IMPACT ASSESSMENT OF THE EFFECTS OF A SELECTED RANGE OF FISHING GEARS IN THE NORTH SEA

ILVO
TECHNISCH VISSERIJONDERZOEK

H. POLET
J. DEPESTELE

Report comissioned by Stichting Noordzee en WNF

Instituut voor Landbouw en Visserijonderzoek

Eenheid: Dier - Visserij

TECHNISCH VISSERIJONDERZOEK

Ankerstraat 1
B-8400 Oostende, België
Tel.: +32 59 342250
Fax: +32 59 330629
www.ilvo.vlaanderen.be

Sectie Technisch Visserijonderzoek

Hans Polet
(Coördinator)
hans.polet@ilvo.vlaanderen.be

Eddy Buyvoets
(Vistuig - Zeereizen)
eddy.buyvoets@ilvo.vlaanderen.be

Fernand Delanghe
(Technische ondersteuning - Zeereizen)
fernand.delanghe@ilvo.vlaanderen.be

Jochen Depestele
(Ecologie - Dataverwerking)
jochen.depestele@ilvo.vlaanderen.be

Kris Van Craeynest
(Adviesverlening - Dataverwerking)
kris.vancraeynest@ilvo.vlaanderen.be

Norbert Van Craeynest
(Vistuig - Schipper)
norbert.vancraeynest@ilvo.vlaanderen.be

Christian Vanden Berghe
(Meetapparatuur - Zeereizen)
christian.vandenberghe@ilvo.vlaanderen.be

Els Vanderperren
(Strategie - Visserijtechniek)
els.vanderperren@ilvo.vlaanderen.be

Kevin Vanhalst
(Databeheer - Mediabeheer)
kevin.vanhalst@ilvo.vlaanderen.be

Johny Vanhee
(Visserijtechniek - Zeereizen)
johny.vanhee@ilvo.vlaanderen.be

Dirk Verhaeghe
(Projectondersteuning - Zeereizen)
dirk.verhaeghe@ilvo.vlaanderen.be

Bart Verschueren
(Technologie - Meetapparatuur)
bart.verschueren@ilvo.vlaanderen.be

IMPACT ASSESSMENT OF THE EFFECTS OF A SELECTED RANGE OF FISHING GEARS IN THE NORTH SEA

August 2010

Authors

Hans Polet, Jochen Depestele

Contacts

Hans Polet

Comissioned by

Stichting Noordzee

WNF Nederland

Comissioned by Stichting Noordzee
and WNF

CONTENTS

SUMMARY

The environmental impact of fishing is still a widely discussed issue with conflicting opinions. There is, however, ample scientific evidence that fisheries can compromise the structure and functioning of marine ecosystems although the specific characteristics of the fishery will determine the nature and intensity of the impact. Discussions on the origin of the problem often focus on the choice of the fishing gear but the sustainability of a fishery is determined by a combination of factors, not only the gear.

The loss of habitats in relation to fisheries is increasingly becoming an important issue. This is well reflected in international and national legislation, such as the EU Habitats Directive (92/43/EEC) amongst others (ICES, 2009) and the installation of the Natura 2000 network. As species like sole, plaice, cod, whiting etc. are bottom dwelling species, usually in close contact with the seafloor, all commercial bottom fishing for these species potentially impact the seabed. The impact of physical contact of bottom trawls affects biological communities as well as the chemical and physical environment. A major challenge in ecosystems and resource management, however, is the judgment on the degree to which an impact is considered acceptable. Whereas for most fish stocks reference points have been defined, this is less clearly defined for benthic ecosystems. Another uncertainty related to fisheries impact is the concept of recovery and reversibility in ecosystems. In general there is incomplete and often little understanding of the likelihood and nature of recovery of marine systems from substantial perturbations. As such, evaluating ecosystem effects of fishing in an objective way is a difficult task.

Sustainability in fisheries is based on a number of principles that should all be complied with. Fishing is an economic activity that can only exist if it is profitable. Fishing methods should be efficient in catching fish and exploitation costs. Environmental impact should be low but "low" should be defined. Since it is unclear what the long term effects of fishing are, precaution tells us to keep the negative side effects of fishing at the lowest level possible. Side effects that can be perceived as positive, like a possible increase in productivity due to fishing, should be treated with caution. In general, a sound marine environment is the best guarantee for sound fish stocks in the long term. Since fisheries involve labor, social issues should not be neglected. The application of modern technology is necessary to keep the industry competitive and should be encouraged although issues like technological creep should be monitored in order to assess the change in catching capacity of the fleet. Finally, the sea is a complex and dynamic environment that is subject to short and long term changes not induced by human activity. A sustainable fishery should be able to adapt to these changes and setting up adaptation strategies can be an asset for the industry.

The choice of the fishing method is crucial for its direct impact and it will determine potential negative side effects of a fishery such as discarding and seafloor impact. This report makes an attempt to summarize a wide variety of literature dealing with environmental effects of different types of fishing gears used in the North Sea.

The flatfish fishery in the North Sea is a fishery in transition. The persistent criticism of the environmental impact of fishing through seabed impacts, discards, by-catch of marine mammals and impacts on seabirds has been an important driver. Beam trawling has been the focus of much criticism because of its impact on the seabed but several fishing methods have had their share of attention. Seafloor impact is also evident for otter trawling, and while the intensity of seabed impacts is less than for beam trawling, otter trawls affect a much larger surface area. Discarding is not an issue restricted to trawl fisheries. Set nets and demersal seines, as used today, also have selective characteristics that can lead to high discard rates and in mixed fisheries discarding can also arise as a result of quota restrictions or through high-grading. The incidental by-catch of marine mammals is a serious concern in certain set net fisheries, and while marine mammal populations in general are not threatened by such fisheries, this undoubtedly would become a problem if fishing effort were to increase significantly. Fishing also has consequences for seabirds. Some die through interaction with fishing gear but a major impact is caused by discarding of fish and offal which provide an important source of food for certain species. Initiatives like MSC accreditation have increased the pressure to fish in a more sustainable way. The desire for MSC accreditation is not so much consumer-driven, but the commercial interest of retailers who have a desire to promote "green fish" is forcing fishermen to become increasingly open to a change in fishing practices. However, the main driver for change in the North Sea flatfish fisheries, as became clear during the 2008 fuel crisis, which persisted for not much more than half a year, is the unpredictability of the fuel price which led to dramatic changes in the fleets exploiting flatfish. The fuel crisis provided the incentive to develop and adopt fuel saving techniques like the fuel consumption meter, the Sumwing, Dyneema netting and modernization of engine and propeller which have already resulted in a reduction in the fuel bill. Several vessels now tow different (lighter) gears like the outrigger trawl as an alternative for the beam trawl. Others have joined the passive fishing fleet like the Dutch MSC-labeled set netters. The flyshooting method has reappeared in a modern version. This new method is fuel efficient, produces premium quality fish and has low environmental impact. However there are indications that this method may be threatened because of its high fishing efficiency.

A wide mix of fishing methods is being used in the North Sea ranging from active gear like beam trawls, otter trawls, twinrigs, dredges and rope seines (flyshooting) and passive gear like set nets, pots and lines. In terms of fishery

characteristics and management there is a distinct separation between pelagic and demersal fisheries. The flatfish fishery in the North Sea is dominated, in terms of landings and fishing effort, by large vessels which deploy beam trawls. The 80mm mesh is "the" mesh size for the fishery targeting sole but is also important for plaice. The fishery generates positive operational profits (before taxes and financial costs) for each length class of vessel, each gear group and each mesh size group. When looking in detail at a finer métier level, there is a huge variation in profitability and some métiers make significant financial losses. The larger vessels using beam trawls generate most profit.

Larger vessels target flatfish which account for the vast majority of their landings and income. As vessels get smaller, the landings consist of an increasing variable mix of species. When comparing the amount of fuel and the amount of labor needed to generate a unit of income, it is clear that the larger vessels are strongly dependent on fuel while the smaller vessel depend more on labor. A similar conclusion can be made with regard to fishing method where a unit of income for beam trawlers is highly dependent on fuel cost and less on labor costs, compared to all other fishing methods.

Trawling, and especially beam trawling for flatfish, is known to be a fuel-intensive fishing technique. The nets can be relatively heavy, with numerous tickler chains running over the sea bed. In addition, the towing speed can be high (6-7 kts). Expressed in liters of fuel used per kg fish, this project indicated an average for the larger vessels of almost 4 liters/kg fish and according to van Marlen et al. (2008a), the maximum can be as high as 4.6. Rather volatile fuel prices, which led to fuel costs that equated to more than 40% of revenue in the past, put the economic viability of this sector at risk. At present, many actors in the fishing industry believe that there is a need to replace beam trawls with tickler chains by alternative, more fuel efficient and ecosystem-friendly fishing gears.

In general it can be concluded that set nets and demersal seines are fuel efficient compared to all trawling gears and especially compared to beam trawling.

Bottom impact and effects on the marine ecosystem were found to be considerable for beam trawls, although all towed gears significantly impact the seafloor and its communities. One of the main impacts of trawling on the marine environment is the homogenization of the sediment (removal of physical structure), which in turn leads to more homogeneous benthic communities. In general it can also be concluded that trawling reduces biomass, production and species diversity, with a higher sensitivity for the softer sediments and hard substrates. Sweeping the surface with trawls may affect biomass and production of epifauna and may reduce the abundance of sessile organisms. Penetration into the sediment may affect infauna by causing damage or direct mortality and by exposing the animals to predators. The impact of the first passage of a trawl has the greatest effect, while an increase of trawling effort on communities that were already heavily trawled had little additional effect on production or biomass for all habitats.

In soft-bottom ecosystems, benthic densities and species richness are heavily determined by the seabed characteristics and this benthic ecosystem component is important for the densities and species richness of higher trophic levels such as demersal fish and birds. These benthic environments are often under threat as fishing with mobile fishing gear is known to be a major cause of habitat deterioration in soft-bottom ecosystems.

In more dynamic sandy bottoms, the sediment can be quite mobile and unstable. Structuring elements of the ecosystem do, however, occur quite frequently and are called ecosystem engineers. These can form emergent structures in marine ecosystems that reach a few centimeters into the water column and can have a profound effect on the structure and functioning of marine ecosystems. The ecological effects of habitat structuring organisms lie in the increase of habitat complexity. They are well described for all kinds of marine environments: coral reefs, Darwin mounds, kelp forests, ascidians, sea grass meadows, mussel banks, oyster beds and polychaete tubes. Removal of ecosystem engineers by mobile bottom gear could have devastating effects on local biodiversity and important water-sediment processes. The reef structure itself can persist under intermediate beam trawl pressure but the integrity of the reef is affected as the system as a whole degrades immediately after disturbance. In general, dynamic sandy areas are more resilient to trawling but that biogenic reefs that can occur in these areas, like mussel and oyster banks, Lanice etc. are vulnerable.

Scientific studies on the impact of trawling on grounds with stones and boulders are quite scarce, but potential effects on emergent structures attached to boulders have been demonstrated.

The most important element of beam trawl impact is the physical impact caused by the sediment penetration of the trawl heads, tickler chains and bobbin rope. With a penetration into the seabed between 1 and 8 cm, seafloor contact can be classified as very intense but compared to other towed gears the surface swept is relatively low. Due to the patchy distribution of the target species sole and plaice, the distribution of beam trawl effort, and thus its impact, is also patchily distributed and not spread out over the whole North Sea. The main conclusions that can be drawn are that the impact of beam trawling is most likely restricted to a much smaller area than the total fished surface and that certain benthic communities are much more trawled and thus impacted than others. Despite the patchiness of the effort distribution, beam trawling occurs in areas with a different vulnerability to fishing, so the impact may be comparable to natural phenomena in one area and may have serious consequences for the benthic ecosystem in another. In addition to this, studies also indicate that beam trawling effort is directed to certain ecotopes that withstand the impact and the fishery maintains conditions favorable for their own target species. Beam trawling also has a reputation of producing high discards although the minimum mesh size used plays a significant role.

The pulse trawl, as an alternative to the traditional beam trawl, lacks the heavy tickler chains which significantly reduces the seafloor and benthic impact. The towing speed has been reduced from some 7 kn to somewhat more than 5 kn which decreases the fished surface, benthic impact and fuel consumption. The average penetration depth has also been reduced from over 2.5cm to less than 1cm. There are also indications that discarding may be reduced with this technique.

The Sumwing, as an alternative to the beam trawl, reduces fuel consumption with 12% on average for the same catch with maxima over 20%. The average reduction in sediment penetration for the whole gear is 10%.

The development of the Hydrorig as a alternative for the beam trawl is still in a too early stage of development to draw any conclusions.

Demersal seining (such as flyshooting) also shows a wide variability in gear design and operation. There are undoubtedly many positive benefits of seining when compared to trawling with respect to bottom impact, fuel economy and fish quality, however, concerns have been expressed about levels of discarding and high-grading as seine netters aim to maximize returns. Also as the pressure on grounds increase and seiners are forced into areas of harder ground, there is evidence of technological creep in seine net design with much heavier seine ropes and heavy hopper footropes now commonly used.

Bottom otter trawls encompass a large variety of designs, riggings and dimensions with strongly varying operational characteristics. The passage of an otter trawl was found to have a generally minor physical and visual impact on the seabed compared to beam trawling. The main physical effect of otter trawling appears to be the tracks left in the sediment by the trawl doors. Despite the less intense seafloor contact, otter trawls appear to fish a much larger surface for the same amount of fish compared to beam trawls.

Besides the physical impact, bottom trawling may trigger considerable productivity pulses due to the rate of dissolved and particulate nutrient releases from seabed disturbance These releases may be transported to the euphotic zone to support new production, which is in support of the bottom-up mechanism for increasing the amount of food available to planktivorous fish. The effects of different fishing techniques on the physical environment are specific to each gear. In terms of secondary production, studies have made clear that bottom trawling has an effect which can be positive and negative. Besides the effects on ecosystem productivity, trawling can affect the species composition. Effects will differ according to fishing intensity, community structure, diet of fish species and habitat.

In order to get an idea on the order of magnitude of fishing impact, we cite Hiddink et al. (2006b) who concludes that benthic biomass in the Dutch and UK sector of the North Sea is 56% lower than would be expected in the absence of bottom trawling. Benthic production in the Dutch and UK sector of the North Sea was 21% lower, consistent with a shift in the benthic community towards smaller individuals and species with higher P:B (Production to Biomass) ratios. A reduction of trawling impact can be achieved by redirecting trawling effort from vulnerable to more resilient habitats.

Bottom disturbance by trawling may have positive as well as negative effects for some fish species, from an economic perspective. It may improve feeding conditions for e.g. plaice but bottom trawling can have undesirable effects on the ecosystem and other commercial fish (e.g., on fish species that feed on large invertebrates, such as Atlantic cod). As such the resultant effect of fishing for commercial species depends on the balance between positive and negative effects. On a longer time scale, fishing may affect the species assemblage. Over time, there seems to have been a shift in the Southeastern North Sea from fish that eat large benthic invertebrates (such as cod and rays) to ones that eat small worms (such as plaice, dab and sole). As such, certain fishing methods favor their own target species. It is clear that trawling can influence the productivity of fish species either positively or negatively, depending on a range of factors such as fishing effort, community structure (large or small invertebrates), the diet of fish species, etc. The decision to change to different fishing methods, increase or decrease fishing effort or redistribute fishing effort and the potential effects on benthic communities needs to be carefully considered.

The environmental impact of passive fishing gear is quite different in nature compared to towed gear. The principal components of seabed effects for passive gear set on the seafloor (like set nets, longlines and pots) are the anchors and weights used to fix the gear on the seabed. By-catch of marine mammals and ghost fishing, however, can be considered the main disadvantage of this type of fishing gear. Discarding can be considerable for set nets.

As for the long term effects of fishing, it has been observed that reductions in spatial presence occurred especially in the central and southern North Sea, where beam trawl effort has been highest. The affected species are known to be sensitive to damage by fishing gear. Conversely, the benthic species expanding their distribution over the last century are relatively tolerant to fishing gear or likely to benefit from reduced competition by other species and high numbers

of damaged species suitable as prey. Overall, the most profound changes in the epibenthos appear to have taken place before the 1980s; since then there has been further change, but the communities of recent decades probably reflect faunal assemblages adapted to long-term impacts. Climate change, eutrophication and other factors are highly likely to have contributed to the observed changes. The nature of the changes, however, indicates that to a considerable extent, and especially in the central and southern North Sea, long-term changes in epibenthos can be linked to a century of sustained, high trawling effort Evidence from the literature also indicates that the synergistic effects of overfishing in the North Sea and predicted climatic changes provide a particularly powerful driver of ecosystem structure that shortens the period for change to occur. This is primarily because overfishing is known to simplify food webs, trigger trophic cascades and promote the proliferation of jellyfish, which feed on fish eggs, fish larvae, and zooplankton. The net result of these changes has been to create a simplified ecosystem structure focused on lower trophic level invertebrates. The proliferation of jellyfish that can exert both top-down and bottom-up control of fish recruitment may signal the ecological climax of these changes. The extent of the synergistic effects of fishing and climate in the North Sea suggests that management may be unable to reverse current climate and human-induced changes.

In this report, the impact of the different types of fishing gear has been quantified in terms of fuel consumption, average penetration depth, surface fished, sediment displaced, benthic effects and discards of key species. The focus lied on studies carried out in the North Sea. In terms of scientific studies available to assess the effects of fishing, there are many studies on beam and otter trawling and rather few on other fishing methods, which makes it difficult to come to a balanced conclusion. Therefore, a general ranking of fishing methods according to their ecosystem effects is a very intricate and delicate task, although attempts have been made and are valuable for a general conception. The authors felt, however, that there is a serious imbalance in the amount of scientific studies available for the different fishing gears and a fair ranking is difficult. In addition, it is impossible to break the link between the gear and the fishing practice which depends on the fisherman.

The attitude of the fisherman plays a central role in sustainable fishing but the idea of a better spatial planning of fisheries may facilitate the transition to sustainability. This spatial planning should be based on the type of fishing gear in relation with type of habitat and occurrence of animals unwanted for by-catch like juvenile fish or marine mammals. How to move forward with this issue is an important matter of debate but is not addressed in this report.

ABOUT THIS REPORT

This report makes an attempt to summarize a wide variety of literature dealing with environmental effects of different types of fishing gear used in the North Sea and tries to present the information in an accessible way. It starts with a description of the main features of the gear types, presents qualitative data on fuel efficiency and the physical seafloor impact. Discard data are presented, observed as well as simulated data. The effects on the habitat are presented in terms of tow path mortality, biological habitat impact, effects on productivity and recovery and long-term impacts.

Discussions in the scientific literature, mainly on the methodology of impact studies, and in the media on the "questionable conclusiveness of the science", make clear that scientific results can easily be interpreted in different ways. It is indeed the case that the conclusions of the different studies can be contradictory if no attention is paid to the specifics of the experiment. The complexity of the marine ecosystem and the complexity of the interactions between fishing gear and life on the seafloor allow many conclusions. Put in the right perspective, however, most of these conclusions will confirm each other.

