	37F4	907.23	0.21587	586.21	0.43674	0.646
2008	BEAM.80-99	<=221kW	35F4	411.77	0.69259	104.98	0.4572	0.255
2008	BEAM.80-99	<=221kW	36F3	304.2	0.85111	318.21	0.66864	1.046
2008	BEAM.80-99	<=221kW	36F4	319.86	0.97501	574.02	0.97137	1.795
2008	BEAM.80-99	<=221kW	36F5	203.99	0.90239	309.67	0.59667	1.518
2008	BEAM.80-99	<=221kW	36F7	479.9	0.98939	368.92	0.6665	0.769
2008	BEAM.80-99	<=221kW	37F7	351.42	0.98467	96.02	0.60157	0.273
2005	BEAM.80-99	>221kW	33F3	1239.32	0.42936	4718.52	0.63585	3.807
2005	BEAM.80-99	>221kW	33F4	3690.11	0.85465	1144.95	0.4272	0.31
2005	BEAM.80-99	>221kW	34F3	817.74	0.34193	3390.52	0.56968	4.146
2005	BEAM.80-99	>221kW	34F4	1047.83	0.80664	3108.63	0.54071	2.967
2005	BEAM.80-99	>221kW	35F3	1536.94	0.83579	5408.87	0.58342	3.519
2005	BEAM.80-99	>221kW	35F4	1107	0.87738	3103.75	0.5008	2.804
2005	BEAM.80-99	>221kW	36F2	1481.64	0.88219	5164.98	0.69206	3.486
2005	BEAM.80-99	>221kW	36F3	1826.36	0.89107	6174.93	0.55378	3.381
2005	BEAM.80-99	>221kW	36F4	1408.66	0.96147	9983.59	0.52284	7.087
2005	BEAM.80-99	>221kW	36F5	1988.37	0.83194	9668.44	0.53783	4.862
2005	BEAM.80-99	>221kW	37F1	1766.29	0.95661	6166.88	0.8165	3.491
2005	BEAM.80-99	>221kW	37F2	2348.31	0.43744	5365.92	0.43532	2.285
2005	BEAM.80-99	>221kW	37F3	3206.7	0.74229	5534.96	0.68029	1.726
2005	BEAM.80-99	>221kW	37F4	1976.38	0.94046	5659.94	0.26789	2.864
2005	BEAM.80-99	>221kW	37F5	1247.14	0.78562	11535.63	0.74804	9.25
2005	BEAM.80-99	>221kW	37F6	1915.58	0.94062	8991.39	0.54711	4.694
2005	BEAM.80-99	>221kW	37F7	656.74	0.71244	5739.3	0.88013	8.739
2005	BEAM.80-99	>221kW	38F5	630.51	0.54631	5085.68	0.65741	8.066
2005	BEAM.80-99	>221kW	38F6	1549.96	0.98021	4349.36	0.51287	2.806
2005	BEAM.80-99	>221kW	39F7	5663.04	0.70455	9000.5	0.58244	1.589
2006	BEAM.80-99	>221kW	33F3	1056.28	0.78689	2753.58	0.94835	2.607
2006	BEAM.80-99	>221kW	33F4	1792.23	0.8986	343.34	0.47864	0.192
2006	BEAM.80-99	>221kW	34F3	1330.66	0.85826	2564.17	0.95551	1.927
2006	BEAM.80-99	>221kW	34F4	1238.58	0.7465	1537.21	0.89006	1.241
2006	BEAM.80-99	>221kW	35F2	2596.66	0.86208	3748.51	0.98396	1.444
2006	BEAM.80-99	>221kW	35F3	1344.04	0.91821	3075.66	0.96491	2.288
2006	BEAM.80-99	>221kW	35F4	1529.51	0.87965	1694.79	0.92502	1.108
2006	BEAM.80-99	>221kW	36F2	1714.43	0.92252	2948.87	0.91811	1.72
2006	BEAM.80-99	>221kW	36F3	1590.38	0.97581	3028.6	0.5726	1.904
2006	BEAM.80-99	>221kW	36F4	1569.62	0.96907	5299.86	0.90759	3.377
2006	BEAM.80-99	>221kW	36F5	2064.68	0.96335	3159.97	0.81669	1.53
2006	BEAM.80-99	>221kW	37F1	1222.44	0.14189	3620.48	0.86469	2.962
2006	BEAM.80-99	>221kW	37F2	5043.3	0.89361	3596.73	0.64557	0.713
2006	BEAM.80-99	>221kW	37F3	1723.33	0.71704	3917.19	0.64855	2.273
2006	BEAM.80-99	>221kW	37F4	1534.25	0.96581	3204.59	0.54152	2.089
2006	BEAM.80-99	>221kW	37F5	1497.3	0.85228	3921.72	0.91769	2.619
2006	BEAM.80-99	>221kW	37F6	2197.93	0.81284	4922.24	0.8939	2.239
2006	BEAM.80-99	>221kW	37F7	1021.39	0.58299	2771.74	0.94212	2.714
2006	BEAM.80-99	>221kW	38F5	1911.84	0.95046	2514.38	0.66791	1.315
2006	BEAM.80-99	>221kW	38F6	1381.25	0.81778	3334.91	0.95483	2.414
2006	BEAM.80-99	>221kW	39F6	2272.29	0.99653	2719.12	0.9318	1.197
2006	BEAM.80-99	>221kW	39F7	4608.23	0.97947	2197.29	0.48805	0.477
2006	BEAM.80-99	>221kW	40F7	2413.25	0.17197	2076.76	0.82781	0.861
2007	BEAM.80-99	>221kW	33F4	2967.49	0.9845	347.28	0.77318	0.117
2007	BEAM.80-99	>221kW	34F3	1349.55	0.99993	2497.45	0.96474	1.851
2007	BEAM.80-99	>221kW	34F4	778.44	0.69762	1245.01	0.83546	1.599
2007	BEAM.80-99	>221kW	35F2	1967.9	0.99984	3752.98	0.97622	1.907
2007	BEAM.80-99	>221kW	35F3	1435.29	0.80429	2899.43	0.97972	2.02
2007	BEAM.80-99	>221kW	35F4	1182.72	0.93297	1945.58	0.91272	1.645
2007	BEAM.80-99	>221kW	36F2	1557.46	0.75958	3428.74	0.89238	2.201
2007	BEAM.80-99	>221kW	36F3	1274.98	0.9699	3590.01	0.9446	2.816
2007	BEAM.80-99	>221kW	36F4	1603.86	0.96819	5721.07	0.93415	3.567
2007	BEAM.80-99	>221kW	36F5	1336.96	0.63791	2833.58	0.7747	2.119
2007	BEAM.80-99	>221kW	37F2	2896.13	0.81367	3739.68	0.92055	1.291
2007	BEAM.80-99	>221kW	37F3	1585.16	0.62769	3082.05	0.92492	1.944
2007	BEAM.80-99	>221kW	37F4	2004.27	0.9589	4461.81	0.9386	2.226
2007	BEAM.80-99	>221kW	37F5	1837.28	0.9665	4432	0.95017	2.412
2007	BEAM.80-99	>221kW	37F6	1350.22	0.96004	4452.1	0.96392	3.297
2007	BEAM.80-99	>221kW	38F4	955.34	0.78137	2707.64	0.52448	2.834
2007	BEAM.80-99	>221kW	38F5	1111.49	0.51165	2915.92	0.807	2.623
2007	BEAM.80-99	>221kW	39F6	4489.07	0.77318	1582.44	0.38809	0.353
2008	BEAM.80-99	>221kW	35F3	1517.86	0.99846	2489.95	0.90766	1.64
2008	BEAM.80-99	>221kW	35F4	769.73	0.79718	1314.09	0.80704	1.707
2008	BEAM.80-99	>221kW	36F2	3155.69	0.7517	3044.51	0.84414	0.965
2008	BEAM.80-99	>221kW	36F3	1322.75	0.86672	2810.05	0.96142	2.124
2008	BEAM.80-99	>221kW	36F4	1878.95	0.94435	4807.51	0.9334	2.559
2008	BEAM.80-99	>221kW	36F5	1593.88	0.89566	2340.29	0.69608	1.468
2008	BEAM.80-99	>221kW	37F2	3356.91	0.91111	3052.85	0.90866	0.909
2008	BEAM.80-99	>221kW	37F4	1703.53	0.86582	4016.8	0.77089	2.358
2008	BEAM.80-99	>221kW	37F5	1579.72	0.8652	3201.17	0.7741	2.026
2008	BEAM.80-99	>221kW	37F6	1271.9	0.80286	3849.2	0.97054	3.026
2008	BEAM.80-99	>221kW	37F7	2320.07	0.99751	2402.47	0.92914	1.036
2008	BEAM.80-99	>221kW	38F4	1267.95	0.51908	3238.36	0.92037	2.554
2008	BEAM.80-99	>221kW	38F5	763.03	0.62425	3036.72	0.87973	3.98
2005	OTTER.100-119	>221kW	38F3	717.55	0.53552	2454.93	0.46067	3.421
2005	OTTER.100-119	>221kW	39F4	778.02	-0.14876	1599.83	0.7143	2.056