In this context we cite Gray et al. (2006) in reaction to an FAO report (Løkkeborg, 2005), posing the problem:

> *" The United Nation's Food and Agriculture Organisation commissioned and published a review of the impacts of trawling and scallop dredging on benthic habitats and communities (Løkkeborg, 2005). The main conclusion of this report (p. 47) is that, "It is difficult to conduct impact studies leading to clear and unambiguous conclusions because knowledge of the complexity and natural variability of benthic communities is rudimentary". The review speculates further on the utility of grabs and box-corers as sampling tools (p. 9) stating that "these methods are not suitable for sampling benthic fauna with patchy distribution and low abundance." These worrying assertions reflect a profound ignorance of an abundant literature and could lead to inappropriate conclusions by a non-expert reader. "*

Making their point clear:

> *"But how does disturbance affect an ecological assemblage? The "intermediate disturbance" hypothesis has been shown to be a useful ecological rule, although it is scale dependent. A moderate disturbance can lead to an increase in species richness as some dominant species are reduced in abundance, so there is opportunity for new species to colonise and for species richness to increase. Trawling may have such an effect in systems characterized by low habitat structure and relatively ephemeral species. However, this conceptual response does not provide evidence that trawling is somehow beneficial simply because it may increase species richness at low levels of disturbance. Damage caused by trawling on a 400 year old cold water coral will take hundreds of years to repair. Such communities dominated by large and long-lived organisms are being impacted by fishing and elegant experiments are not need to prove the obvious immediate effects. Nevertheless we do need to learn about the full consequences of such impacts on biodiversity and define rates of recovery so that the ecological risks can be fully assessed. The intermediate disturbance hypothesis also predicts that as the disturbance persists or increases in strength, or frequency, then richness will decrease. Thus, the response is not a simple one and neither is a simple response expected by experienced researchers."*
>
> *"Almost certainly the most significant effect of trawling on benthic assemblages is that of habitat homogenisation and/or destruction (a very large literature reviewed in Thrush and Dayton, 2002). This can have important effects on sediment biogeochemical processes as well as modify structure above the sediment surface."*
>
> *"Natural sedimentary environments are not vast homogeneous plains of sand or mud but contain a variety of three-dimensional structure. These may be caused by natural physical variations in substratum such as isolated stones and patches of different types of sediment. Biological alteration of the sediment is extremely important; shells, animal tubes of a variety of shapes, sizes and durability, faecal piles, holes and pits are all key elements of the structure and functioning of these habitats. Research has shown that such structures are important cues for settlement processes of many organisms, can act as refugia from predators and affect ecosystem processes. Yet trawling tends to homogenise the sediment and reduces three-dimensional structure above and below the sediment-water interface."*

The study of environmental impact of fishing gear is complex and with this report we hope to add some clarity in the discussion. We welcome any comment or suggestion at hans.polet@ilvo.vlaanderen.be and jochen.depestele@ilvo.vlaanderen.be. We intend to improve this report so it can be a useful and accessible reference.

1. GENERAL INTRODUCTION

1.1. Sustainability

Sustainability in fisheries is based on a number of principles that should all be complied with. Fishing is an economic activity that can only exist if it is profitable. Fishing methods should be efficient in catching fish and exploitation costs. Environmental impact should be low but "low" should be defined. Since it is unclear what the long term effects of fishing are, precaution tells us to keep the negative side effects of fishing at the lowest level possible. Side effects that can be perceived as positive, like a possible increase in productivity due to fishing, should be treated with caution. In general, a sound marine environment is the best guarantee for sound fish stocks in the long term. Since fisheries involve labor, social issues should not be neglected. The application of modern technology is necessary to keep the industry competitive and should be encouraged although issues like technological creep should be monitored in order to assess the change in catching capacity of the fleet. Finally, the sea is a complex and dynamic environment that is subject to short and long term changes. A sustainable fishery should be able to adapt and setting up adaptation strategies can be an asset for the industry.

FAO (2009) describes the term “unsustainable fishing” as: (i) a situation (in contradiction with the Law of the Sea Convention) characterized by overfishing or inadequate fishing pattern; (ii) fishing activities that lead to long-term losses in the biological and economic productivity, biological diversity, or impacting ecosystem structure in a way that impairs functioning of the exploited system across several generations. For the purpose of this report, and following the CBD (Convention on Biological Diversity) requirements, unsustainable fishing will be decomposed in partly interconnected components as follows: (i) Overfishing; (ii) Destructive fishing; and (iii) IUU fishing. It is recognized that extreme forms of overfishing could be destructive and that IUU is an aggravating factor of both overfishing and destructive fishing. These terms are explained by FAO (2009) and are presented below.

1.2. Overfishing

The term covers three interconnected phenomena: biological overfishing, economic overfishing and ecosystem overfishing. Biological overfishing of whatever exploited species (target or non-target) is defined as a situation in which the fishing pressure exerted on the species is higher than the pressure theoretically required for harvesting the maximum sustainable yield (MSY), or would, if continued in the medium term, impair the population productivity. Economic overfishing occurs when a fishery is generating a rent lower than the maximum rent obtainable (e.g. below maximum economic yield [MEY]), primarily because an excessive level of fishing effort was applied. Ecosystem overfishing is defined as the situation in which the long-term historical species balance (i.e. species composition, dominance, and their natural oscillations) have been significantly modified by fishing – e.g. the reductions of fish predators can lead to increases of small and short-lived species at lower trophic levels.

1.3. Destructive fishing practices

The term refers to the use of fishing gears in ways or in places such that one or more key components of an ecosystem are obliterated, devastated or ceases to be able to provide essential ecosystem functions. From an ecosystem and precautionary approach perspective, destructive fishing refers to the use of gears and/or practices that present a high risk of local or global damage to a population of target, associated or dependent species or their habitat, to the point of eliminating their capacity to continue producing the expected goods and services for present and future generations, particularly if recovery is not possible within an acceptable time frame. Few, if any, fisheries are consistently “destructive”. Only a very small number of fishing gears or fishing methods are recognized as inherently “destructive” wherever and however they are used, the primary examples being explosives and synthetic toxins. In the absence of any formal agreement regarding the term, the classification of a gear or practice as destructive is a policy choice related to pre-set objectives and consistent with national and international law.

1.4. Illegal, unreported and unregulated (IUU) fishing

IUU fishing is defined in the International Plan of Action to Prevent, Deter and Eliminate Illegal Unreported Unregulated Fishing as follows: Illegal fishing refers to: the following fishing activities: (i) those conducted by national or foreign vessels in waters under the jurisdiction of a State, without the permission of that State, or in contravention with its law and regulations; (ii) those conducted by vessels flying the flag of States that are parties to a relevant regional fisheries management organization, but operate in contravention of the conservation and management measures adopted by that organization; or (iii) those conducted in violation of national laws or international obligations, including those undertaken by cooperating States to a relevant regional fisheries management organization (RFMOs). Unreported fishing refers to: (i) fishing activities which have not been reported, or have been misreported to the relevant national authority, and in contravention of national laws and regulations; or (ii) fishing activities undertaken in the area of competence of RFMO, which have not been reported, or have been misreported, and in contravention of the reporting procedures of that organization. Unregulated fishing refers to: (i) fishing activities in the area of application of a relevant RFMO, that are conducted by vessels without nationality, or by vessels flying the flag of a State not party to that organization, or by vessels in a manner that are not consistent with or contravenes the conservation and management measures of that organization; or (ii) fishing activities in areas, or for fish stocks in relation to which there are no applicable conservation or management measures, and where such fishing activities are conducted in a manner inconsistent with States' responsibilities for the conservation of living marine resources under international law.

1.5. Acceptable level of impact

A major challenge in ecosystems and resources management is the judgment on the degree to which an impact is considered acceptable. At the global scale guidance on standards for such judgments is found in the provisions of international agreements that are negotiated and adopted. States and regional jurisdictions then develop legislation and policies to implement these agreements, augmenting them, as appropriate with their societal values.

In the case of fishery target species, the 1982 UNLOSC (United Nations Convention on the Law of the Sea) has enshrined the concept of maximum sustainable yield (MSY) as a target reference value, both in terms of biomass and fishing pressure. This implied that virgin fish populations could be decreased to about half of their size, to their level of maximum biological productivity. This has been modified by the UN Fish Stocks Agreement which uses the MSY level as a maximum limit for development (to be therefore avoided) and as a minimum level for stock rebuilding. In the case of ecosystems, the Rio Declaration States agreed to prevent serious or irreversible harm to ecosystems. This provides a global standard of acceptable impact of any activity, including fisheries, on ecosystems. To make this standard operational, an obligation is placed on the science advisors to identify what constitutes impacts whose consequences are ecologically serious, and the reversibility of impacts.

1.6. Recovery and reversibility

There has been substantial interest in the concepts of recovery and reversibility of impacts in all ecosystems, marine and terrestrial. In general there is incomplete and often little understanding of the likelihood and nature of recovery of marine systems from substantial perturbations. However, a number of issues and tentative conclusions emerge from most studies of recovery of marine ecosystems or reversibility of specific perturbations:

1. Ecosystems vary greatly in capacity to recover from impacts, for many different reasons.
2. Different types of impacts differ greatly in both likelihood that they cause substantial changes to ecosystems and the likelihood that recovery from the changes will be rapid and secure.
3. Ecosystems will not follow the same path during recovery that was taken during the period when the perturbation was occurring.
4. Ecosystems are naturally variable, so even a successful recovery program will not return an ecosystem to exactly the state is was in prior to the perturbation.
5. What point constitutes recovery – presence or maturity?

1.7. Integrated management (IM) and the ecosystem approach (EA) to fisheries

Biodiversity considerations are a major component of bringing both the ecosystem approach and integrated management into fisheries. They are part of both major challenges in IM and EA, dealing with:

Multiple effects – Accounting for multiple forcers in setting objectives, choosing indicators, setting reference levels, and diagnosing causes of changes. The latter is of particular concern because of the resultant difficulty in determining what activity (manageable or not) is causing a detrimental trend in a biodiversity feature, or if improvements in a biodiversity feature are due to management actions that have been taken or a natural process.

Complexity of management options – How to account for pressures from multiple human activities and how to allocate necessary mitigation actions fairly and effectively among multiple user communities. This is a challenge even when harmonizing management options across sectors for a single ecosystem feature such as stock fished by several fisheries. It becomes much more complex when management options must be harmonized across many groups with different goals, and considering many different biodiversity features.

The present document focuses on the environmental impact of the North Sea fisheries and addresses issues like the physical impact of selected fishing methods, fuel efficiency, tow path mortality, discarding, habitat specific impacts, productivity, cumulative impact and recovery.

1.8. Introductory example

As a general introduction, the example is given of an exercise carried out by the ICES Working Group on Fishing Technology and Fish Behaviour (ICES, 2006a) to conduct a qualitative assessment of different gears types with the aim of identifying “responsible fishing methods”, with respect to a number of “ideal gear properties”. A range of capture methods were considered, including: beam trawling, bottom trawling, Danish/Scottish Seining, diving, dredging, drift nets, gillnets, jigging, long-lines, pelagic trawling, pole & line, purse seining, pots, trammel nets and traps.

The “ideal gear properties” were considered to be definitive of three key areas of impact, with respect to “Responsible fishing”, and were grouped accordingly: Controllability of Catch, Environmental Sustainability and Operational Functionality (**Table 1.1**). Each capture method was scored with respect to each “ideal property” and then a simple index (index = mean score) was defined, with respect to each of the key impact areas (Table 1.2). To visualize the relationship between the three impact areas, for different capture methods, the indices were plotted in Figure 1.1, Figure 1.2, and Figure 1.3.

Please note, none of the indices described account for the relative catch efficiency (i.e. catch per unit effort) of the different capture methods. This omission is deliberate and was necessary for the following reasons. The catch efficiency of a particular capture method is fishery specific; i.e. it is highly dependent on the target species, location of the fishery, prevailing environment conditions, etc. Furthermore, it was generally accepted that most commercial fisheries will have evolved to use the most efficient capture method available to them. Therefore, most “alternatives” are likely to be less efficient than the current capture method. So, it was not practical, nor particularly informative, to assign an efficiency score in this qualitative overview.

Table 1.1. Summary of "Ideal Gear Properties", with the most suitable capture methods identified for each proprerty (Source ICES, 2006a).

PROPERTY	DEFINITION / RATIONAL FOR "IDEAL GEAR"	SUITABLE CAPTURE METHODS
Catch Controllability		
Quality of Catch	Minimal physical impact on catch, with a minimal delay recovering catch → maximising catch quality	diving, pole & line, pots and traps, jigging and Danish seine
Species Selectivity	Catching only target species → minimising bycatch	diving, pole & line & purse seine
Size Selectivity	Ability to catch a specific size range of target species, → to the exclusion of smaller/larger individuals	drift nets, gill nets and diving
Environmental Impact		
Habitat Impact	Minimal habitat impact on the environment in which it is used, including the potential for "ghost-fishing".	diving, pole & line, jigging, purse seine and pelagic trawls
Energy Cost	Minimal use of fuel during fishing operations / trips → reduced "carbon footprint".	drift nets, gillnets, diving, pole & line, long-lines, jigging, pots, traps and trammel nets
Non-commercial Bycatch	Minimal catch of non-target species, in particular endangered non-commercial species.	diving, pole & line and pots
Catch Welfare	Minimal physical impact and psychological stress on catch → minimising discard mortality	diving, pots and traps
Operational Functionality		
Safety	Minimal risk of injury/fatality to fishers using gear	traps, gillnets, trammel nets and pots
Durability	Longevity of gear, including maintenance requirements and costs	traps, pots, jigging, pole & line and pelagic trawl
Gear Costs	Minimal initial investment cost → allowing quick shift in gears as fishery management requires	jigging, pole & line, Danish seining and gillnets
Ease of use	Minimal training requirements → allowing quick shift in gears as fishery management requires	jigging, pole & line, gillnets, traps, pots and trammel nets
Applicability	Usable in all aquatic habitats, without seasonal or environmental limitations	jigging, pole & line, gillnets, traps, pots and trammel nets

Table 1.2. Summary of "Ideal Gear Properties" mean scores and indices for different capture methods.

	Catch Controllability				Environmental Sustainablity					Operational Functionality					
	Catch Quality	Species selective	Size selective	*index*	Habitat Impact	Energy cost per kg fish	Non commercial Bycatch	Welfare	*index*	Safety	Durability	Gear cost	Ease of use	Applic - ability	*index*
Beam trawl	0.3	1.0	0.0	*0.4*	0.0	0.0	1.7	0.0	*0.4*	0.7	1.0	0.0	0.0	0.0	*0.3*
Bottom trawl	0.0	0.0	1.0	*0.3*	0.0	0.0	1.7	0.0	*0.4*	0.7	1.3	0.0	0.0	0.0	*0.4*
Danish seine	1.7	1.0	1.0	*1.2*	1.0	1.0	1.7	1.0	*1.2*	1.7	1.0	2.0	0.0	0.0	*0.9*
Diving	2.0	2.0	2.0	*2.0*	2.0	2.0	2.0	2.0	*2.0*	0.0	1.7	1.0	0.0	0.5	*0.6*
Dredge	0.7	0.3	0.0	*0.3*	0.0	0.0	1.7	0.0	*0.4*	0.7	1.0	1.0	0.0	0.0	*0.5*
Drift-net	0.0	0.3	2.0	*0.8*	1.3	2.0	0.0	0.0	*0.8*	1.0	1.0	1.0	1.0	1.0	*1.0*
Gillnet	0.0	1.0	2.0	*1.0*	1.3	2.0	0.0	0.0	*0.8*	2.0	0.0	2.0	2.0	2.0	*1.6*
Jigging	1.7	2.0	1.0	*1.6*	2.0	2.0	0.7	0.0	*1.2*	1.3	2.0	2.0	2.0	2.0	*1.9*
Longline	0.7	1.0	1.0	*0.9*	1.3	2.0	0.3	0.0	*0.9*	1.0	1.0	1.0	1.0	2.0	*1.2*
Pelagic trawl	0.0	1.0	0.0	*0.3*	2.0	1.7	1.7	0.0	*1.3*	0.7	2.0	0.0	0.0	0.0	*0.5*
Pole and line	2.0	2.0	1.3	*1.8*	2.0	2.0	2.0	1.0	*1.8*	1.0	2.0	2.0	2.0	2.0	*1.8*
Pot	2.0	1.0	0.7	*1.2*	1.3	2.0	2.0	2.0	*1.8*	1.7	2.0	1.0	2.0	2.0	*1.7*
Purse seine	1.0	2.0	0.7	*1.2*	2.0	1.3	1.3	1.0	*1.4*	1.0	0.0	0.0	1.0	1.5	*0.7*
Trammel net	1.0	0.0	0.0	*0.3*	1.3	2.0	0.0	0.0	*0.8*	2.0	0.0	1.0	2.0	2.0	*1.4*
Trap	2.0	1.0	0.7	*1.2*	1.7	2.0	0.3	2.0	*1.5*	2.0	2.0	1.0	2.0	1.0	*1.6*

0 least reponsible
1 moderately responsible
2 most responsible

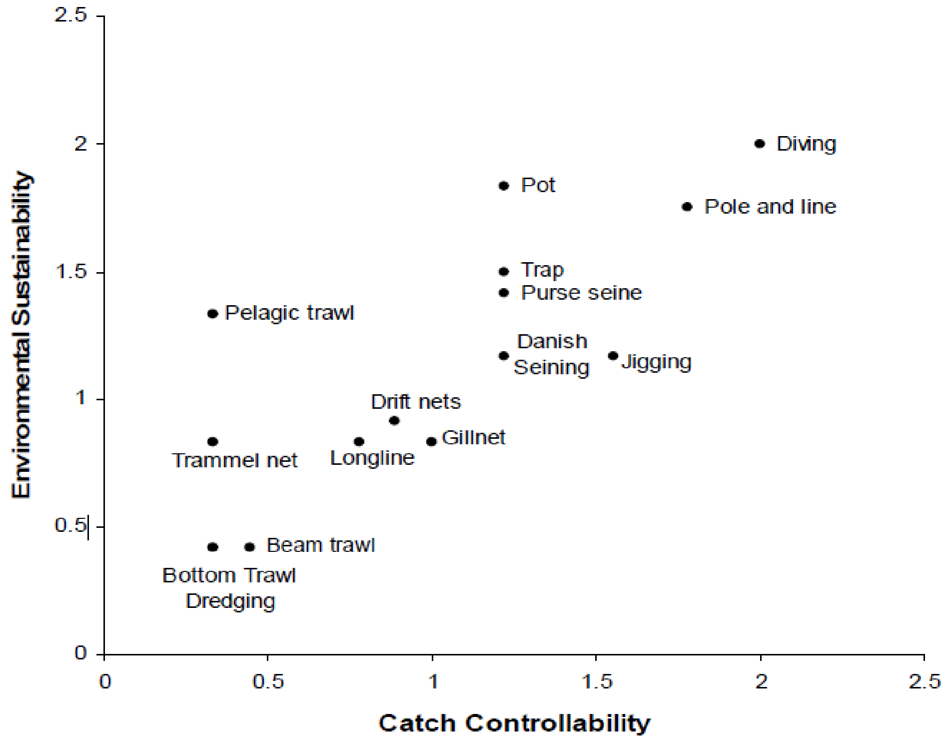


Figure 1.1. The relationship between Indices of "Environmental Impact" and "Catch Controllability" for different fish capture methods.