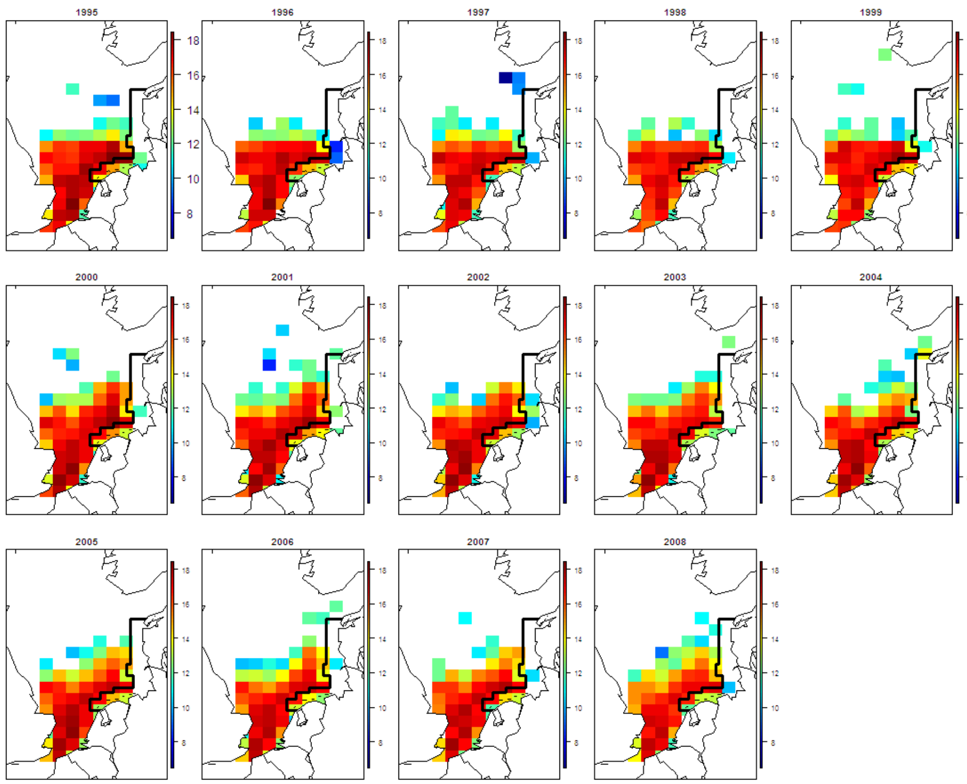
2005	OTTER.80-99	<=221kW	35F3	137.49	-0.56481	22970.19	0.26342	167.07
2005	OTTER.80-99	<=221kW	35F4	174.1	0.88164	16.37	-0.49066	0.094
2005	OTTER.80-99	<=221kW	36F2	231.83	0.82198	531.42	0.98379	2.292
2005	OTTER.80-99	<=221kW	36F3	254.95	0.55959	1037.72	0.50886	4.07
2005	OTTER.80-99	<=221kW	36F4	246.05	0.63586	1743.61	0.36376	7.086
2005	OTTER.80-99	<=221kW	36F5	326.57	0.95545	777.06	0.22634	2.379
2005	OTTER.80-99	<=221kW	37F2	295.59	0.44965	1446.97	0.16441	4.895
2005	OTTER.80-99	<=221kW	39F7	259.74	0.9851	1941.43	0.80784	7.475
2006	OTTER.80-99	<=221kW	35F4	1140.02	0.92413	261.54	-0.00965	0.229
2006	OTTER.80-99	<=221kW	36F2	1121.65	0.59884	394.76	0.57023	0.352
2006	OTTER.80-99	<=221kW	36F3	264.95	0.96101	565.41	0.45988	2.134
2006	OTTER.80-99	<=221kW	36F4	200.89	0.80167	1644.54	0.73573	8.186
2006	OTTER.80-99	<=221kW	36F5	212.55	0.92467	1600.1	0.60509	7.528
2006	OTTER.80-99	<=221kW	37F2	295.1	0.81977	805.94	0.7557	2.731
2006	OTTER.80-99	<=221kW	37F4	332.39	0.98485	4507.54	0.51999	13.561
2006	OTTER.80-99	<=221kW	37F5	257.96	0.86713	4423.85	0.94659	17.15
2006	OTTER.80-99	<=221kW	38F6	228.12	0.91368	107.78	-0.70295	0.472
2006	OTTER.80-99	<=221kW	39F6	413.61	0.97987	867.22	0.70519	2.097
2006	OTTER.80-99	<=221kW	40F5	262.88	0.93808	1959.47	0.60966	7.454
2006	OTTER.80-99	<=221kW	40F6	749.45	0.64095	1198.96	0.99965	1.6
2007	OTTER.80-99	<=221kW	36F2	232.64	0.68309	764.28	0.4018	3.285
2007	OTTER.80-99	<=221kW	36F3	314.47	0.97904	802.33	0.85449	2.551
2007	OTTER.80-99	<=221kW	36F4	208.34	0.63904	2085.57	0.03787	10.01
2007	OTTER.80-99	<=221kW	36F5	133.18	0.69126	2607.53	0.63119	19.579
2007	OTTER.80-99	<=221kW	37F2	329.51	0.95619	232.94	0.37698	0.707
2007	OTTER.80-99	<=221kW	37F4	299.74	0.9851	1319.31	-0.09273	4.401
2007	OTTER.80-99	<=221kW	37F5	241.94	0.56263	366.2	-0.19925	1.514
2007	OTTER.80-99	<=221kW	38F6	184.39	0.91647	2733.7	0.11213	14.825
2007	OTTER.80-99	<=221kW	39F6	354.84	0.99239	1719.73	0.8688	4.847
2007	OTTER.80-99	<=221kW	40F5	294.59	0.97996	1045.33	0.80811	3.548
2007	OTTER.80-99	<=221kW	40F6	269.62	0.87113	1996.82	-0.13763	7.406
2007	OTTER.80-99	<=221kW	41F5	225.89	0.94851	644.24	-0.06873	2.852
2008	OTTER.80-99	<=221kW	36F2	408.23	0.94037	2007.25	0.66998	4.917
2008	OTTER.80-99	<=221kW	36F3	224.27	0.73009	1122.12	-0.12853	5.003
2008	OTTER.80-99	<=221kW	36F4	510.05	0.93505	1182.09	0.94694	2.318
2008	OTTER.80-99	<=221kW	37F2	285.17	0.92191	470.21	0.80902	1.649
2008	OTTER.80-99	<=221kW	37F4	328.57	0.84296	1040.92	0.8501	3.168
2008	OTTER.80-99	<=221kW	37F5	174.35	0.98052	779.05	0.98243	4.468
2008	OTTER.80-99	<=221kW	39F5	372.06	0.87261	751.24	0.5531	2.019
2008	OTTER.80-99	<=221kW	39F6	306.72	0.94848	1347.77	0.82434	4.394