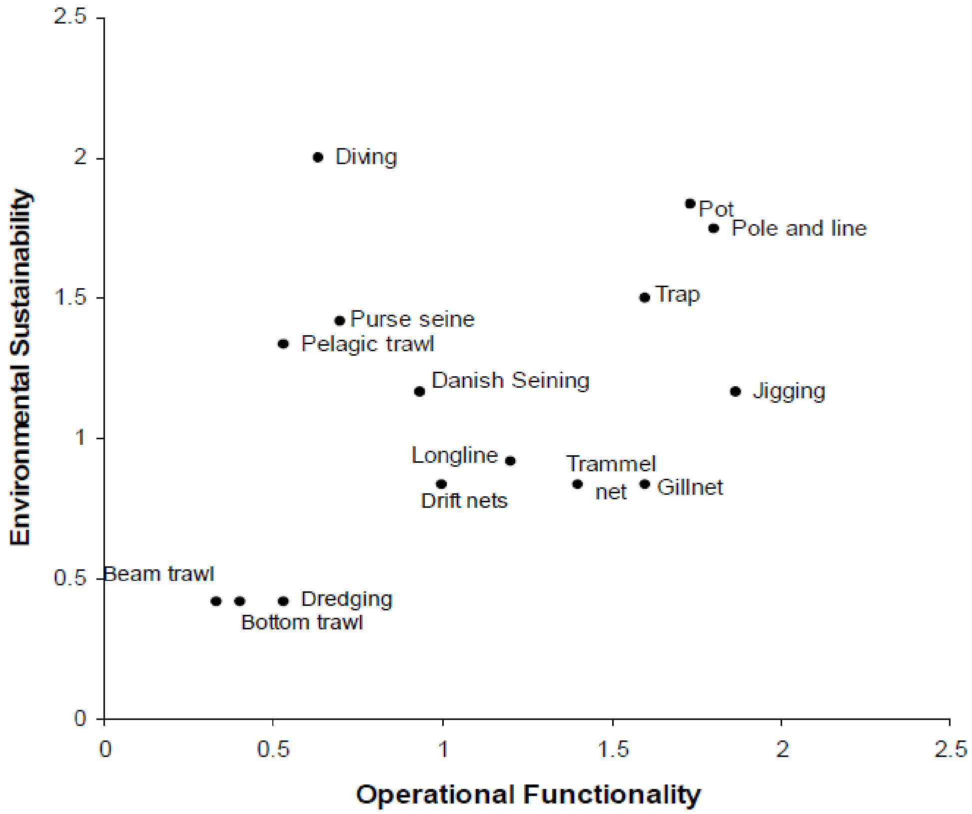


Figure 1.2. The relationship between Indices of "Environmental Impact" and " Operational Functionality" for different fish capture methods.

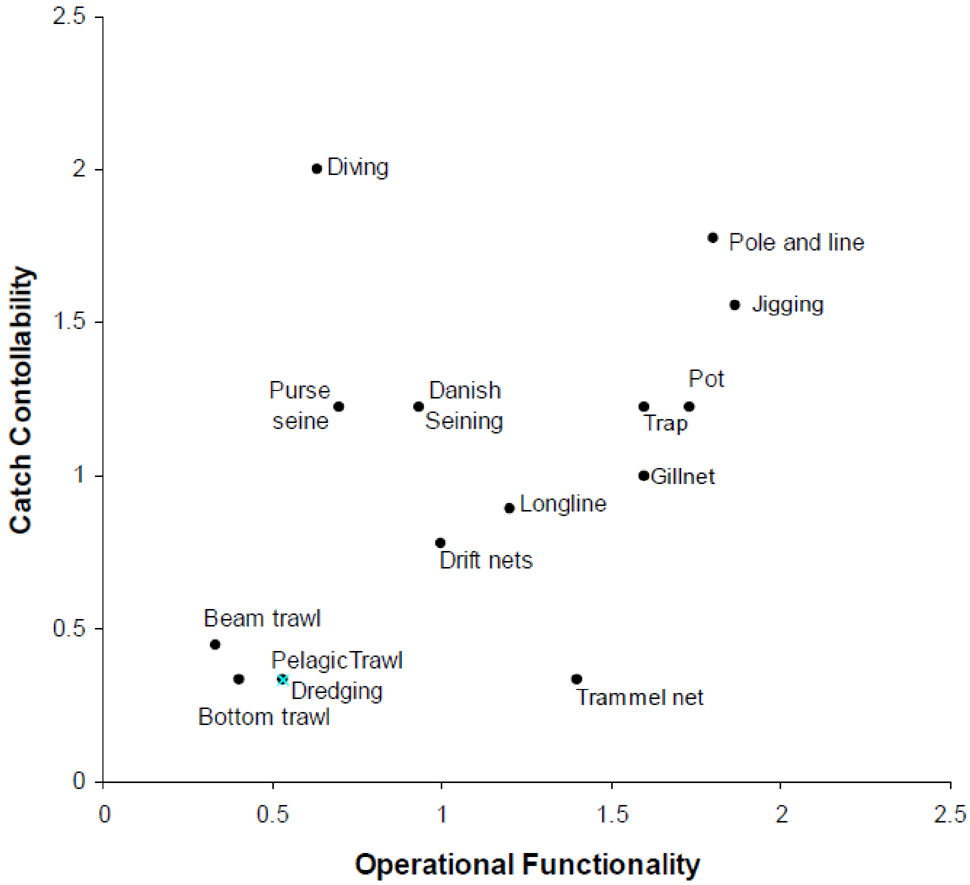


Figure 1.3. The relationship between Indices of "Environmental Impact" and "Catch Quality & Selectivity" for different fish capture methods.

In general, it was the opinion of the ICES Topic Group members that no single capture method could be described as "an ideal gear". Different fisheries and management strategies will of course prioritize each of the "ideal gear properties" differently and will therefore have different requirements of a responsible fishing method. But when considering each of the properties equally, three capture methods were prominent as potentially responsible techniques:

- Diving – This technique was considered to be the most environmentally sustainable method, with the greatest control of the catch. However, its application in a commercial fishery is very restricted. It is a highly specialised technique that is limited by working depth (<50m using air), which would make it almost impossible to apply to most commercial fisheries.
- Pole & line – This technique also scored highly for environmental sustainability and catch control. Moreover, along with jigging, it was thought to have the greatest operational functionality: having low investment costs, usable in most habitats and relatively user safe. However as a practical capture method, it is generally limited to larger, and mostly predatory, fish species.
- Pots – This technique was also considered to have a minimal impact upon the environment; apart from the potential for ghost fishing, which can be mitigated for with inbuilt bio-degradability of pots and gear recovery schemes. The moderate score for catch controllability was primarily due to the poor size selectivity of current gears, which again could be improved with minor design changes. However, in terms of application as an alternative gear pots score highly. They can be used relatively safely in most habitats, with only moderate investment in terms of gear costs and training.

Finally, the scores given here are the consensus opinion of the members of the ICES WGFTFB Topic Group on Alternative Fishing Gears. As such the results of this exercise should not be considered as definitive, but this approach has been a useful tool in considering what properties may be important with respect to the ideal responsible fishing method. Moreover this approach, with a wider and more thorough application with respect to input "opinions", could prove to be a useful management tool when considering the introduction of "alternative" capture methods to commercial fisheries.

This exercise could easily be carried out for the North Sea, with the necessary expert input.

2. SHORT DESCRIPTION OF THE FLATFISH FISHERY IN THE NORTH SEA

The results presented in Section 1 of this report are based on a collaborative study carried out by the scientists and institutes given in Table 2.1 and are based on the fishery in 2006 (B, Dk, E, Nl).

Pooled North Sea landings (B, Dk, E, Nl) are given in Figure 2.1 and pooled effort by vessel length and by gear type is given in Figure 2.2 and Figure 2.3 respectively. The beam trawl is by far the most important fishing gear in the North Sea sole and plaice fishery and the larger vessels also dominate in terms of effort expressed as kWdays. Note that following métiers are excluded:

- <33 mm mesh fisheries
- Pelagic fisheries
- Fisheries with vessel < 10m LOA
- Fisheries with less than 5.000 kg sole and plaice and less than 5% sole and plaice

Table 2.1. Summary of "Ideal Gear Properties", with the most suitable capture methods identified for each proprerty (Source ICES, 2006a).

Belgium	Hans Polet, Jochen Depestele	ILVO-Fishery
Denmark	Niels Madsen, Bo Sølgaard Andersen	DTU Aqua
Netherlands	Ralf Van Hal, Bob van Marlen	IMARES
	Erik Buisman, Katrine Soma	LEI
UK	Alex Tidd, Thomas Catchpole	CEFAS

2.1. Fishing effort

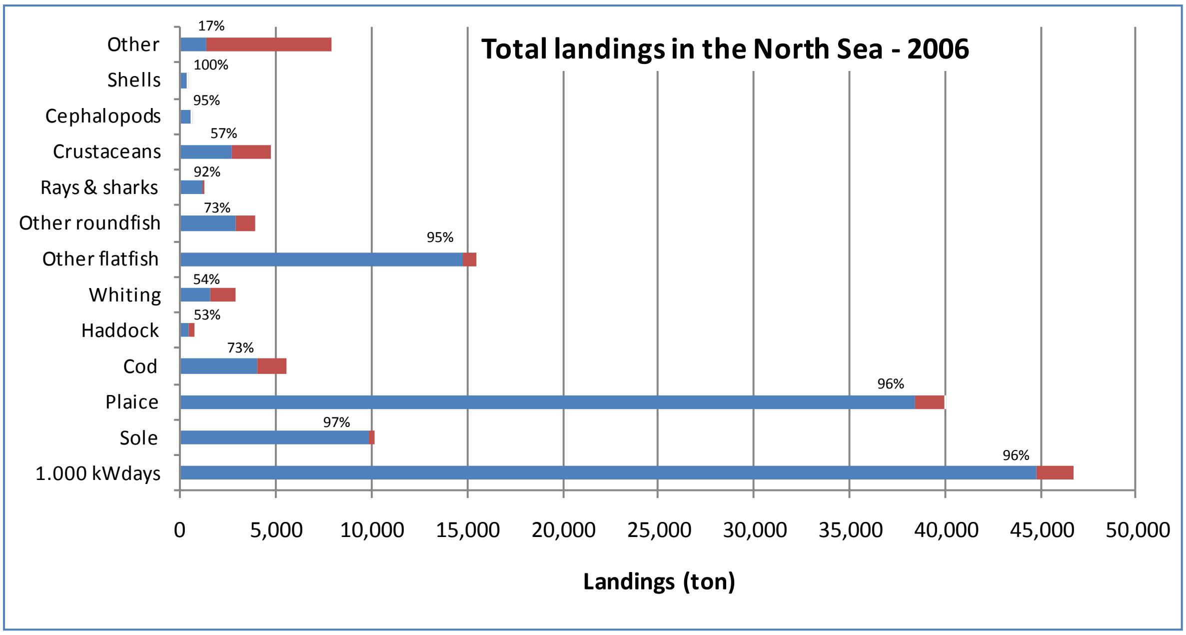


Figure 2.1. Landings in the North Sea (2006, B, Dk, NL, UK) for five species and seven species groups, split up for the fishery landings >5 % sole and plaice (blue) and the rest (red). The fishing effort is presented in "1000 kWdays". The percentages indicate the share of the flatfish directed fisheries relative to the total.

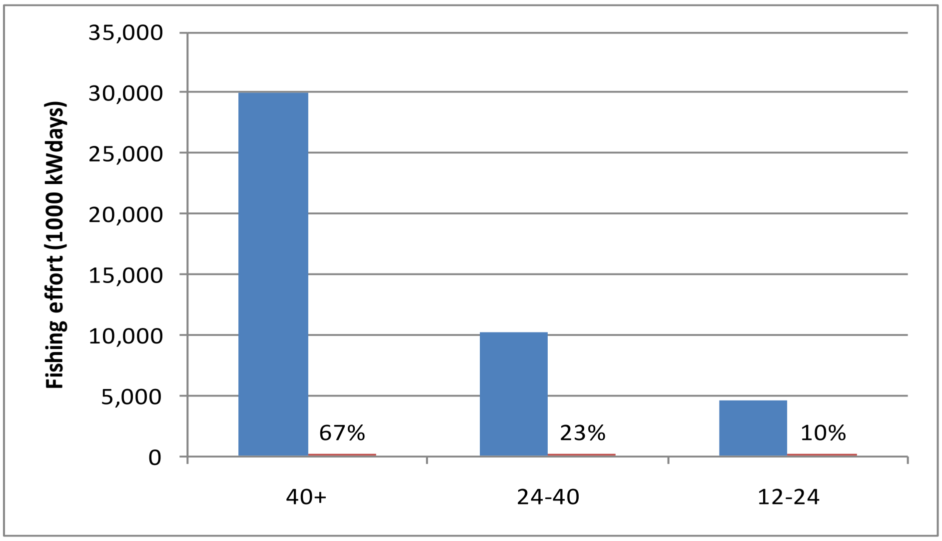


Figure 2.2. Fishing effort in 1.000 kWdays by vessel Group (based on vessel length) and the share in the total effort.

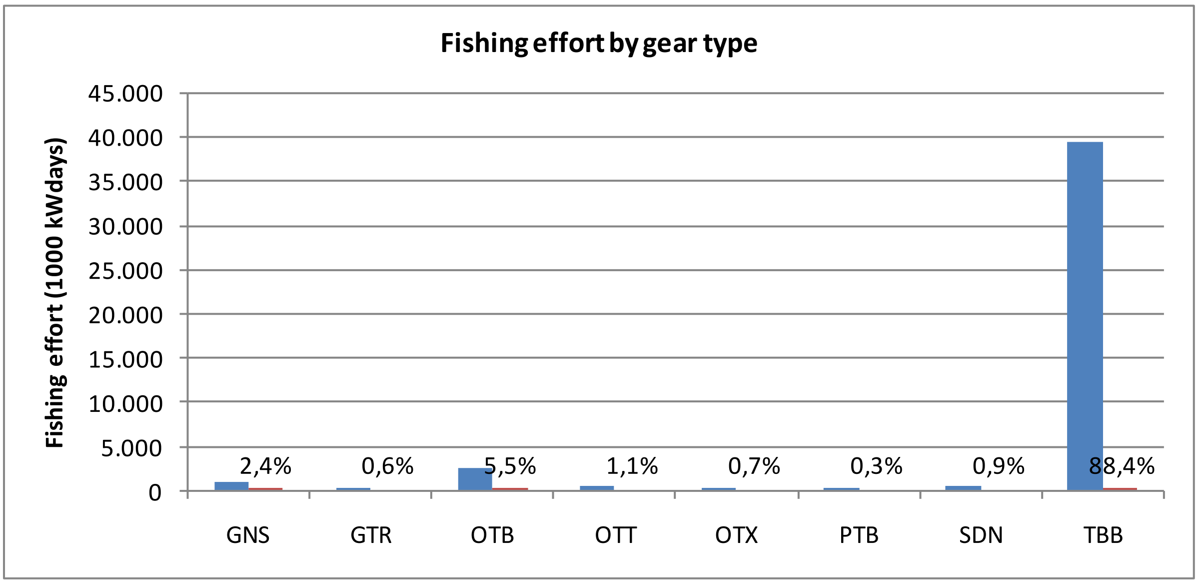


Figure 2.3. Fishing effort in "1000 kWdays" for the different gear types and the relative fishing effort by gear type in %.

2.2. Landings

Figure 2.4 to Figure 2.6 indicate which part of the total landings (by species group) each gear type catches and is a rough indicator on the relative efficiency of a given gear type for a given species group. Target species, discarding and high grading can bias this indicator. The skipper, the choice of fishing ground and available quota may also influence this indicator. Consequently, these data should be interpreted with care and should be seen as an indicator for catch efficiency related to external factors, mainly target species, regulations and technical measures.

Beam trawls seem to be above average efficient in catching sole and shells and on average for "other flatfish" and "rays and sharks". Beam trawls have an efficiency below average for plaice because this vessel group mainly targets sole. Beam trawls have a low efficiency for cod and a very low efficiency for haddock and whiting, although especially for these species, high grading may influence this parameter.

Otter trawls seem to have a high efficiency in catching most of the species, except for sole and shells. Twin rig otter trawls mainly target crustaceans (Nephrops), plaice and "other" whereas the OTX gear type (often beam trawlers seasonally fishing with twinrig or outrig) mainly target crustaceans and rays & sharks. Despite the fact that these three types of trawls, single otter trawls, twin rig otter trawls and outrig otter trawls, have similar characteristics and have similar catching efficiency for the different species, the composition of the landings is fundamentally different. This is may be caused by the choice of the skipper and is related to tradition, available quota and skippers knowledge of fishing grounds.

Pair trawls have a similar composition of the landings compared to otter trawls. The Danish seine has a far above average efficiency to catch plaice, cod and haddock as well as other roundfish and species classified as “other”.

Static gear like gillnets and trammel nets mainly land plaice and cod and “other” species and are efficient in catching sole as well.

Below, the legend with the abbreviations used related to types of fishing gear:

Legend:

OTB: single otter trawl	*OTX: outrigger or twin otter trawl*	*GTR: trammel net*	*SDN: Danish seine*
OTT: twin otter trawl	*GNS: set gillnet*	*PTB: pair trawl*	*TBB: twin beam trawl*

On the next pages the FAO gear classification is presented. This classification is under review and the updated version is expected to become available soon.