2008	OTTER.80-99	<=221kW	40F5	398.42	0.88986	1160.26	0.91456	2.912
2008	OTTER.80-99	<=221kW	40F6	502.57	0.70499	822.55	0.96436	1.637
2005	OTTER.80-99	>221kW	34F4	578.49	0.94006	927.99	0.79621	1.604
2005	OTTER.80-99	>221kW	36F3	1107.96	0.33726	350.56	0.24195	0.316
2005	OTTER.80-99	>221kW	36F4	8213.57	0.08034	1571.54	0.86709	0.191
2005	OTTER.80-99	>221kW	37F2	578.88	0.67645	2501.13	-0.05695	4.321
2005	OTTER.80-99	>221kW	37F3	563.73	0.93288	1167.37	0.21875	2.071
2005	OTTER.80-99	>221kW	37F4	1456.22	0.30115	514.37	0.95671	0.353
2005	OTTER.80-99	>221kW	38F4	545.7	0.68507	2391.13	0.99037	4.382
2006	OTTER.80-99	>221kW	34F4	407.16	0.99912	243.95	0.49285	0.599
2006	OTTER.80-99	>221kW	35F3	2581.15	1	88.5	0.03624	0.034
2006	OTTER.80-99	>221kW	36F3	1438.75	0.98018	320.61	0.67502	0.223
2006	OTTER.80-99	>221kW	36F4	823.32	0.57265	183.68	0.56165	0.223
2006	OTTER.80-99	>221kW	37F2	291.56	0.95803	1327.5	0.68085	4.553
2006	OTTER.80-99	>221kW	37F3	668.99	0.74742	1682.5	0.99115	2.515
2006	OTTER.80-99	>221kW	37F4	1236.82	0.99302	255.11	0.24488	0.206
2006	OTTER.80-99	>221kW	39F6	1569.93	0.90401	1516.55	0.61405	0.966
2006	OTTER.80-99	>221kW	40F5	1787.33	0.90059	766.64	0.55929	0.429
2007	OTTER.80-99	>221kW	36F2	904.66	0.62324	2217.02	0.78374	2.451
2007	OTTER.80-99	>221kW	36F3	1311.04	0.75264	239.57	0.59869	0.183
2007	OTTER.80-99	>221kW	36F4	1452.2	0.93448	80.64	0.41309	0.056
2007	OTTER.80-99	>221kW	37F2	976.17	0.9369	1652.99	0.88078	1.693
2007	OTTER.80-99	>221kW	37F4	1196.15	0.97841	84.56	0.60987	0.071
2007	OTTER.80-99	>221kW	37F5	3504.85	0.82534	175.39	0.89537	0.05
2007	OTTER.80-99	>221kW	37F6	664.44	0.46063	374.1	0.33073	0.563
2007	OTTER.80-99	>221kW	38F5	680.98	0.4227	1867.02	0.79182	2.742
2007	OTTER.80-99	>221kW	38F6	1278.38	0.63078	542.89	0.4626	0.425
2007	OTTER.80-99	>221kW	39F6	1081	0.93085	1264.53	0.81113	1.17
2007	OTTER.80-99	>221kW	40F5	743.29	0.31478	896.8	0.92923	1.207
2007	OTTER.80-99	>221kW	40F6	1423.7	0.76126	626.49	0.97985	0.44
2007	OTTER.80-99	>221kW	41F5	757.17	-0.11168	733.79	0.89888	0.969
2008	OTTER.80-99	>221kW	36F3	765.58	0.97803	388.7	0.77305	0.508
2008	OTTER.80-99	>221kW	36F4	937.14	0.89776	87.91	0.3347	0.094
2008	OTTER.80-99	>221kW	37F2	262.05	0.63568	1018.3	0.57959	3.886
2008	OTTER.80-99	>221kW	37F3	878.68	0.58341	1107.98	0.37789	1.261
2008	OTTER.80-99	>221kW	37F4	1500.85	0.99742	158.74	0.46488	0.106
2008	OTTER.80-99	>221kW	37F5	1218.12	0.5527	304.43	0.74762	0.25
2008	OTTER.80-99	>221kW	39F5	1180.36	0.56062	2608.31	0.34526	2.21
2008	OTTER.80-99	>221kW	39F6	1012.49	0.85604	1415.21	0.40666	1.398
2008	OTTER.80-99	>221kW	40F5	1099.18	0.8746	2095.06	0.54491	1.906
2008	OTTER.80-99	>221kW	40F6	1905.26	0.88734	2961.79	0.24944	1.555



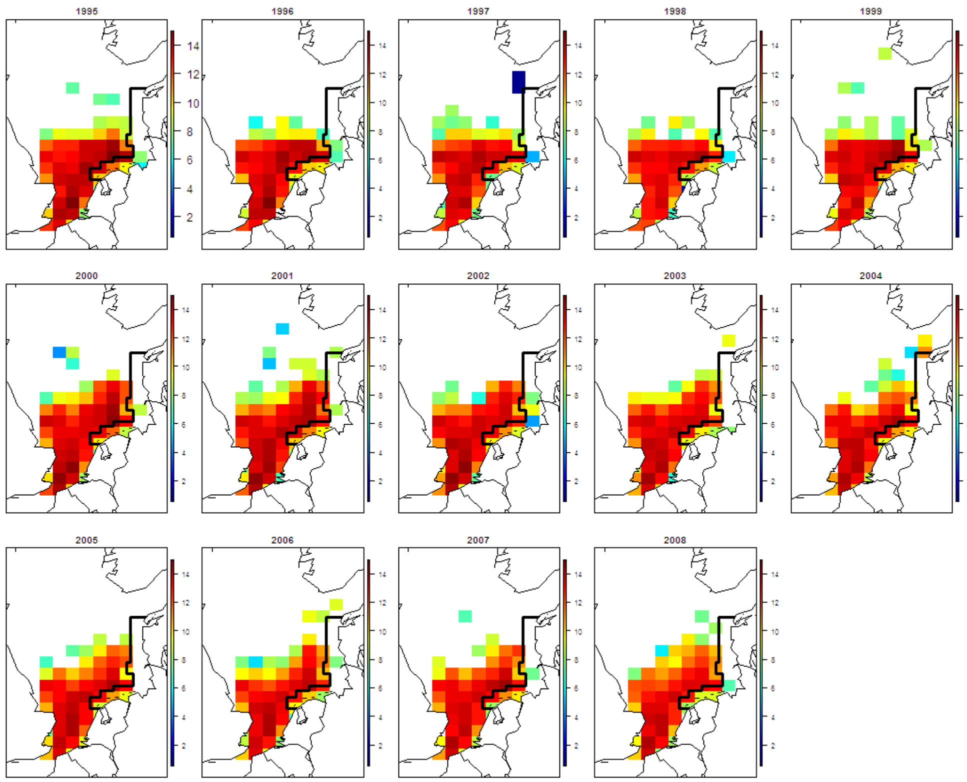
AppChpt4.Figure 1: Fishing effort (log kwhours) for Beam trawlers 80-99mm mesh, lt 221kw between 1995 and 2008.