International Standard Statistical Classification of Fishing Gear (ISSCFG)
(29 July 1980)

Gear Categories Abbreviation Code	Standard Abbreviations	ISSCFG
SURROUNDING NETS		01.0.0
With purse lines (purse seines)	PS	01.1.0
- one boat operated purse seines	PS1	01.1.1
- two boats operated purse seines	PS2	01.1.2
Without purse lines (lampara)	LA	01.2.0
SEINE NETS		02.0.0
Beach seines	SB	02.1.0
- boat or vessel seines	SV	02.2.0
- Danish seines	SDN	02.2.1
- Scottish seines	SSC	02.2.2
- pair seines	SPR	02.2.3
Seine nets (not specified)	SX	02.9.0
TRAWLS		03.0.0
Bottom trawls		03.1.0
- beam trawls	TBB	03.1.1
- otter trawls[1]	OTB	03.1.2
- pair trawls	PTB	03.1.3
- nephrops trawls	TBN	03.1.4
- shrimp trawls	TBS	03.1.5
- bottom trawls (not specified)	TB	03.1.9
Midwater trawls		03.2.0
- otter trawls[1]	OTM	03.2.1
- pair trawls	PTM	03.2.2
- shrimp trawls	TMS	03.2.3
- midwater trawls (not specified)	TM	03.2.9
Otter twin trawls	OTT	03.3.0
Otter trawls (not specified)	OT	03.4.9
Pair trawls (not specified)	PT	03.5.9
Other trawls (not specified)	TX	03.9.0
DREDGES		04.0.0
Boat dredges	DRB	04.1.0
Hand dredges	DRH	04.2.0

International Standard Statistical Classification of Fishing Gear (ISSCFG)
(29 July 1980) (cont'd)

Gear Categories Abbreviation Code	Standard Abbreviations	ISSCFG
LIFT NETS		05.0.0
Portable lift nets	LNP	05.1.0
Boat-operated lift nets	LNB	05.2.0
Shore-operated stationary lift nets	LNS	05.3.0
Lift nets (not specified)	LN	05.9.0
FALLING GEAR		06.0.0
Cast nets	FCN	06.1.0
Falling gear (not specified)	FG	06.9.0
GILLNETS AND ENTANGLING NETS		07.0.0
Set gillnets (anchored)	GNS	07.1.0
Driftnets	GND	07.2.0
Encircling gillnets	GNC	07.3.0
Fixed gillnets (on stakes)	GNF	07.4.0
Trammel nets	GTR	07.5.0
Combined gillnets-trammel nets	GTN	07.6.0
Gillnets and entangling nets (not specified)	GEN	07.9.0
Gillnets (not specified)	GN	07.9.1
TRAPS		08.0.0
Stationary uncovered pound nets	FPN	08.1.0
Pots	FPO	08.2.0
Fyke nets	FYK	08.3.0
Stow nets	FSN	08.4.0
Barriers, fences, weirs, etc	FWR	08.5.0
Aerial traps	FAR	08.6.0
Traps (not specified)	FIX	08.9.0
HOOKS AND LINES		09.0.0
Handlines and pole-lines (hand operated)[1]	LHP	09.1.0
Handlines and pole-lines (mechanized)[1]	LHM	09.2.0
Set longlines	LLS	09.3.0
Drifting longlines	LLD	09.4.0
Longlines (not specified)	LL	09.5.0
Trolling lines	LTL	09.6.0
Hooks and lines (not specified)[2]	LX	09.9.0

[1] Including jigging lines
[2] Code LDV for dory-operated line gears will be maintained for historical data purposes

International Standard Statistical Classification of Fishing Gear (ISSCFG)
(29 July 1980) (concluded)

Gear Categories Abbreviation Code	Standard Abbreviations	ISSCFG
GRAPPLING AND WOUNDING		10.0.0
Harpoons	HAR	10.1.0
HARVESTING MACHINES		11.0.0
Pumps	HMP	11.1.0
Mechanized dredges	HMD	11.2.0
Harvesting machines (not specified)	HMX	11.9.0
MISCELLANEOUS GEAR[1]	MIS	20.0.0
RECREATIONAL FISHING GEAR	RG	25.0.0
GEAR NOT KNOWN OR NOT SPECIFIED	NK	99.0.0

[1] This item includes: hand and landing nets, drive-in-nets, gathering by hand with simple hand implements with or without diving equipment, poisons and explosives, trained animals, electrical fishing.

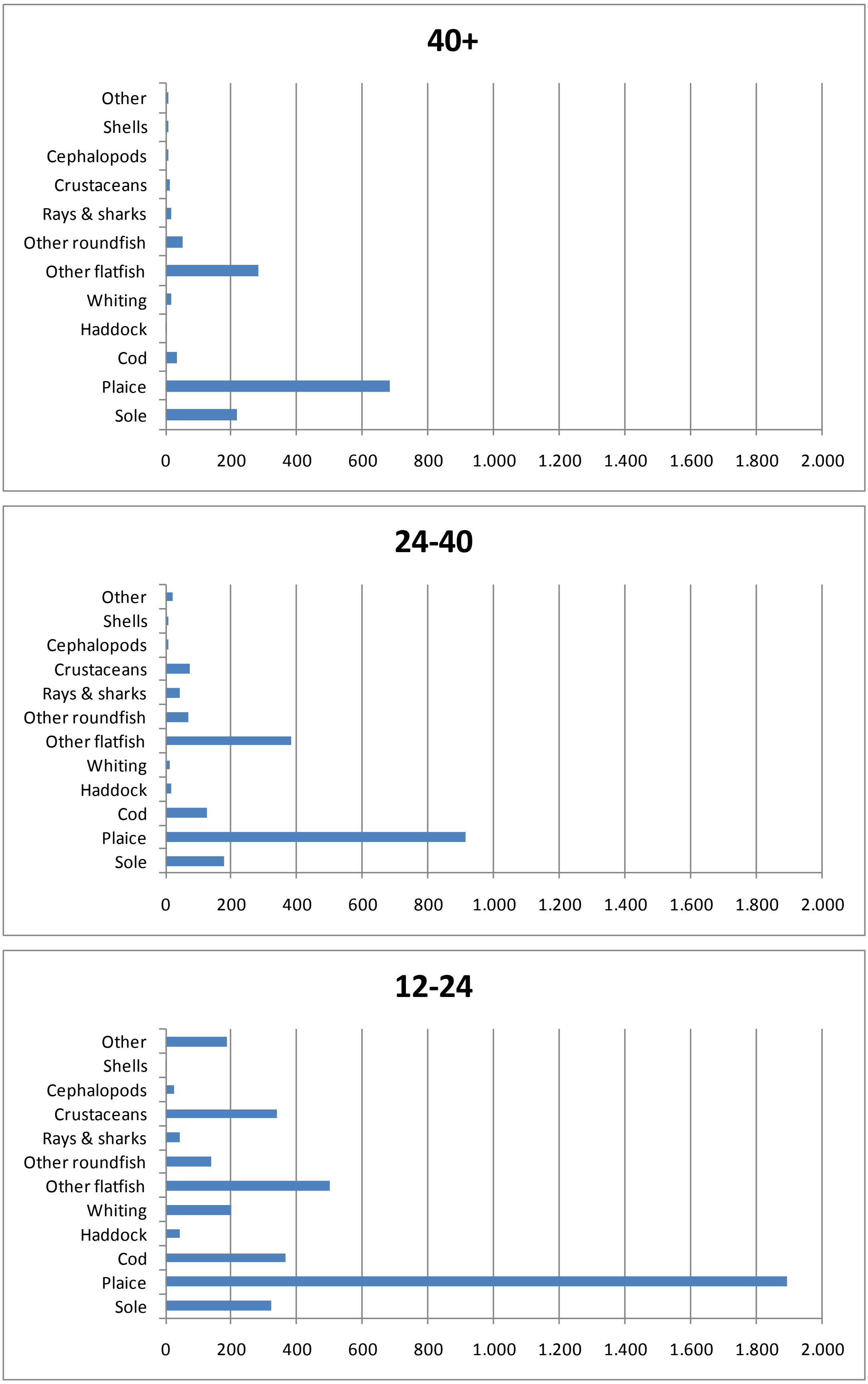


Figure 2.4. Landings per unit of effort (LPUE in kg/1000 kWdays) by vessel type and species group.

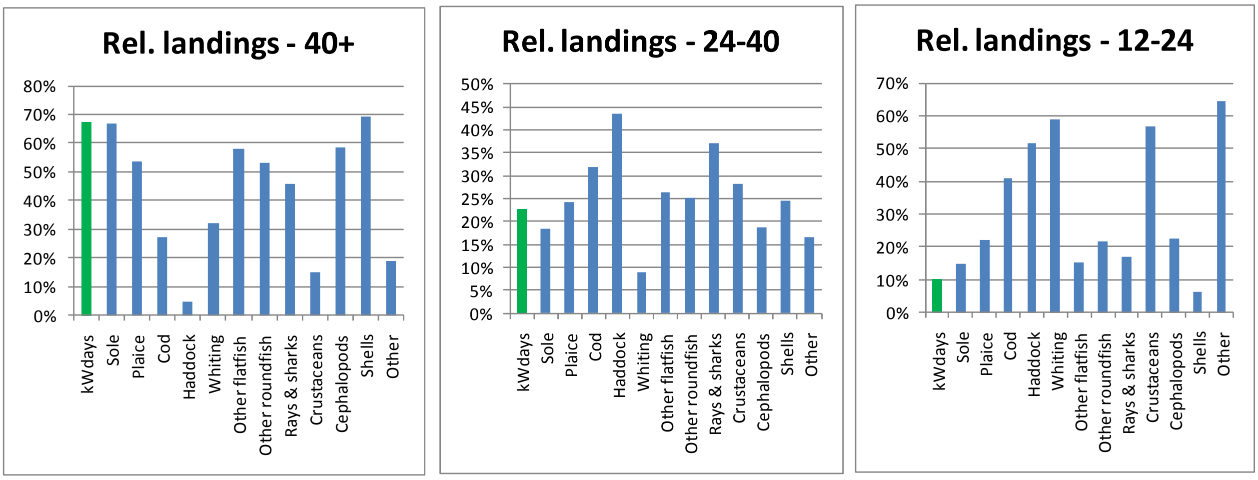
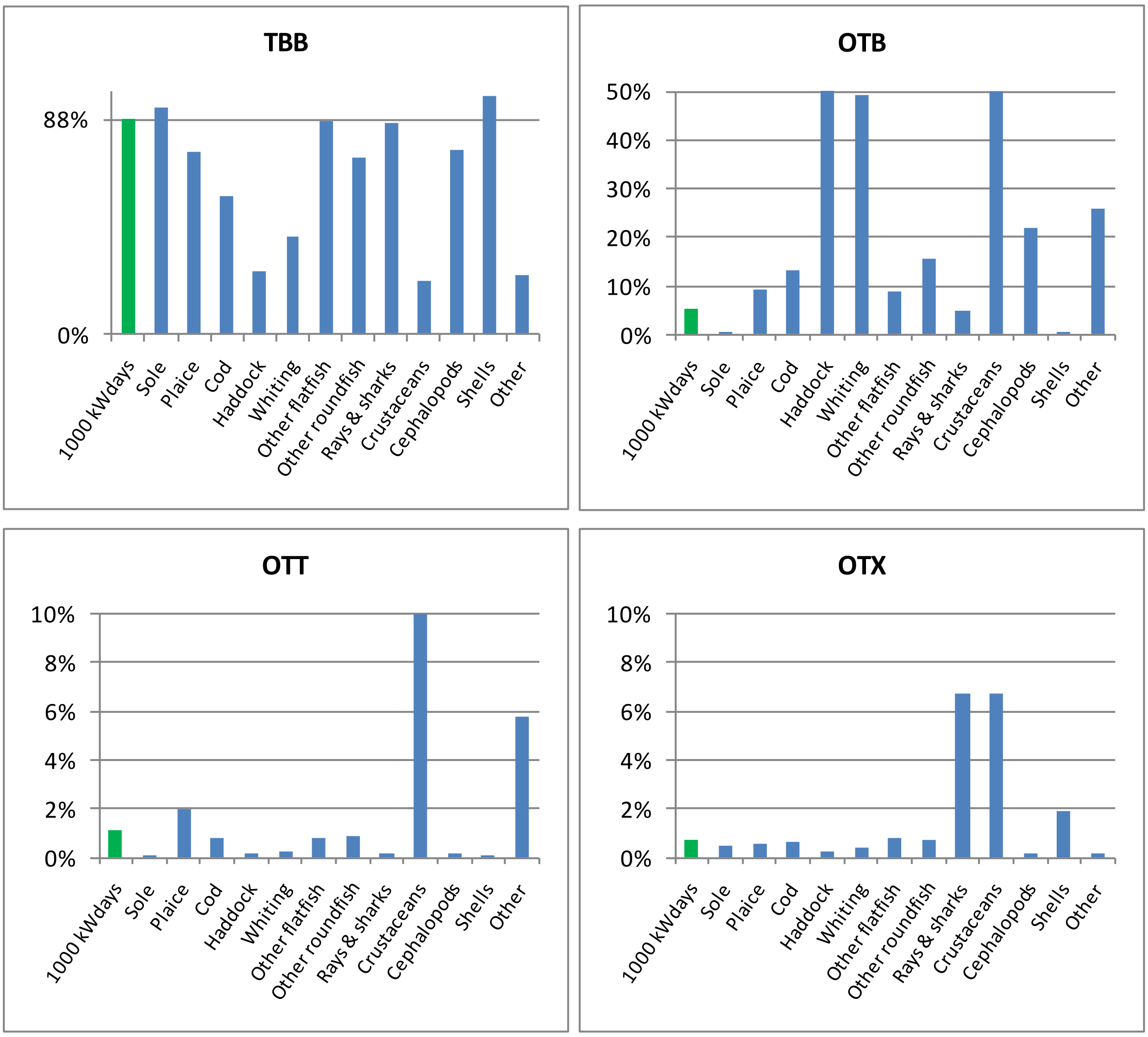


Figure 2.5. Relative fishing effort (based on kWdays) and relative landings by vessel length class.

Relative effort and landings by gear type relative to the total



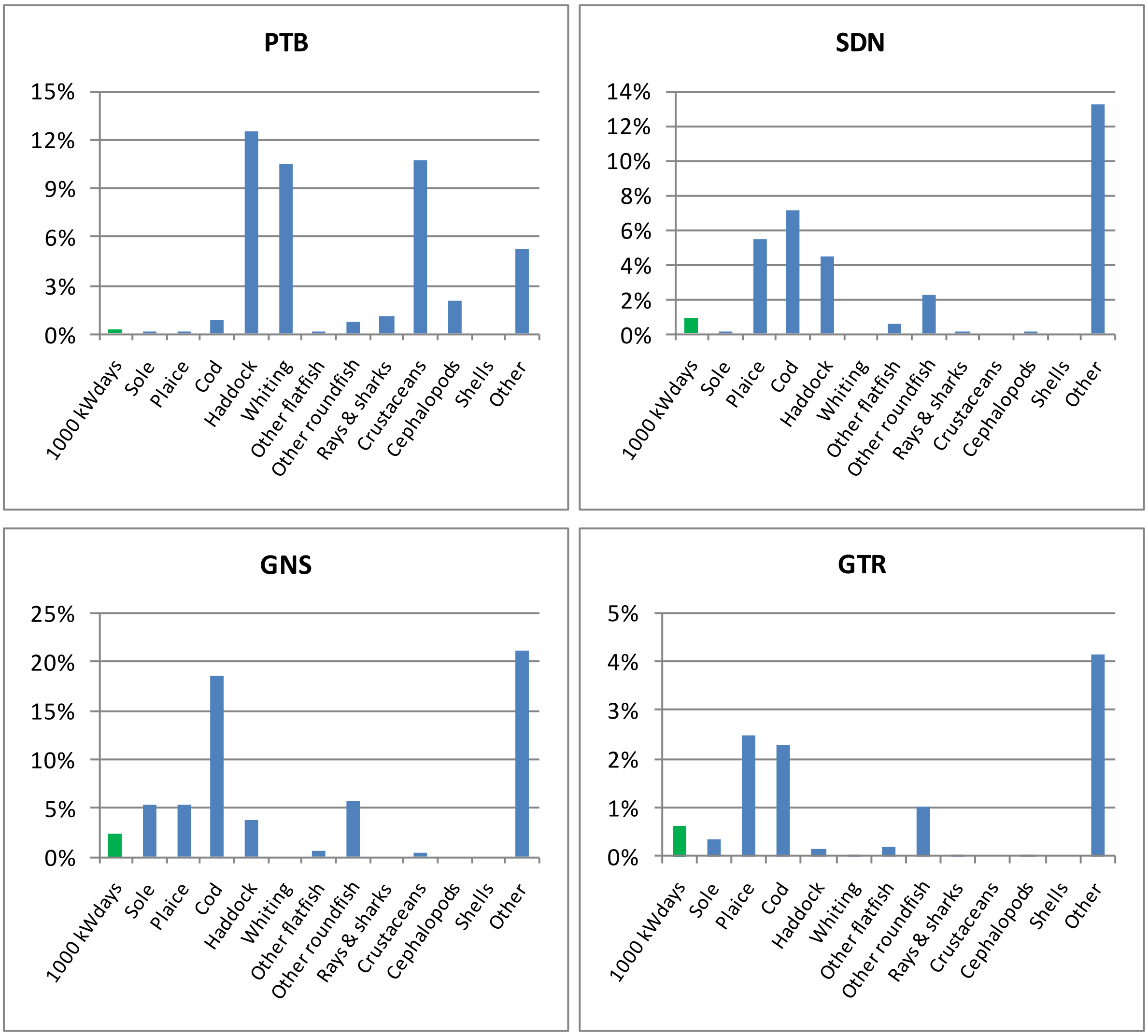


Figure 2.6. Relative fishing effort (based on kWdays) and relative landings by gear type.

3. DESCRIPTION OF THE FISHING METHODS, FUEL EFFICIENCY AND SEAFLOOR IMPACT

The loss of habitats in relation to fisheries is increasingly becoming an important issue. This is well reflected in international and national legislation, such as the EU Habitats Directive (92/43/EEC) amongst others (ICES, 2009) and the installation of the Natura 2000 network. As species like sole, plaice, cod, whiting etc. are bottom dwelling species, usually in close contact with the seafloor, all commercial bottom fishing for these species potentially impact the seabed. The impact of physical contact of bottom trawls affects biological communities (e.g. Kaiser et al. (2006), Schratzberger et al. (2009)) as well as the chemical (e.g. Dounas et al. (2007) and physical environment (e.g. Fonteyne (1999), Løkkeborg (2005)). All of those parameters constitute a habitat. This section focuses on the physical part of a habitat.

Physical impact in the broader sense, i.e. inclusive impact on sessile organisms that shape the structure of the seafloor, has been described by Rabaut (2009) as an introduction to a study on the effect of trawling on Lanice conchilega communities. Following is an extract out of the introduction of Rabaut (2009).

"Physical disturbance of the sea bottom by mobile fishing gear is considered to have a major impact on the ecosystem. Macrobenthos (i.e. bottom fauna defined as invertebrate animals larger than 1 mm) is recognized as fundamentally important in the functioning of marine ecosystems as is reflected in their inclusion in metrics to calculate the intrinsic biological value (Derous et al., 2007) or the environmental quality (Borja et al., 2003). In soft-bottom ecosystems, benthic densities and species richness are heavily determined by the seabed characteristics (mainly sediment types) (Bergman et al., 1991, Van Hoey et al., 2004, Vanaverbeke et al., 2000) and this benthic ecosystem component is important in determining the densities and species richness of higher trophic levels such as demersal fish (Cabral, 2000, Langton and Watling, 1990, Molinero and Flos, 1992, Rijnsdorp and Vingerhoed, 2001) and birds (Cramp and Simmons, 1977, Degraer et al., 1999, Godet et al., 2008, Van Waeyenberge et al., 2001, Von Blotzheim and Bauer, 1968, 1969).