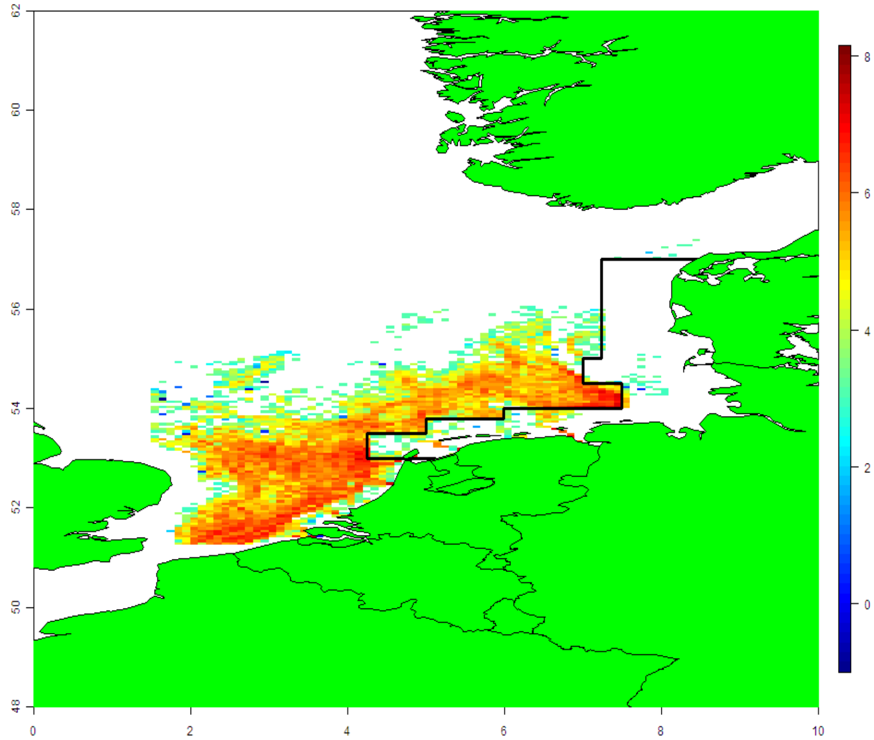
AppChpt4.Figure 2: Fishing effort (log kwhours) for shrimp Beam trawlers 16-32mm mesh, lt 221kW between 1995 and 2008.



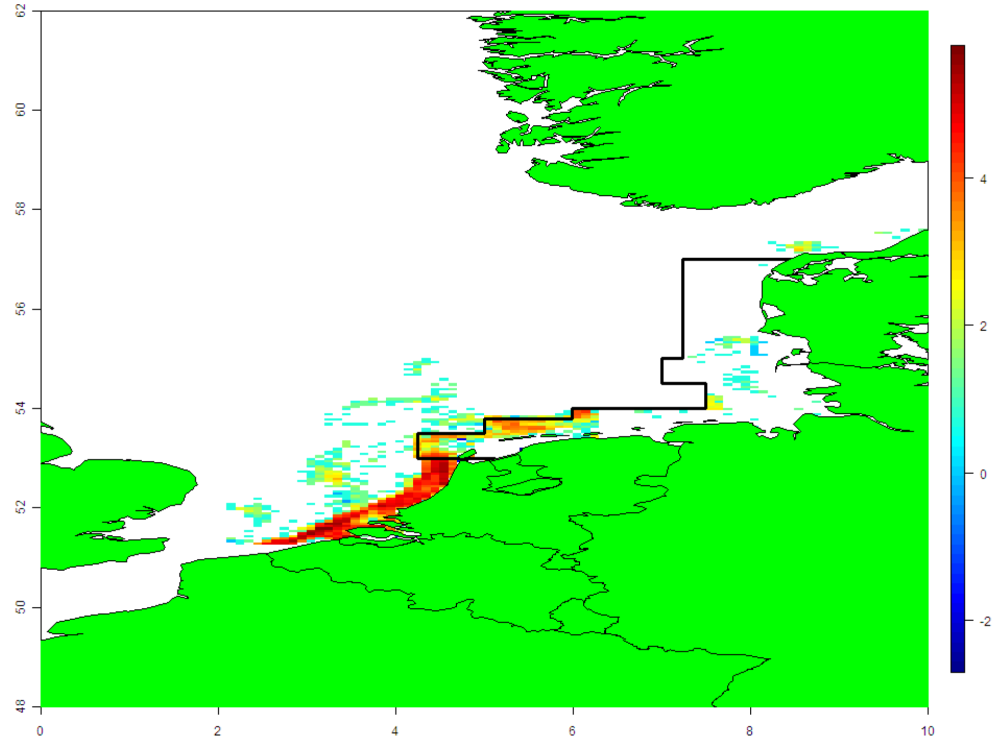
AppChpt4.Figure 3: Fishing effort (log kwhours) for beam trawlers 80-99mm mesh, gt 221kW between 1995 and 2008.