These benthic environments are often under threat as fishing with mobile fishing gear is known to be a major cause of habitat deterioration in soft-bottom ecosystems (Dayton et al., 1995). Physical destruction of marine habitats has been reported as one of the main impacts of fisheries, with benthic communities particularly hard hit by trawling (Salomon, 2009). Kaiser et al. (2002) describe how macrobenthic productivity is decreasing as fishing intensity increases and high-biomass species are being removed from the benthic habitat. Jennings et al. (2001a) found that total biomass of infauna and epifauna significantly decreased with trawling disturbance. Moreover, there is plenty of evidence of damage and mortalities of invertebrates in trawl nets (Bergman and Hup, 1992, Brylinsky et al., 1994, Kaiser and Spencer, 1996, Schratzberger et al., 2002, Witbaard and Klein, 1994). Therefore, not only overexploitation is of concern, but also direct damage to benthic biota urgently needs to be addressed in areas where bottom gear is applied (Bergman and Hup, 1992, Kaiser and Spencer, 1996, Sparks-McConkey and Watling, 2001). However, the largely unknown temporal and spatial dynamics of target and non target species as well as of fishermen makes it difficult to find a link between species composition and fishing effort (Craeymeersch et al., 2004)"

"Ecosystem engineers

The structurally complex framework provided by emergent features constitutes an important organizing aspect and is critical to the functioning of many ecosystems (Jones et al., 1994). The relationship between structure and functioning owing to biotic-abiotic interactions was conceptualised in the idea of 'ecosystem engineering' (Jones et al., 1994, 1997, Wright and Jones, 2006). Ecosystem engineers are organisms that directly or indirectly modulate the availability of resources to other species by causing state changes in biotic or abiotic materials. In doing so they modify, maintain and/or create habitats (Jones et al., 1994). By reshaping the landscape, ecosystem engineers change the abiotic context upon which biotic interactions heavily depend (Byers et al., 2006). Due to their functional characteristics, ecosystem engineers can exert a strong influence on ecosystem properties that exceeds what may be expected based on their relative abundance alone (Hooper et al., 2005). The value of the ecosystem-engineering concept, therefore, lies in its ability to formalize interactions among organisms that are mediated by the physical environment (Wilby, 2002).

Emergent structures in marine ecosystems that reach a few centimetres into the water column can have a profound effect on the structure and functioning of marine ecosystems. The ecological effects of habitat structuring organisms lie in the increase of habitat complexity. They tend to dominate in stressful *environments (Jones et al., 1997) and therefore they are well described for all kinds of marine environments: coral reefs (e.g. Holbrook et al. (1990)), Darwin mounds (e.g. Van Gaever et al. (2004)), kelp forests (e.g. Steneck et al. (2003)), ascidians (e.g. Castilla et al. (2004)), sea grass meadows (e.g. Alfaro (2006), Hovel (2002)), mussel Banks (e.g. Hild and Günther (1999), People (2006), Ragnarsson and Raffaelli (1999)) , oyster beds (e.g. Lenihan (1999)) and polychaete tubes (e.g. Callaway (2006), Van Colen et al. (2008)). In many coastal sediments, they are known to have far reaching consequences (Bouma et al., 2009). These systems provide habitat for a wide range of taxa, including post-settlement juveniles of commercially important fish species (Watling and Norse, 1998). They may provide refuge from predation, competition and physical as well as chemical stresses, or may represent important food resources and critical nursery or spawning habitats. In addition, these structures modify the hydrodynamic flow regime near the sea floor, with potentially significant ecological effects on sedimentation, food availability, larval and/or juvenile recruitment, growth and survival. As such, habitat structures and heterogeneity influence faunal abundance, species richness and species composition of invertebrate and fish communities (Koenig et al., 2000, Turner et al., 1999). This engineering template has received less ecological attention than the processes generating spatial and temporal patterns of organisms within engineered landscapes (Crain and Bertness, 2006)."*

"… Therefore, in the marine environment, ecosystem engineers are key species when it comes to the preservation of both the ecological functions and fishing activities. Removal of ecosystem engineers by mobile bottom gear could have devastating effects on local biodiversity and important water-sediment processes (Coleman and Williams, 2002)."

Many authors (Jennings et al, 2000; Rijnsdorp et al., 1998) have stressed the importance of understanding the spatial and temporal patterns in fishing effort for investigating the effects of fishing in the marine environment. Reported effort from the national statistics provides a general picture of the areas where fishing effort is concentrated. The large-scale resolution, however, (by ICES statistical rectangle) provides a poor indication of the specificity of fishing grounds and thus the specificity of impact of fishing. Although VMS data (Vessel Monitoring System) are available today for scientific use within the EU, the data were not yet sufficiently accessible for supporting this study and address the different gear types. These data would allow a much more accurate and precise appraisal of impact of fishing gear, related to the biotope where they are deployed. Most studies available report on beam trawling.

Spatial analysis (Polet et al, 2010) indicates that the proportion of beam trawling increases from north to south in the North Sea, the proportion of otter trawling is higher in the Central North Sea and the deployment of set nets is highest at the Danish, the Dutch and the Belgian coast. This is similar to the observation of Jennings et al (2000) for the early nineties. There is a tendency for the effort to be concentrated in a limited number of statistical rectangles, as was also the case in the early nineties.

3.1. Beam trawls

3.1.1. The fishing method

The net of a beam trawl (Figure 3.1) is kept open horizontally by means of a steel beam, which is supported at each end by a trawl head. The length of the beam varies between 4 and 12 m depending on the size of the vessel and extant regulations. Flat steel plates, the sole plates, are welded to the bottom of the trawl heads. When fishing, the sole plates are in direct contact with the seabed and generally slightly tilted. To reduce the wear of the sole plates, a heel is welded to the aft end. Beam trawls are normally provided with tickler chains to disturb the flatfish from the seabed. On rough grounds the tickler chains are replaced by a chain matrix to prevent boulders from being caught by the net. The target species of the beam trawl fishery are flatfish, mainly plaice and sole. Light beam trawls, without tickler chains or chain matrices, are used to catch brown shrimps, Crangon crangon in coastal waters. Double-rig beam trawlers tow two beam trawls, one from either side of the vessel, by means of two derrick booms. The weight (in air) of a complete beam trawl varies from several hundred kg for a shrimp trawl to up to 7 tons (and more) for the flatfish trawls equipped with tickler chains. The towing speed varies between 3.5 and 7 knots.

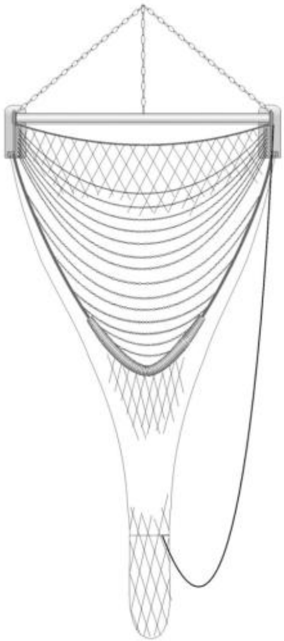


Figure 3.1. A beam trawl with chain mat (left) and with tickler chains (right).

3.1.2. Seafloor contact

The pressure on the seabed exerted by beam trawls is strongly related to the towing speed (Fonteyne, R., 2000). For a beam trawl, the pressure exerted by the trawl heads varied from 0.2 to 1.1 N/cm². The actual pressure can be 2-3 times higher if the sole plate is tilted. With increasing towing speed, the fishing gear will at a certain point leave the seafloor. Although larger vessels use heavier gears, this is compensated by the larger sole plate dimensions and the higher towing speeds.

By adjusting the length of the warp, the towing speed and the weight of the gear, fishermen will strive to a certain intensity of seafloor contact, irrespective the size of the gear or vessel. This seafloor contact will be a compromise between the efficiency of the gear in stimulating the fish and friction on the seafloor resulting in a certain level of fuel consumption. The experiments carried out by Fonteyne (2000) demonstrate that the intensity of seafloor contact does not differ strongly between the different sizes of bam trawls.

In practice fishermen will tune the intensity of seafloor contact to the type of sediment. On soft grounds, where the risk of fastening is high, seafloor contact will be less intense compared to harder grounds.

3.1.3. Physical impact

The parts of the trawl gear in closest contact with the seabed are the trawl head, the tickler chains or chain matrix and the groundrope. The pressure exerted by a beam trawl on the seabed is strongly related to the towing speed. As the speed increases the lift on the gear increases and the resultant pressure force decreases. A less firm bottom contact, e.g., on softer grounds, can also be obtained by shortening the warp length. In normal conditions the warp length/depth ratio is 3:1. For a 4 m chain matrix beam trawl the pressure exerted by the trawl heads varied from 1.7 to 3.2 N/cm² at towing speeds of 4 to 6 knots (Fonteyne 2000). Although larger vessels use heavier gears, this is compensated for by larger sole plate dimensions and higher towing speeds. The maximum average pressure exerted by the heels of the sole plate of a 10 m chain matrix beam trawl, weighing 5 tons, was 3.9 N.cm–2 (Paschen et al., 1999).

The pressure from the tickler chains or matrix chain elements is substantially lower than that exerted by the trawl heads, in the order of 0.5 N/cm² (Paschen et al., 1999), although the area covered is significantly greater. During the passage of a gear component the pressure in the sediment at a certain point will gradually increase up to a maximum and then gradually decrease. Model tests have shown that, irrespective of the weight of the gear, the reaction pressure is reduced to 10 % of the near-surface value at a depth of 10 cm and unchanged at depths greater than12.5 cm (Paschen et al., 1999). Whether benthic infauna can detect this change in pressure whether they would consequently react is unknown at present.

When towing a tickler chain or a chain matrix over the seabed, sediments will be transported and pass through and/or over the links and resettle after passage. Smaller particles will go into suspension and may be transported away by currents or resettle in the track of the trawl. Local variations in morphology such as ripples will be flattened out.

The effect of an array of chains running consecutively over the seabed is that the increase in penetration depth becomes less and the additional effect is smaller with an increasing number of chains. The passage of the first chain compacts the sediment, diminishing the effect of elements passing later. After about seven passages the increase in penetration is hardly noticeable (Paschen et al., 1999). Fluctuations in the pressure exerted on the seabed indicate that beam trawls are not in a steady contact with the seabed (Fonteyne 2000). Both variations in seabed morphology and vessel movements may cause a variable bottom contact of the gear. As a consequence the penetration depth is not constant along the track.

Measurements showed penetration depths between 1 and 8 cm (Paschen et al., 1999). The penetration depth depends on the sediment type. The largest values were noticed on very fine to fine muddy sand.

As for the otter trawls, the composition of the groundrope depends on the seabed condition. The tickler chain beam trawls, used on clean grounds, have a simple and rather light groundrope. The groundropes of chain matrix beam trawls, for use on rough grounds, are equipped with bobbins. Beam trawls leave detectable marks on the seabed. The duration that the beam trawl marks remain visible depends on the upper sediment layer and on the hydrographic conditions. On a seabed consisting of medium to coarse sand, tracks have been observed to remain visible for up to 6 days. On sediments with mainly finer particles a corresponding figure of 37 hours was observed (Fonteyne 2000, Paschen et al., 1999). A beam trawl passage also flattens the seabed and exposes shell debris at the surface (Lindeboom and De Groot, 1998) and thus also benthic organisms that become available as food.

3.1.4. Resuspension

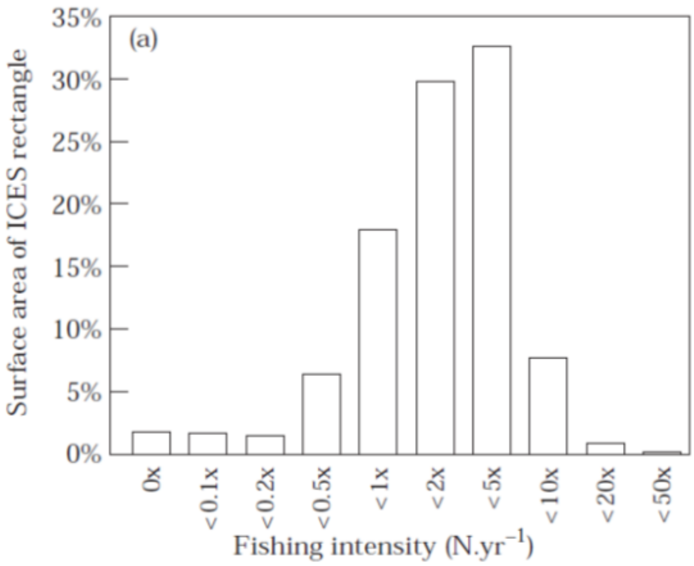
The movement of the gear causes resuspension of the lighter sediment fraction (Fonteyne, 2000)). The changes are more pronounced in areas with finer sand. The suspended particles settle within a few hours.

3.1.5. Effort and spacial issues

Jennings et al. (2000) used SPUE data (Sightings Per Unit of Effort) to demonstrate that parts of the ICES statistical rectangles are heavily fished while others are unfished. This was also apparent from Rijnsdorp et al. (1998) who used VMS data to determine the micro-scale distribution of beam trawl effort in the southern North Sea. Beam trawl activity proved to be very patchy with a high degree of overlap between vessels. For instance, in eight of the most heavily fished ICES rectangles (30 latitude1longitude), 10% of the seabed was trawled less than once every five years, 33% less than once per year, and 3% more than 10 times per year.

An interesting observation was made by Witbaard and Klein (1994) who studied (fishery-) scars in the shells of A. islandica collected at a location in the German Bight. They showed that scar frequencies increased over time in agreement with the increase in beam trawl effort, reaching a level of about 40% around 1990.

Rijnsdorp et al. (1998) found that beam trawling effort is patchy at the level of 30x30 and 3x3 miles squares and increasingly patchy for 10x10 miles square. Only at the level of 1x1 miles square the patchiness becomes less important and the fishery is rather random.



Poos and Rijnsdorp (2007) and Poos (2010) also indicated that target species of the beam trawl fisheries have a patchy distribution and that the effort distribution of the fleet is related to it. The observed seasonal patterns of catch rates concur with the seasonal distribution patterns revealed by tagging studies, the location of spawning grounds indicated by egg surveys and the location of nursery grounds indicated by pre-recruit surveys. Important for the relation between fishing effort and seafloor impact (in relation with different biotopes) is the predictable pattern in spatial distribution in both plaice and sole that changes seasonally in relation to adult migration patterns and juvenile recruitment. Superimposed on these seasonal patterns, local aggregations of fish may build up, which may only exist for only one or two weeks. Their limited persistence allows the fleet to concentrate on these hotspots, because fishers build up local knowledge on the resource distribution through exchange of information. Poos and Rijnsdorp also indicated that the patchiness of the flatfish species is likely to be related to the patchiness of their food and likely the type of benthic community. Marine organisms generally show a patchy distribution (Valiela, 1984) and this also applies to Annelida, Bivalvia and Crustacea in the North Sea (Duineveld et al., 1991; Künitzer et al., 1992), the main prey species of plaice and sole (Braber and De Groot, 1973; Rijnsdorp and Vingerhoed, 2001). The abundance and distribution of benthic fauna is highly dependent on sediment characteristics (e.g. grain size and silt content) and other environmental variables such as water depth and temperature. It is therefore likely that beam trawlers will concentrate their effort in certain biotopes which may have consequences or opportunities in the discussion on spatial planning in the North Sea.

The persistence of the local patches was estimated to be up to 2–3 weeks, which may reflect the time needed for a local concentration of plaice or sole to deplete the local density of its prey (Poos and Rijnsdorp, 2007). Alternatively, local patches of sole or plaice may be depleted by the fishery.

The consequence of using effort distribution based on ICES rectangles instead of a finer resolution becomes clear from Piet et al. (2000). The annual fishing mortality based on higher effort resolution or sediment-depth strata and ICES rectangles were on average a factor 0.61 and 0.63, respectively, lower than when a homogeneous fishing intensity for the entire stratum or ICES rectangle was assumed.

Seafloor impact cannot be generalized, not even within one gear type, because of the systematically different ecotopes that are fished. Smaller beam trawlers e.g. generally fish in coastal waters, whereas the larger ones fish in offshore waters and along the borders of the 12 mile zone and the plaice box (Piet et al., 2000). Piet et al. also demonstrated that the distribution of fishing activities of the larger beam trawlers in the northern part follows the contours of the sediment, suggesting that the distribution of the fleet is related to environmental characteristics. Deeper waters (>30 m) with sediments of medium sands are more intensively fished with about 38% of the surface trawled less than once a year. In contrast, 65% (depth <40 m) and 69% (depth 40 m) of the surface of the whole depth range of sediments with very fine sand were trawled less than once a year.

Usually, though, data availability is not sufficient to link “gear specific” trawling effort to clearly delimited ecotopes because the environmental variables available to distinguish different strata were restricted (Piet et al., 2000).

The main conclusions that can be drawn are that the impact of beam trawling is most likely restricted to a much smaller area than the total fished surface and that certain benthic communities are much more trawled and thus impacted than others.

3.1.6. Ecotopes

Rijnsdorp et al. (1998) state that it is likely that beam trawling will have a different effect according to the characteristics of the environment it is deployed in. According to Duineveld et al. (1991) the benthos in the southern North Sea can be divided into three different benthic clusters which were related to sediment characteristics. In shallow (<30 m) coastal waters and in the Southern Bight, the benthos is characterized by relatively small, highly productive organisms in shallow coarse sand or shallow fine sand, which are particularly resilient to physical disturbance. In these areas, physical disturbance is a natural feature due to strong tidal currents and the effect of storm surges. The deeper offshore waters (>30–40 m), coinciding with muddy sand, were characterized by a more sensitive cluster, including larger animals such as *Arctica islandica*. Since, despite the patchiness of the effort distribution, beam trawling occurs in areas with a different vulnerability to fishing, the impact may be comparable to natural phenomena in one area and may have serious consequences for the benthic ecosystem in another.

Rijnsdorp et al. (1998) also state that beam trawling may be micro-habitat specific. Hence, some specific habitats, and therefore specific benthic communities, can be exposed to intensive trawling much more than others. The areas of intensive beam trawling have already been trawled intensively for several years and still provide profitable fishing grounds. Without ample benthic food for plaice and sole, these fishing grounds would have lost their profitability for fishing. Beam trawling effort is directed to certain ecotopes and these withstand the impact

Piet et al. (2000) concluded that fishing mortality based on environmental strata differed considerably from the fishing mortality based on ICES rectangles, at least for some species. He explains this by the fact that both the benthos densities and the beam-trawl effort distribution seem to follow the environmental strata. This suggests that the spatial distribution of the fish that are targeted by the fleet is determined by the same environmental variables that determine the spatial distribution of the benthic species selected. The observation that these species still occur in the southern North Sea, in spite of estimated annual fishing mortalities over 50%, suggests that their populations are sustainable at the present level of additional mortality caused by beam trawling. This, of course, is no guarantee that all benthic invertebrate species originally present have been able to withstand these levels of fishing mortality. Presumably the species selected possessed life-history characteristics (e.g. early reproduction, high reproductive rate, and low longevity) that enabled them to maintain a population in spite of the beam-trawling activities. Densities of species that do not possess such life-history characteristics might have decreased because of commercial trawling earlier this century (Lindeboom and de Groot, 1998) to such low levels that they could not be used in this study.

It has been suggested by different authors that the increased growth rate of plaice and sole in the 1960' and 70', which coincided with the introduction of the beam trawl, was causally linked with beam trawling (Rijnsdorp and Vingerhoed, 2001). De Veen (1976) postulated that beam trawling contributed to the increase in growth rate by enhancing the availability of food through damaging benthic organisms in the trawl path. Several studies have shown scavenging behaviour in dab, whiting, cod, dragonet and dogfish (Arntz; Kaiser; Ramsay and Fonds). Benthic predators may also have benefited if repeated beam trawling results in a change in the species and size composition of the epi- and infauna towards highly productive small and short-lived species at the expense of the low-productive larger and long-lived organisms (ICES, 1988 and Rijnsdorp).