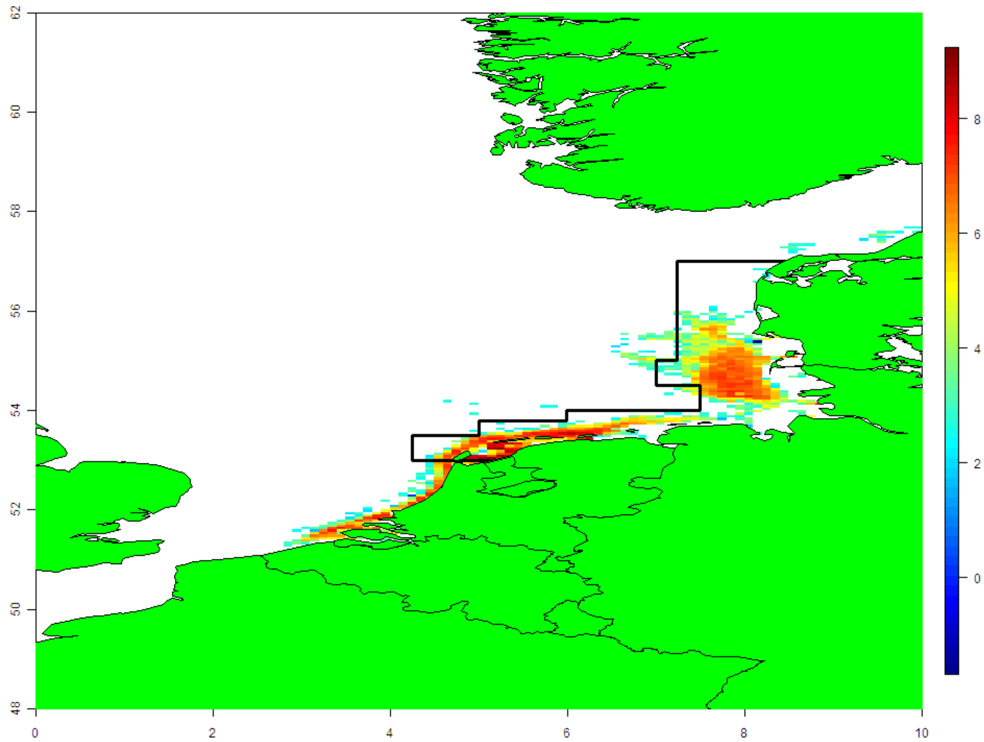
AppChpt4.Figure 4. Plaice landings for Beam trawlers 80-99mm mesh, gt 221kW between 1995 and 2008.



AppChpt4.Figure 5: Dutch VMS data 2008 for larger Beam trawlers 80-99mm mesh gt 221kW.



AppChpt4.Figure 6: Dutch VMS data 2008 for small Beam trawlers 80-99mm mesh lt 221kW



AppChpt4.Figure 7. Dutch VMS data 2008 for small shrimp beam trawlers 16-32mm me

Appendix to Chapter 6

ANOVA Tables summarizing models fitted to BTS data for plaice abundance (nos hr-1) in Chapter 6 as a function of year, year, and year*b4 where b4 is a dummy variable indicating whether an observation was made before 1995 or after. The areas 'in-in', 'in-out', 'out-in' and 'out-out' are described in Chapter 6. Models selected are in bold font.

Table A6.1: Age 1s in-in

model	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	21	32.5	NA	NA	NA	NA
y~year	**20**	**5.23**	**1**	**27.34**	**110.30**	**0.0**
y~year+b4	19	4.50	1	0.73	2.95	0.1
y~year*b4	18	4.46	1	0.04	0.15	0.7

Table A6.2. Age 1s in-out

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	21	5.54	NA	NA	NA	NA
y~year	**20**	**4.40**	**1**	**1.15**	**5.32**	**0.03**
y~year+b4	19	3.88	1	0.52	2.41	0.14
y~year*b4	18	3.88	1	0.00	0.00	0.98

Table A6.3. Age 1s out-in

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	**21**	**10.8**	**NA**	**NA**	**NA**	**NA**
y~year	20	10.8	1	0.01	0.01	0.90
y~year+b4	19	10.3	1	0.43	0.84	0.37
y~year*b4	18	9.08	1	1.30	2.58	0.13

Table A6.4. Age1s out-out

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	21	27.4	NA	NA	NA	NA
y~year	**20**	**5.39**	**1**	**22.08**	**80.59**	**0.00**
y~year+b4	19	5.34	1	0.05	0.18	0.67
y~year*b4	18	4.93	1	0.41	1.50	0.24

Table A6.5. Age 5s in-in

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	21	36.3	NA	NA	NA	NA
y~year	**20**	**16.7**	**1**	**19.66**	**21.85**	**0.00**
y~year+b4	19	16.2	1	0.51	0.57	0.46
y~year*b4	18	16.1	1	0.03	0.04	0.85

Table A6.6. Age 5s in-out

	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	**21**	**17.**	**NA**	**NA**	**NA**	**NA**
y~year	20	17.	1	0.01	0.02	0.90
y~year+b4	19	16.	1	1.88	2.13	0.16
y~year*b4	18	15.	1	0.14	0.16	0.69

Table A6.6. Age 5s out-in

	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	**21**	**19.**	**NA**	**NA**	**NA**	**NA**
y~year	20	19.	1	0.42	0.44	0.52
y~year+b4	19	19.	1	0.07	0.08	0.79
y~year*b4	18	17.	1	1.66	1.71	0.21

Table A6.7. Age 5s out-out

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	**21**	**19.2**	**NA**	**NA**	**NA**	**NA**
y~year	20	14.5	1	4.74	7.56	0.01
y~year+b4	19	13.6	1	0.86	1.37	0.26
y~year*b4	18	11.2	1	2.38	3.80	0.07

Table A6.8. Dutch fishing effort in the PB (y=kWhours)

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	18	4.485878e+1	NA	NA	NA	NA
y~year	**17**	**9.387087e+1**	**1**	**3.547169e+17**	**79.82**	**0.00**
y~year+b4	16	7.689187e+1	1	1.697900e+16	3.82	0.07
y~year*b4	15	6.666191e+1	1	1.022996e+16	2.30	0.15

Table A6.9. Dutch fishing effort outside the PB (y=kWhours)

	Res.	RSS	Df	Sum of Sq	F	Pr(>F)
y~1	18	6.616297e+1	NA	NA	NA	NA
y~year	**17**	**4.447398e+1**	**1**	**2.168899e+19**	**17.58**	**0.00**
y~year+b4	16	3.101523e+1	1	1.345876e+19	10.91	0.00
y~year*b4	15	1.850147e+1	1	1.251375e+19	10.15	0.01