Rijnsdorp and Vingerhoed (2001) found that beam trawling has indeed improved the feeding conditions for plaice and sole by enhancing the abundance of opportunistic species like polychaetes in the heavy trawled areas, although eutrophication may also have played a role. The observed increase in growth rate of both sole and plaice species, which prey mainly upon the smaller opportunistic benthic species, may be a result of the increased productivity of suitable benthic food in the heavily trawled areas (de Veen, 1976; Rijnsdorp and van Beek, 1991; Rijnsdorp and van Leeuwen, 1996, Rijnsdorp et al., 1998).

3.2. The flatfish pulse trawl

The principle of the flatfish pulse trawl is that electric pulses are being used as an alternative stimulation for the mechanical stimulation of tickler chains. The electric field is generated by a pulse generator mounted on the beam of the trawl and the pulses are released to the seawater through electrodes rigged longitudinally in the net mouth.

The system was invented by Piet Jan Verburg from Colijnsplaat (Netherlands) in 1992 and was purchased by the ministry for Food Quality in 1998. In 2005, the UK 153 was equipped with two pulse nets to test the system in the field. In 2006, the UK153 fished fulltime using the pulse net. At the end of 2006, the European Community gave permission for pulse-fishing for 5% of the fleet in the North Sea.

Two similar systems are being developed and are currently tried in commercial conditions in the Netherlands (Figure 3.2) being the pulse trawl developed by Verburg ltd (Nl) and the PulseWing designed by HfK Engineering (Nl). The former is being tested aboard TX 68 and the latter aboard TX 36.

Figure 3.2. The currently tested two varieties of the pulse trawl: Verburgh Ltd design (left), HfK design (right).

In principle this trawl remains a beam trawl since the net is held open horizontally with some sort of beam. The pulse trawl however lacks the heavy tickler chains which significantly reduces the seafloor and benthic impact. The towing speed has been reduced from some 7 kn to somewhat more than 5 kn which decreases the fished surface and thus benthic impact. The average penetration depth has also been reduced from over 2.5cm to less than 1cm (Table 3.1). Fuel consumption is at least 45% less and anecdotal information points at a further reduction with the PulseWing.

The fish caught are in principle not killed or paralyzed by the electricity, but are only startled. This is in contrast with traditional electro-fishing, which is forbidden without a license.

Table 3.1. Data on the pulse trawl.

	Pulse trawl small beam trawler	Pulse trawl large beam trawler
Fuel consumption	-45%	-45%
Towing speed (kn)	4.5	5.5
Horizontal net opening (m)	=	=
Sediment penetration (cm)	0.9	0.8

Preliminary field trials have indicated reduced discards with the pulse trawl compared to the traditional beam trawl. First of all, from the field data it cannot be distinguished whether the lower discard rates are due to a better selectivity or because of the lower towing speed. It seems logical that the lower towing speed will have a significant effect on by-catch and discards of non-target species but there is also evidence that lower catch weights in the cod-end may improve selectivity (although evidence exists that proves the contrary). Insufficient data are available to draw firm conclusions.

On the issue of escapee mortality, the following can be said based on the recent laboratory experiments carried out by IMARES:

Lesser spotted dogfish: No evidence was found of differences in feeding response or likelihood of injury or death between the exposure groups. There was no evidence that fish sustained injuries as a result of the exposures. Respectively 8 and 9 months after the experiment a single specimen of the “above field” category and “near field” category died. In the 14 days observation period after the exposures no aberrant feeding behaviour could be distinguished. Fish in all tested groups started feeding normally the same day directly after the exposures. In a period of 7 months after the exposures all exposed groups produced eggs in numbers varying between 5-39 per group. Surprisingly the control group did not produce eggs.

Cod: The fish exposed in the “far field” range, representing the fish just outside the working range of the trawl, showed hardly a reaction to the exposures and responded normally to the feeding cycles. The fish exposed in the “above field” range showed a moderate contraction of the muscles, but all recovered well and responded normally to the feeding cycles. The effects on the fish exposed in the “near field” range were more pronounced, 4 fishes died shortly after the exposure, and another 2 died in the observation period thereafter. In the observed period of 14 days after the exposures the surviving fish packed together outside the feeding zone and hardly responded to the feeding cycles.

Post mortal analysis using X-ray scans revealed that 5 out of 16 remaining fishes exposed in the “near field” range had hemorrhages close to the vertebral column, and of these five, 4 had vertebral bone fractures. No injuries were found on the fish exposed in the “above field” range, that showed weaker reactions to the electric exposure.

It must be noted that the smallest fish in the series tested was 41cm, thus well above MLS. Regarding escapee mortality, only small fish can be taken into account, i.e. the ones that can escape an 80mm mesh. The results for small fish can be different from the large fish because the intensity of the electric field decreases with the length of the fish.

Benthic invertebrates: For two species (ragworm and European green crab) a 3:5% statistically significantly lower survival was found compared to the control group, when all exposures were lumped together. For the near field exposure a 7% lower survival was also found for Atlantic razor clam. For the other species (common prawn, subtruncate surf clam, common starfish) no statistically significant effects of pulses on survival were found. Surf clam seemed not to be affected at all, common prawn seemed to show lower survival in the highest exposures (near and medium field), while common starfish showed lower survival, but not for the highest (near field) exposure.

Food intake turned out to be significantly lower (10:13% less) for European green crab, except in the far field exposure for which the reduction (~5%) was non-significant. No effect at all was found for ragworm, surf clam and razor clam, lower food intake for common prawn, and higher for common starfish, but all these results were statistically non-significant.

Surf clam and starfish did not show any behavioural reaction at all, they did not move. The other species showed very low responses in the far field exposure range. In the medium and near field ranges the reactions were stronger. Food intake and behaviour recovered after exposure.

In general terms the effects of the pulse stimulus in terms of mortality and food intake can be described as low. It is therefore plausible that the effects of pulse beam trawling, as simulated in this study, are far smaller than the effects of conventional beam trawling.

ICES WKPULSE: The reviewing experts concluded that there is primarily more information needed on the effect on cod before the pulse trawl can be allowed on a commercial basis. The reviewing experts could not be convinced that the simulator provided an adequate representation of the in situ pulse, due to the fact that they were not able to review the specifications of the pulse characteristics resulting from confidentiality issues. They recommended that a three-dimensional temporal-spatial model of exposure of cod inside the trawl using information about behavioural responses validated by direct underwater observation would be useful. Furthermore it was suggested to investigate the effect of pulses on the electro-receptor organs of elasmobranchs, and determine the catch rates of these fish in beam trawls. Also to look at other gadoid species: e.g. haddock, and whiting. It was also suggested to investigate the effect of the pulse on the reproductive capabilities of benthos, but weigh this against the mortality in the conventional tickler chain beam trawl.

3.3. Sumwing

The Sumwing (Figure 3.3) is a wing shaped hydrodynamic trawl beam assuring the horizontal opening of the net. It has been designed by the Dutch company HfK Engineering to reduce the hydrodynamic resistance of the beam trawl beam and increases its effectiveness with increasing fishing speed (and thus turbulence).

The wing is steered by the nose (Figure 3.4). The equilibrium of the hydrodynamic and gravitational forces in the warp, wing or beam, and the net with tickler chains, tilt the wing downwards so that the gear is sent to the seafloor. Once the nose touches the seafloor, it causes the wing to tilt upwards until it is in a hydrodynamically neutral position. The nose is an essential part of the gear and allows the gear to closely follow the surface profile of the seafloor.

A Dutch (van Marlen et al, 2009) and a Belgian report (Huyghebaert et al, 2010) have reported first results of commercial trials. Fuel savings reported were 11% (van Marlen et al, 2009) to 13% (Huygghebaert et al, 2010), avg. 12%. Recently fuel savings up to 23% have been reported.

The difference in penetration depth has been calculated as follows (van Marlen, pers. comm..):

Gear characteristics of a standard beam trawl (Paschen et al., 2000):

- Beam trawl shoe width: 0.5 m
- Gear width: 12 m
- Chain link thickness: 20 mm
- Penetration depth_1: 11 mm
- Penetration depth _8: 20.4 mm (factor 1.857, because > 7 tickler chains)
- Penetration depth_shoe: 40 mm

Characteristics of the Sumwing:

- Penetration depth nose: 40 mm
- Nose width: 0.24 m

We assume for the standard gear that the tickler chains touch the seafloor at 0.25 * shoe width from the outside and that both gears have the same tickler chains.

The average penetration depth of the standard beam trawl can be calculated as:

$$APD = ((GW - 2 * BTSW) * PD\_8 + 2 * BTSW * PD\_shoes) / GW = \mathbf{22.9mm}$$

APD = Average penetration depths

GW = Gear width

BTSW = Beam trawl shoe width

PD = Penetration depth

For the Sumwing this equation transforms to:

$$APD = ((GW - 0.5 * BTSW) * PD\_8 + NW * PD\_nose) / GW = \mathbf{20.6mm}$$

NW = Nose width

This is a reduction of about 10%.

Figure 3.3. The Sumwing in action in between hauls.

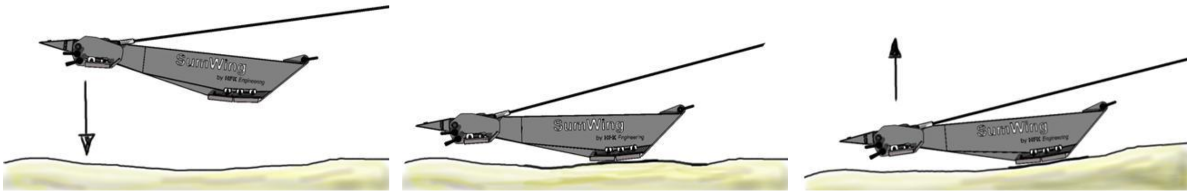


Figure 3.4. The functioning of the nose of the Sumwing (towing direction is to the right)

3.4. Hydrorig

The Hydrorig is subject of a project development in the Netherlands aiming at a reduction of fuel consumption and benthic impact. The principle of this fishing gear is that the traditional tickler chains of the beam trawl have been replaced by half-circular cups (Figure 3.5). These cause turbulence in the water which acts as an alternative stimulation for the flatfish that are buried in the sediment.

The project is still in the experimental phase. Maintaining the commercial catches and reducing the benthos by-catch have been the major focus of this project. The success rate has been very variable.

Figure 3.5. The beam and the beam trawl shoes of the Hydrorig equipped with cups.

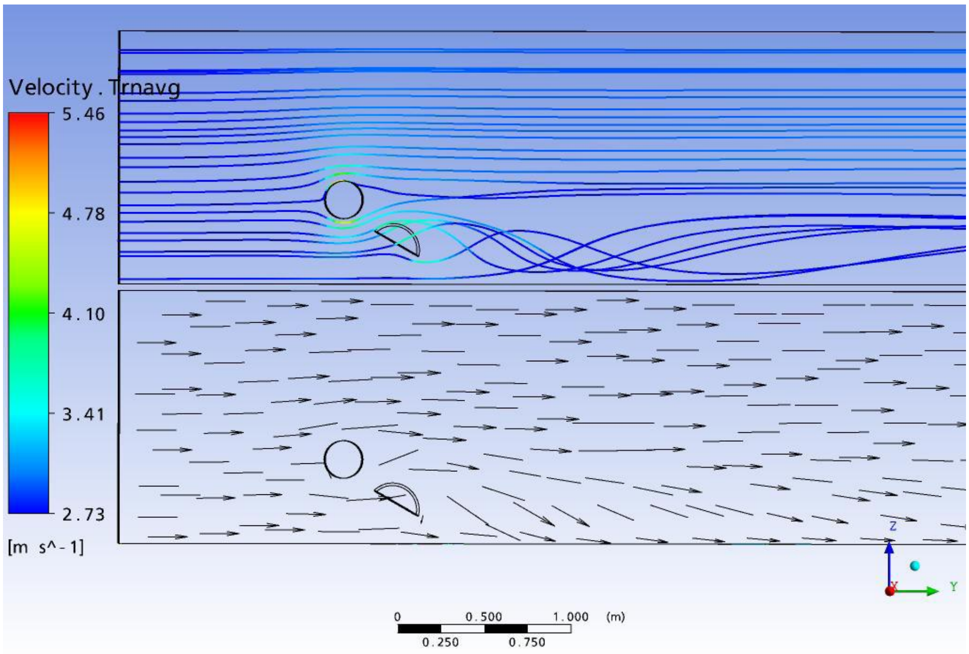


Figure 3.6. Output of a simulation with the Hydrorig (Source: Delares, Nl).

3.5. Otter trawls

3.5.1. The fishing method

The gear components of a demersal trawl are (1) otter boards, (2) bridles/sweeps and (3) the ground gear. In a multirig configuration, weights are additional parts of the trawl system: (4) e.g. a roller clump for twin trawls.

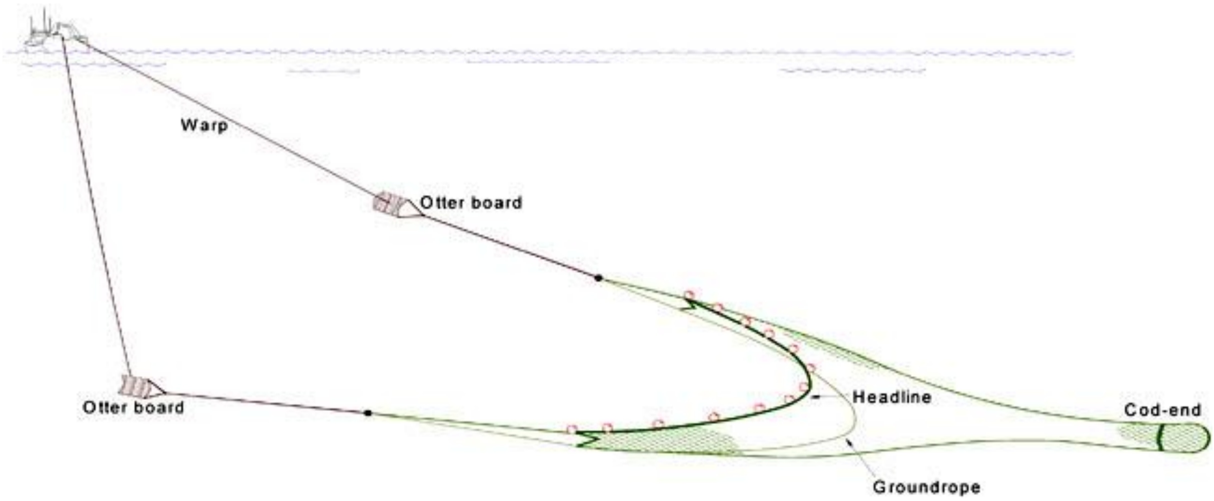


Figure 3.7. The basic components of an otter trawl ©FAO.

Bottom otter trawls encompass a large variety of designs, riggings and dimensions. Towing speed ranges from 2 knots (1 m/s) to 6 knots (3 m/s) and fishing might be conducted at depths from 10 to 2,500 m. A bottom trawl design generally consists of netting divided into two wings, a belly and a cod-end. The front part of a trawl is framed with a headline often equipped with floats along the top and a fishing line along the bottom equipped with various types of ground gears (Figure 3.8) the purpose of which is to protect the netting of the trawl from damage and to allow continuous towing without hook-ups.

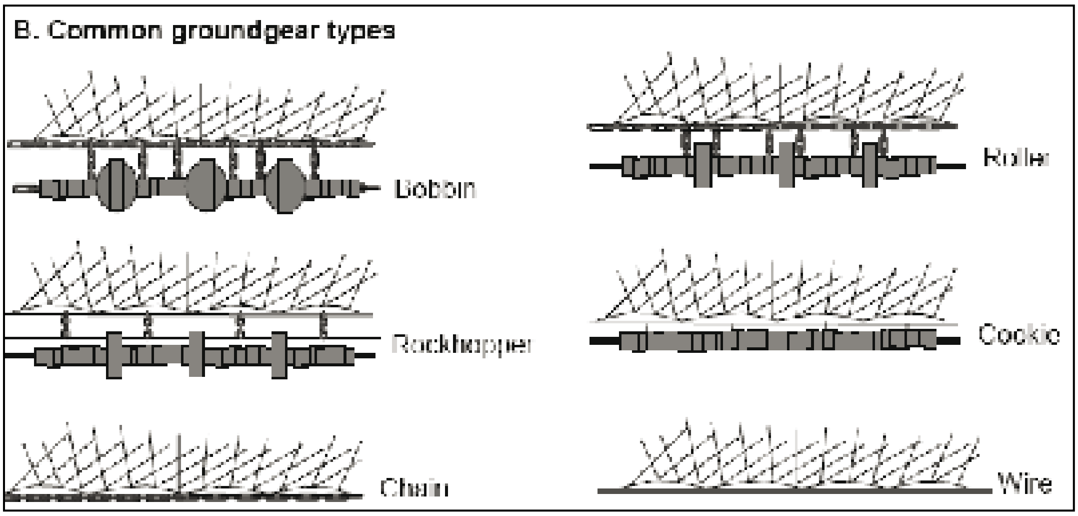


Figure 3.8. Examples of common groundgear designs used in commercial fisheries (Source: He et al., 2006).

In a bottom otter trawl rigging the trawl is held open horizontally with a pair of trawl doors which have three main functions:

- to open the trawl horizontally;
- to provide the front bottom contact points of the trawl gear; and
- to stimulate fish to swim towards the trawl path.

Trawl doors (otter boards) are rigid structures that use hydrodynamic forces and weight to depress the trawl to the seabed and to spread it horizontally. The earliest trawl doors were simple flat plates that were longer than they were high (low aspect ratio) and derived spreading force from both hydrodynamic forces and shearing against the seabed. Flat doors also create strong turbulence, suspending sediment (sand cloud) in their wake. In some fisheries, this sand cloud is an important part of the capture system. Advances in trawl door design have included changes to increase their hydrodynamic efficiency, usually reducing turbulence and resulting sediment suspension. This has included higher aspect ratio doors that rely very little on seabed contact for spreading force, have a smaller footprint and produce much less sand cloud.

While towing, the shoe of a trawl doors is often angled relative to the trawl track. When a door is 4 metres long, the width of the track is thus 2 metres with a door angle of 30 degrees.

In a double trawl rigging a weight is used to achieve bottom contact of the front part of the inner sweeps/bridles located in the centre between the two trawl nets. This weight might be heavier than the weight of a trawl doors (normally 30 percent heavier in double trawl riggings). The weights differ in shape and rigging, and their effect on the bottom will vary.

The doors and weights are connected to the trawl wings by sweeps or bridles (wire/chain/ropes). These connections vary in length from a few meters up to a few hundred meters. The lower bridle or sweep has normally bottom contact during towing.

3.5.2. Physical impact

The passage of an otter trawl was found to have a generally minor physical and visual impact on the seabed compared to beam trawling (Lindeboom and De Groot, 1998). The main physical effect of otter trawling appears to be the tracks left in the sediment by the trawl doors.

Otter trawls have several components that contact or approach the seabed and variations in the composition and design of these components influence their effects on benthic ecosystems. For example, in a study of the marks made by one otter trawl, Brylinski et al., found that 12 % of the seabed in its path was noticeably changed. Marks included narrow, scraped areas created by the doors and the compressed tracks of the spherical footrope bobbins. No marks were apparent in the area covered by the bridles. A change from silty to sandy substrate resulted in shallower door tracks and a disappearance of the roller tracks. A heavier door deepened the door tracks.

Trawl door marks are the most recognizable and frequently observed effect of otter trawls on the seabed (Caddy 1973, Friedlander et al., 1999). Doors travel across the seabed oriented at an angle to the direction of travel. The resulting marks consist of an area scoured by direct contact and a berm of sediment displaced toward the trawl centerline (Gilkinson et al., 1997). Of the major components of a trawl, doors affect the smallest area of seabed, usually producing two swaths totaling a few meters in width. The downward force exerted by the door on the seabed and the width of that contact affect the extent of these marks. The weight of the door is partly cancelled by the upward force from the cables attaching it to the towing vessel. The vertical attitude of bottom trawl doors is generally adjusted so that hydrodynamic forces have a small downward component, increasing the force of seabed contact (Seafish et al., 1993). The design of the door can influence the degree of contact significantly. The v-door traditionally used in many *Nephrops* fisheries in Europe is designed with a hinged bracket to which the warp is attached. The door is designed to have only light contact with the seabed because it is used on muddy grounds where digging in must be avoided. The hinge also allows the main plate to swivel when an obstruction such as a large boulder is encountered. However, because of its inefficient hydrodynamic shape seabed material is put into suspension by the vortices behind the main plate. The dimensions of these trailing clouds of suspended matter behind some types of otter boards are reported in Main and Sangster (1981).

Bridles or sweeps are cables that connect the trawl doors to the trawl net and may be in contact with the seabed for part of that distance. The selection of length of these cables and their angle of attack, which determine the area of seabed that they sweep, will be based on the herding characteristics of the target species. Flatfish trawls may be fished with bridles longer than 200 m, while shrimp trawls usually have short bridles. Sometimes, bridles are covered with hose or strung with a contiguous series of rubber disks (cookies), up to 15 cm diameter, to protect the cables and to increase their 110 herding effectiveness. The length of bridle wires is also dependent on the seabed type. On rough ground where there is a high risk of snagging on boulders or other obstructions, only short wire lengths are feasible. When using long bridles to target herdable species, the bridles contact more seabed than any other trawl component. The force of contact of these sections with the seabed results from their weight (in water) per length. Unless chain is used, or supplementary weights are added, this limits their action to skimming the surface of the seabed. Small scale vertical features on soft substrates can be flattened by this action. Emergent structures and organisms can be vulnerable to penetration or undercutting by bridles, especially where the bridles have a small diameter. The ease with which wires travelling across the seabed can be displaced upwards by these structures will be reduced as the tension in the wire increases.

Footropes are the components of a trawl that are directly attached to the lower, leading edge of the net and contact the seabed. They have two, often conflicting, functions of separating the target species from the seabed and raising the netting far enough above the seabed to prevent damage. Large diameter footropes protect the netting more effectively, but may inhibit fish from passing back into the net and allow more opportunities for escape under the net. Footropes are constructed similarly to bridles, with a cable or chain that may be covered with protective material. Diameters are commonly larger than bridles (up to 1 m) and often vary along the length. Thus only part of the footrope may be in direct contact with the seabed. The footrope and bridles cover most of the area swept by a trawl, and the proportion of that covered by the footrope is dependent on the relative length of the bridles. Footrope effects are influenced by the contact force and the area over which it is distributed. Allowing footrope components to roll may reduce these effects, but this generally only occurs in the center section of the footrope.

Some protective groundgears are designed specifically so that the components do not roll, e.g., so-called rockhoppers, because the action of the rockhoppers when they hit an obstacle is to turn back under the belly netting and lift it over the obstruction. A large diameter footrope component can produce a vortex in its wake, contributing to sediment suspension. This large diameter also makes a component less likely to undercut emergent structures or to penetrate the substrate, but more likely to run over them. The downforce on the substrate exerted by the footrope is dependent on the weight per unit length (which may vary along the length) and by the up-pull from the netting to which it is attached. Nets that are designed to fish on rough ground will have steeply tapered netting behind the footrope to reduce the chance of damage. The general design criterion for a footrope is to ensure that it has sufficient positive restoring downforce to maintain seabed contact when disturbed from equilibrium (e.g., by a boulder).

Auxiliary weights may be added to trawl gear to increase downward force at various points. Weights installed at the lower corners of pelagic trawls may contact the seabed when these are fished near or on the seabed. Clump weights are used to depress the center bridles of a twin trawl rig, where two trawl nets are fished side-by side with only two doors. The pressure that these exert on the seabed is the resultant of their weight in water and the upward forces exerted on them by other gear components.

On most trawls, the netting itself is not designed to directly contact the substrate and anything that protrudes far enough above the seabed to contact the netting has already been overrun by the footrope. The netting may retain objects and organisms that are undercut or suspended off the seabed by passage of the footrope. When rocks enter a cod-end or it becomes loaded with dense fish (i.e., flatfish), the cod-end may be weighed down enough to drag on the seabed.

Pair trawls are fished between two vessels. They have similar components to otter trawls, except that doors are no longer necessary to spread the gear. Weights may be used to sink the sweeps to the seabed. To maximize swept area, much longer sweeps are used than with otter trawls. Thus, the above discussion applies to pair trawls except for references to doors.

3.6. Demersal seines

The text on demersal seines has been based on the draft 2010 report of the ICES Working Group on Fishing Technology and Fish Behaviour (WGFTFB). The authors are:

Haraldur A. Einarsson	MRI – Iceland
Dominic Rihan	BIM – Ireland
Sonia Mehault	IFREMER – France
Quiterie Sourget	IFREMER – France
Ulrik Jes Hansen	Catch-Fish, - Denmark
Rob Kynoch	Marine Scotland Marine Laboratory Aberdeen
Petri Suuronen	FAO

3.6.1. The fishing method

The fishing method of seining is reputed to have first been carried out by a Danish fisherman, Jens Laursen Vaever, in 1848. This method of seining, known as anchor seining, is still carried on in Denmark and other countries today. In the early 1920s Scottish fishermen developed a different method of seining which dispensed with the need for an anchored dhan, but which utilized the thrust of the vessel’s propeller to balance the drag of the gear as it was slowly winched aboard. Over the years Scottish seining, or fly-dragging, as the method came to be known, has firmly established itself as an important method of capture used by demersal fleets in a number of countries.

Seining, either fly-dragging or anchor seining, are considered to be “environmentally friendly” fishing methods with a number of positive benefits. Traditionally the gear used tended to be of much lighter construction and as there are no trawl doors or warps, results in less impact on the seabed than trawling. The use of such light gear also means the method is very fuel efficient. Another positive aspect of the method is that fish are only caught in the very last part of the capture process, and therefore are not in the cod-end of the net very long leading to high catch quality of fish compared to trawled fish.

In recent years the fuel prices have steadily increased and attention has once again shifted to this method of fishing. There has been a switch back to this method in some countries e.g. Scotland and Ireland and interest in developing the technique in other EU countries, notably France and Netherlands and further afield in countries such as the Philippines and South Africa. While there is no doubting the positive benefits of seining as indicated, concerns have been expressed that there are negative aspects associated with the method that should be addressed, given the increased interest and adoption by fishermen globally.

A WGFTFB Topic Group was formed to address this TOR. This Topic Group met from 20th-22nd May in Ancona. Initially the TOR was introduced by the chair along with Harldur Einarsson of Iceland. Following the discussions of the Topic Group the conveners reported back to plenary WGFTFB.

There are essentially three seine net techniques used around the world and although there is a huge amount of variation with respect to net design, seine rope weight and lengths used most Danish seine net operations can be categorized under three headings as follows:

- Anchor seining
- Scottish seining (Fly-dragging or fly-shooting)
- Pair seining

Purse seining is not discussed under this term of reference.

Scottish Seining (Fly-dragging)

Scottish seining is well described by Galbraith and Rice (2004). This fishing method depends on long lengths of rope used, up to three kilometres a side, herding fish into the path of a net as the gear is hauled back slowly. The gear is set roughly in the shape of an isosceles triangle with the dhan, which marks the end of rope first shot and to which the vessel returns to complete the set, as the apex and the net as the centre of the base. Having picked up the dhan the vessel then starts to steam slowly ahead while heaving in both ropes, gradually advancing winch speed as the gear closes to keep the net moving forward at a steadily increasing rate.

Danish Anchor Seine

"Anchor seining", evolved in Denmark and is the original seine netting technique from which "fly dragging" described above was a later development. As described by Sainsbury (1996), basically, the operation does not defer so much from fly dragging except that the marker buoy is anchored while hauling, and the warps and net are closed entirely by winch. The net is set out from an anchored dhan (marker) buoy. The operation is carried out directly by the main vessel, so called "seiner" or sometimes from an additional smaller boat. First, one drag line is put into the water, then one net wing follows and, while the seiner turns round in a surrounding move, back to the buoy, the setting continue with the bag of the seine, then the other wing, then, finally, the other drag line. Hauling in of the net is carried out using the two drag lines by the boat anchored at the marker; the two drag lines are simultaneously hauled with the help of a rope-coiling machine until the bag with the catch can be taken on board the vessel.

Pair Seine

Pair seining is a technique developed in Scotland as a more efficient and simpler method than traditional single boat seining. As reported by Galbraith and Rice (2004), pair seining involves a second vessel picking up the dhan and both vessels towing the gear in the manner of a demersal pair trawl before hauling as per single seining. After one vessel shoots its net the bridles are passed across to the partner with the aid of a messenger and connected to the heavy sweep wire. Both boats pay out wire and rope as they steam ahead to take up towing positions. At the end of the haul both boats come together again and the previously transferred bridle is passed back to allow the first vessel to complete hauling operations. This procedure substantially increases the area of seabed swept by the gear and can improve catches when fish concentrations are small and widely dispersed. However, pair seines are now commonly rigged, shot and hauled similarly to pair trawls, with wire towing warps and sweeps in front of 880 m of polypropylene seine net combination rope per side. Vessels maintain station up to 0.5 nautical miles apart while towing.

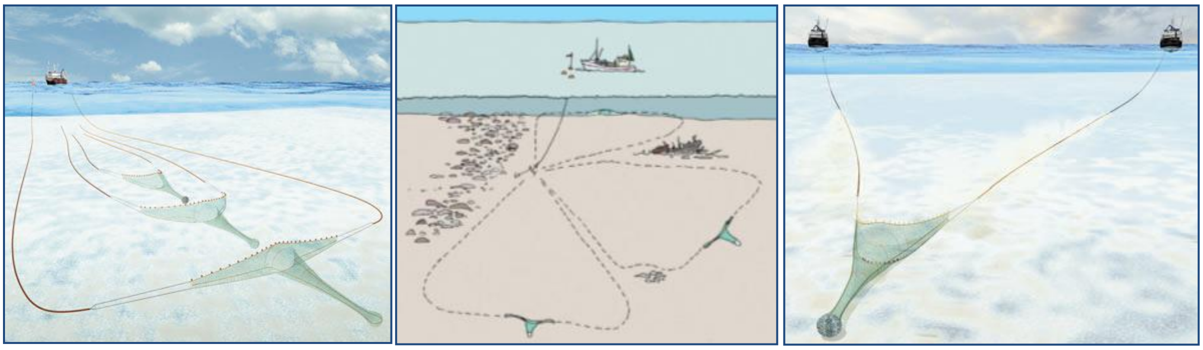


Figure 3.9. Scottish Seine, Danish anchor siene and pair Seine (© Crown copyright – taken from ICES, 2010).

3.6.2. Assessment of the fishery

There are undoubtedly many positive benefits of seining when compared to trawling with respect to bottom impact, fuel economy and fish quality, however, concerns have been expressed that there are negative aspects associated with the method that should be addressed. In some Danish/Scottish seine fisheries there are concerns about levels of discarding and high-grading as seine netters aim to maximize returns. Also as the pressure on grounds increase and seiners are forced into areas of harder ground, there is evidence of technological creep in seine net design with much heavier seine ropes and heavy hopper footropes now commonly used. There are similar concerns in some quarters in the adoption of seine net techniques by French and Dutch vessels given these vessels are often targeting non-quota species such as red mullet for which there is little or no scientific assessment.

Fuel Efficiency

In most forms seining has been demonstrated to have lower fuel consumptions compared to other mobile fishing gear methods but age and design of the fishing vessel is important and some of the newer vessels built as dual purpose seiners/trawlers may have higher engine horsepower's than is needed for single seine net operations. It should also be pointed out when comparisons of fuel consumption are made, accessibility to fishing grounds can be very different depending on the country. Commonly seining is carried out by boats in relatively shallow waters (typically < 200m) on inshore grounds in close proximity to their home port. However, there are examples of modern day seine net vessels travelling long distances to fish e.g. French vessels off the south coast of Ireland. As a general rule though, when fishing effectively with seine net gear, catch per unit of fuel is generally low compared to other fishing methods. The Topic group reviewed data from a number of countries and found that seine net vessels generally operated at 0.2 - 0.3 litres of fuel/kg of catch compared to 1-1.5 litres/kg for other active fishing methods.

Icelandic data was reported recently by Guðbergur Rúnarsson of The Federation of Icelandic fish processing plants who showed that the variation in fuel consumption can in fact be large between seine net vessels due to different fishing effort, steaming to fishing ground, age and design of the vessels. In 2008 Rúnarsson collected new data from 9 Icelandic seiners and found the average fuel consumption to be 0.20 l/kg fish with a range from 0.14 l/kg to 0.28 l/kg from these nine vessels.

Rúnarsson also compared seine netting to other gears used in Iceland. For bottom trawlers fuel consumptions was approximately 0.41 litres/kg or twice that of the seiners. Boats using other passive gears, however, were lower with longliners on average using 0.15 litres/kg and Purse Seiners 0.035 litres/kg (Table 3.2).

Table 3.2. Oil consumption from some main fishing methods' in Iceland. Based on data gathered in 1990 to 1997, 2000 and 2008 (Rúnarsson, 2008).

Type of fishing boat	Liter oil / Kg catch
Pelagic factory trawler	0.09
Purse Seine	0.035
Gillnetters	0.1
Longliners	0.15
Seine netterd	0.2
Bottom trawler	0.42

In Norway, Bouwer Utne (2007) reported similar findings for average fuel consumption for seine nets of ~0.25 l/kg catch (See Table 3.3 below). This compared very favourably to all categories of trawlers which used much more fuel with the highest being from the shrimp trawlers of 1.8 litres/kg catch (Bouwer Utne., 2007).

Table 3.3. Fuel consumption by fishing method in Norway (Bouwer Utne., 2007).

Type of fishing boat	Kg oil / Kg catch
Pelagic factory trawler	0.063
Longliner (costal)	0.205
Seine Net	0.259
Gillnets	0.302
Purse Seine	0.313
Longliner (offshore)	0.38
Bottom trawler	0.8
Shrimp trawler (offshore)	1.8

Thrane (2005) reports data from the Danish seine net fleet compared to the trawling fleet. He reports that the fuel consumption in the flatfish fishery can vary from 2.6 litres/kg for beam trawls to 0.2 litre/ kg flatfish caught with a Danish seine showing the advantages of Danish seining.

Seafish reported economic data for the UK fishing fleet in 2005 and showed that fuel costs as a % of gross earnings were 9.1 % for seine net vessels and 12.9% for pair seine vessels (Anderson et al., 2008). This compared favourably with the figures for trawlers of between 15-20% and 29% for beam trawlers but was slightly more than the figure for gillnetters of 6%. Table 6 below summarises these findings.

Table 3.4. Economic Data for the UK Fleet 2005 (Anderson et al, 2008).

Segement	FUEL AS A % OF EARNINGS
Seine Net	9%
Pair Seine/ Pair Trawl	13%
Single-rig demersal 12-24m	16%
Single-rig demersal >24m	31%
Twin-rig demersal	23%
Single-rig *Nephrops*	16%
Twin-rig *Nephrops*	15%
Beam Trawl	29%
Gillnet	6%

All of these data sets show seine netting to be a fuel efficient method compared to other active fishing methods.

Seafloor Impact

Seine nets are generally regarded as having low bottom impact, although the group could find few specific studies that had measured the impact of seine net gear. WGECO (ICES, 2006b) carried out an assessment of the effects of fishing on the ecosystem in the North Sea and reported that, "Because of the direct contact of the seine gear coils with the seabed, and fact that the gear relies on the disturbance of the seabed sediment in order to herd fish into the path of the closing seine, this gear in all likelihood has a direct effect on benthic invertebrates within the circle of the gear". This report details attempts to obtain a first impression of the actual footprint of fishing including seines on the mortalities of benthic invertebrate communities using a benthic impact model. Per fishing event mortality rates for each of the four main fishing gear categories were derived from Tulp et al. (2005). The first run used gear average mortalities calculated across 12 benthic invertebrate phyla and these mortalities were found to be 0.25 for beam trawl, 0.1 for two otter trawl fisheries (*Nephrops* and mixed roundfish) and only 0.05 for seine gears, showing seines to have the lowest mortality for towed gears.

Wayte et al. (2004) report on an Ecological Risk Assessment for Effects of Fishing carried out for trawl and seine net fisheries in Australia. This is a comprehensive assessment of all of the impacts of the two gear types and identified that trawls had a set of 7 activities that had risk scores greater than 2 (classified as moderate or greater). These activities were: capture by fishing, direct impact from fishing without capture, gear loss, discarding catch, translocation of species, activity/presence on water and disturbance of physical processes by fishing. Other components including target species, byproduct/by-catch species, protected or charismatic species, habitats and communities were classified as requiring some additional analysis or management response. When compared to the Danish seine gear, only 2 of these activities had risk scores greater than 2 (moderate or greater). These activities were capture by fishing and discarding of catch. Additional analysis or management response was recommended for the target species and protected species categories. The other components, byproduct/by-catch species, habitats and communities, were not considered at risk from seining, and were eliminated from further consideration in this study.

In October 2008 a small survey was carried out by the Marine Research Institute of Iceland to research if there were any measurably impact on benthos fauna in areas where seine nets where frequently used and to compare this area with a nearby area closed to bottom contacting gears. Underwater observations were made and various methods were used to collect bio-samples from the bottom and in the sediments below. Seine nets were then used in the closed area and similar samples taken again inside that area. No impact could be measured in or outside the closed area or after shooting the seine net in the closed area. This was a small survey with limited data collected and needs to be repeated at a larger scale but supports the view that seine net gear has a low bottom impact.

Fish Quality

Fish caught with seine nets are normally regarded as being of high quality, however, the group could find very few specific assessments that have tracked fish caught in a seine from landing on deck to the final consumer. Therefore all evidence to support this assertion is based on indications that fish caught by this gear is of premium quality corroborated by auction prices. Catches from Dutch seiners are generally labeled as E quality at Dutch auctions. As a result, these catches also fetch higher prices per kg (for all species caught). This higher quality may be partly due to seining resulting in better quality, but state of the art catch handling on these modern vessels may also play a role (Van Craeynest pers. comm.). Despite this, there are yearly claims about poor quality fish delivered by seine netters. When this happens, it is usually felt not attributable to the gear itself but the vessels ability to cope with large catches over a short period (1 to 2 days).

Technology Creep

Thomson (1981) in his book on seine fishing commented on the rapid technology development in seine netting in the period from 1968 to 1980. Since then there is continuing evidence of technological creep in seine net fisheries. The group carried out an initial review of technological changes in seine net fisheries and summarised the major changes as follows:

- Net Design
- Seine Rope
- Deck Machinery
- Gear Monitoring Equipment
- Move to Pair Seining and Tow-Dragging
- Dual Purpose vessels

3.7. Dredges

3.7.1. The fishing method

Dredges are of two varieties: dredges (or drags) that harvest animals living at the surface of the substrate (e.g., scallops and sea urchins) by scraping the surface of the sea bottom, and dredges that penetrate the sea bottom to a depth of 30cm or more to harvest macro-infauna (e.g., clams and cockles). Some surface dredges include rakes or teeth to penetrate the top layer of substrate and capture animals recessed into the seabed. Infaunal dredges can be further separated into those that penetrate the substrate by mechanical force (i.e., long teeth) and those that use water jets to fluidise the sediment (hydraulic dredges).

3.7.1.1. New Bedford drag

In the United States, scallops are mostly harvested with gear that combines characteristics of a beam trawl and the toothed dredges used elsewhere. Like those dredges, it has a low, rectangular, steel frame at the front, with a chain mesh bag attached to retain the scallops. The lower bar of the frame, however, does not have teeth, and is suspended above the sediment by shoes on each side (Smolowitz 1998). The chain bag is not attached to the bottom of the frame but hangs back like a beam trawl footrope. Scallops are separated from the substrate by the chain footrope or auxiliary tickler chains. Over rocky bottoms, a chain matrix may be used. These drags may be as wide across the mouth as 14 feet and vessels may pull more than one at a time. Some drags are assisted by a design that produces a vortex behind a baffle to assist in raising the targeted shellfish off of the substrate.

The effect of the drag is dependent on the power and capability of the fishing vessel, the towing speed, the drag weight, and its size and design. Like beam trawls, principal contact is made by the shoes, chains and footrope with the lower edge of the frame only encountering higher sand waves and emergent structures. The chain bag adds additional chain material pulled across the seabed. Hydraulic baffles may increase the suspension of sediment, while reducing the need for elements in direct contact with the substrate.

3.7.1.2. Scallop dredge

Towed, toothed dredges, are typically used in U.K. waters for the capture of the scallop, *Pecten maximus* and the queen scallop, *Chlamys opercularis* (Strange, 1981). These animals are usually found recessed in sediments comprised of sand and silt. The dredges are constructed from a triangular frame, the 'base' of the triangle consisting of a toothed bar. A retaining bag is attached to the rear of the toothed bar. This consists of a belly section constructed from steel rings with a heavy netting top and rear section to form a bag. Dredges with the toothed bar rigidly attached to the frame are used primarily on fine ground where there is little risk of gear damage. On harder substrates, damage to the toothed bar is minimized by attaching it to the frame via two shock absorbing springs, which 'give' during impact. The teeth of the dredge are typically 80–90mm long, constructed from ~20mm thick steel bar. Each dredge is generally 0.8m wide, with each bar having approximately 9 teeth per bar. During operation, depending on substrate and tooth sharpness, the teeth will penetrate the substrate by 20 – 50 mm. Each fully rigged dredge may weigh approximately 150–175kg in air. Multiple dredges are attached to a single wheeled towing bar or beam. Typically a vessel will operate two beams towing from either side of the vessel. Depending on the vessel size and power, up 18 dredges per side may be operated, however, this is relatively rare, and for most U.K. vessels, 7–8 per side is more normal. With the beam weight and associated hardware, the combined weight for each side may reach well in excess of two tonnes (in air).

3.7.1.3. Italian rake (Rapido Trawl)

The rapido trawl resembles a toothed beam trawl and is used for the capture of scallops (*Pecten jacobaes*) and sole in the Gulf of Venice (Hall et al., 1999). The dredge consists of a single beam, typically 3m wide, with a mesh bag, with reinforced rubber belly matting, attached for the retention of the catch. To facilitate the movement of the gear over the substrate, the dredge is fitted with four 12cm wide skids. Each dredge is fitted with ~32 fixed teeth, 4mm wide, spaced 8cm apart and extend below the skids by 2cm. A wooden plank is attached to the top of the dredge at an angle of approximately 270 degrees to act as a deflector or spoiler to enhance ground contact. Each dredge weighs approximately 170kg in air. One dredge is operated per warp (cf. UK scallop dredges) and up to 8 dredges may be operated by a single vessel. Italian vessels operate a continuous system; whilst one trawl is being emptied and sorted, the others remain fishing.

3.7.1.4. Portuguese clam and razor dredge

The principal target species for this type of dredge are the clams *Spisula solida* and *Venus striatula* and the razor clams *Ensis siliqua* which inhabit sandy bottoms at depths between 3 and 12m. The basic structure is a small, heavy semicircular iron frame with a lower toothed bar, with an attached net bag for the retention of the catch (Gaspar et al., 1999). The lower bar has a 12–14 teeth, spaced 1.5–2.5cm apart, with a maximum length of 55cm.

3.7.1.5. Benthic effect of mechanical dredges

In relation to benthic effects, three principal components of the gear may give rise to benthic impacts. These are the beam, from which dredges may be towed, the toothed bar or cutting blade and the bellies of the dredge bags. Dredges either rake through or cut into the sediment to a depth determined by the length and structure of the toothed bar or cutting blade and the downward force of the dredge. Diver and remotely operated vehicle observations have shown trenches formed by the passage of dredges over the substrate, with distinct ridges of sediment being deposited on each side (Bradshaw et al., 2000). In the case of the Scottish scallop dredge the use of heavy chain bellies can cause significant benthic disturbance. Gross effects are immediately obvious after passage of the gear. The effects of dredging may include 1) bringing stones to the surface after repeated dredging, 2) sediment compaction and chemical changes, 3) damage to reefs and similar structures, 4) non-catch mortalities and 5) increased vulnerability to predation (Bradshaw et al., 2000). The physical effects then diminish with time, depending on the level of natural disturbance, influenced by exposure to prevailing weather conditions and tidal strength, depth and sediment type. The degree of dredge effects will be influenced by a number of factors, including: the dredge type, width and weight, sediment type, number of dredges operated, method of fishing and whether any form of deflector is used.

3.7.1.6. Hydraulic dredges

Hydraulic dredges are usually used to harvest shellfish on sandy or finer substrates or substrates of a smaller particle size. They can be used on intertidal sea beds when the tide provides enough water for the operation, but are also used on subtidal sea bottom.

Hydraulic dredges and related gears have been in use for a number of years for harvesting shallow burrowing bivalves such as *Cerastoderma edule* (e.g., Chapman et al., 1994), and also to collect deeper burrowing species such as Ensis (McKay, 1992). Suction dredges fluidise sediments and use suction to pull material to the surface where shellfish are separated from the remaining sediments. One effect of this is that non-catch material is distributed farther from the dredging location. Work on the effects of shallow suction dredging on intertidal areas suggested that recovery following fishing occurred after about 56 days (Hall & Harding, 1997).

In deeper water, hydraulic dredges separate the shellfish from the sediments at the seafloor and retain them until the gear is brought to the surface. Dredges use a hollow blade which protrudes into the sediment. Several holes drilled out of the leading face of the blade allow high pressure water to be jetted forward. This blade penetrates the fluidised sand and lifts the shellfish upwards and backwards into a collecting cage, assisted by a backward water jet. Smooth movement over the sea bed is assisted by two skids attached along both sides of the collecting cage.

The effects of water jet dredging for *Ensis sp*. on the seabed and benthos have been examined through experimental fishing (Anon 1998). Immediate physical effects were apparent, with the dredge leaving visible trenches in the seabed. While these trenches had started to fill after five days and were no-longer visible after 11 weeks, the sediment in fished tracks remained fluidized beyond this period. The majority of the infaunal community is adapted morphologically and behaviorally to a dynamic environment and, other than initial removal and dispersal, is not greatly affected by the dredge. Epifaunal scavenging species were attracted injured organisms in the fished tracks. The effect of the hydraulic dredge is dependent on the design of the dredge, it's size, weight, the amount of water volume and pressure used and how it is directed, substrate type and composition and the towing speed. The effect on interstitial organisms is dependent on the species present, their ability to withstand water pressure, being uprooted or exposed to the water column and how quickly they can reattach or rebury themselves.

3.8. Longlines

Demersal longlines consist of two buoy systems that are situated on each end of a mainline to which are attached leaders (gangions) and hooks. The mainline, usually made of line that sinks, can be several miles in length and have several thousand baited hooks attached. Small weights may be attached to the mainline at intervals. At the bottom of each buoyed end is a weight or an anchor. A vessel will make a number of sets, depending on the area, fishery and site.

The principal components of the longline that can produce seabed effects are the anchors or weights, the hooks and the mainline. A key determinant of the effects of longlines is how far they travel over the seabed during setting or retrieval. Significant travel distance is more likely during the retrieval period. If the hauling vessel is not above the part of the line that is being lifted, the line, hooks and anchors can be pulled across the seabed before ascending. During this period the hooks and line can snare exposed organisms, which would cause injury and/or detachment. The relatively small diameter of longlines favors undercutting of emergent structures rather than rollover where the line moves laterally across the seabed.

3.9. Gillnets

Demersal gillnets (Figure 3.10) are made and deployed in a variety of ways. A common method of fishing a demersal gillnet is with buoyed lines at each end that are similar to those of the longlines. The weights or anchors are often heavier or larger than those used with longlines. The body of the gillnet is made of low-visibility twine with the mesh size and hanging of the webbing based on the targeted species. The gillnet is held to the bottom with a leadline that runs along the bottom of the nets and between nets. The net is held vertical by a floatline that can consist of floating line or headline with floats attached. Static nets set on open ground are generally deployed in long fleets, up to 2 km, while gillnets set over ship wrecks are generally shorter. Wreck nets may have metal rings attached to their leadline to reduce snagging on the wreck. Most gillnets are static gears, though some are allowed to drift.

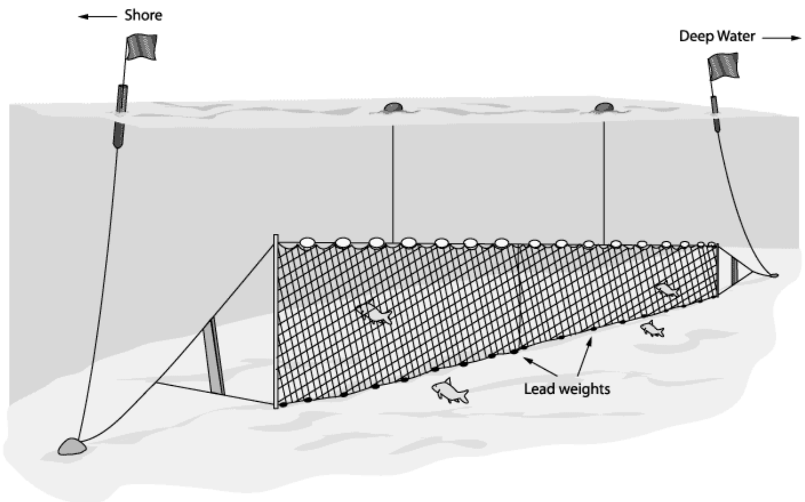


Figure 3.10. The gear components of a "generic" gill net, in contact with the seabed are the anchors and the leadline. © http://www.miseagrant.umich.edu/nets/images/gillnetlg.gif.

The benthic effects of a gillnet fishing operation occurs during retrieval of the gear. At this point the nets and leadlines are more likely to snag bottom structures or the exposed sedentary benthos. The anchoring system can also affect bottom organisms and structure, if they are dragged along the bottom before ascent.

Gillnets are lost primarily through action of heavy weather or through interaction with mobile gears. In the former case, through increased use of GPS, retrieval rates are high. Gillnets caught by mobile gear are less likely to be retrieved. The extent to which ghost fishing may then occur may be related to several factors, including: water depth, light levels and water movements. The net can forcibly tear organisms from the sea bottom or overturn cobble and small boulders to which organisms may be attached.

A ghost gillnet can also provide a new surface for epibenthic organisms to settle on and niches for fish and shellfish (crabs). Although the gillnet can host bryozoans and other organisms, and hence become visible to finfish and reduced in vertical profile, it also can provide a food source as certain organisms in the lower trophic levels settle on the net or are caught in the net. This will commonly attract fish or other scavengers to eat those caught and the scavenger species can also get entangled. Over time, especially in areas of high water flow, nets become bundled up, reducing their ability to entangle fish. In deep water, where fouling is very limited and currents slower, derelict nets may fish for long periods.

3.10. Pots and traps

Pots and traps are enclosures, usually with one-way entrances, that retain entering fish. They may be fished at intervals along a groundline, with anchors and buoys at either end, or each trap may have a separate buoy. The traps, groundline and anchors may affect substrate or organisms that they settle upon or are pulled across during setting or retrieval. The effect of a trap on the seabed will be determined by its weight and structure, as well as how far and fast it moves before ascending. The weight of a trap will be increasingly countered by lift from the hauling line as it comes off of the seabed. Effects of the groundline and anchors will be determined by similar factors to those components of longline and gillnet gear.

The benthic effects of repeated trap fishing in British waters have been extensively studied. Whilst some damage was observed to vulnerable benthic species, there was also a slight increase in primary production and biodiversity (Eno et al., 1996).

Derelict pot and traps can continue to fish after they are lost. Biodegradable panels are often required to prevent extended ghost fishing. Fouling can also reduce the fishing effectiveness of derelict pots.

3.11. Quantification of physical impact for selected fishing gears

A quantitative evaluation of the physical impact is attempted by the selection of a parameter, which can be quantified for all fishing gears. Short-term effects of bottom trawling are well investigated. Otter trawls and beam trawls are likely to have different physical impacts on the sea bed owing to their different catching principles. The most noticeable physical effect of otter trawling is the furrows (up to 20 cm deep) created by the otter boards or trawl doors, whereas other parts of the trawl create only faint marks. Beam trawling causes a flattening of irregular bottom topography by eliminating natural features such as ripples, bioturbation mounds and faunal tubes (Løkkeborg, 2005). From this review, there clearly are different indicators for the characterization of physical impact, e.g. penetration depth, measures for the flattening of seabed structures, changes in roughness and hardness, etc. (e.g. Linnane et al. (2000a), Humborstad et al. (2004)). However, these effects are not well described for the different fishing gears nor for each of the components of a fishing gear. The effects of the roller clump of a twin trawl for instance are still under investigation (e.g. Ivanovic et al. (2008)). With this respect, even methodologies are under continuous improvement (e.g. Humborstad et al. (2004), O'Neill et al. (2009)). Therefore a fully quantitative assessment cannot be based purely on peer-reviewed research, nor on a selection of a wide range of parameters for the physical impact.

However, as physical impact is important to quantify as a pointer for the disruption of habitats, a quantitative approach is taken, mainly based on peer-reviewed papers, but partly also on expert judgment. One parameter prompted as a good indicator for physical disturbance is **penetration depth** and indicates what range of animal species will be impacted. This parameter is reliably quantified for trawl gears, whereas for the other selected gears, a well considered expert judgment can be drawn. A second parameter is **surface fished** (or surface fished/Euro landed fish) and indicates the size of the surface area that will be impacted, e.g. prevent the settlement of 3-dimensional structures. A third parameter is the **sediment displaced** (or sediment displaced/Euro landed fish) and indicates the amount of sediment that is brought in suspension. A fourth parameter is fuel consumption.

3.11.1. General formula for the calculation of the parameters

The penetration depth of all different gears needs to be characterized in a uniform way to allow for a thorough comparison. The penetration depth of different gears depends on many variables which cannot all be taken into account and over which an average has to be calculated. Results from the individual studies have been inferred to the level of the North Sea and it is assumed that studies on penetration depth take into account the substrates where the investigated gears “usually” fish. For beam trawls for instance, a distinction is made between beam trawl with chain matrix and beam trawls with tickler chains. The former mainly fishing at rough grounds, whereas the latter are designed to fish in sandy substrates. The different components of a fishing gear are nevertheless part of the calculation of the penetration depth of a particular gear. The penetration depth of a particular gear is composed of the penetration depth of this gear component and its actual share in the disturbance. In other words, the penetration depth of each fishing gear component is weighted by the width of the component in relation to the complete width of the fishing gear. In general terms, the penetration depth of gear is given by formula (1).

$$P_{gear} = \Sigma (P_i * W_i) / \Sigma W_i \quad (1)$$

Where P_{gear} = Penetration depth of the complete fishing gear (cm)
P_i = Penetration depth of a gear component i (cm)
W_i = Width of the gear component (m)

The values for penetration depth are based on peer-reviewed scientific research, project results or, if no other information is available, on expert knowledge. These values are set equal for each fishery, whereas the total width of the gear can differ from one fishery to another.

The surface fished is given by formula (2)

$$SF_{gear} = W_{tot} * TS * t_{prod} \quad (2)$$

Where SF_{gear} = Surface fished by a certain fishing gear (m²)
W_{tot} = Width of the gear (m)
TS = Towing speed (m/h)
t_{prod} = Productive fishing hours per fishing day (h)

This parameter can be extrapolated to a year fishing and standardized by unit of landed value in order to compare different fishing gears.

The sediment displaced is given by formula (3)

$$SD_{gear} = SF_{gear} * P_{gear} \quad (3)$$

This parameter can also be extrapolated to a year fishing and standardized by unit of landed value in order to compare different fishing gears.

The results presented are based on a collaborative study carried out by the scientists and institutes given in Table 3.5 and are based on **the fishery in 2006**.

Table 3.5. Reference to scientists and institutes who cooperated in delivering data on fuel consumption, surface fished and sediment displaced.

Belgium	Hans Polet, Jochen Depestele	ILVO-Fishery
Denmark	Niels Madsen, Bo Sølgaard Andersen	DTU Aqua
Netherlands	Ralf Van Hal, Bob van Marlen	IMARES
	Erik Buisman, Katrine Soma	LEI
UK	Alex Tidd, Thomas Catchpole	CEFAS

3.11.1.1. The flatfish beam trawl

The physical contact of a beam trawl with the seabed is split up in the contact by the trawl heads and the chain mat or tickler chains (incl. groundrope). Penetration of a trawl head is in principle similar for all beam trawls although differences can occur depending on the weight of the gear, the warp length, the surface area of the sole plate and the tilt angle. The study made by Paschen et al. (1999) based its results on modeled data, controlled tank experiments and in situ measurements and can be considered reliable. Paschen estimates the trawl head penetration between 4 and 8cm (~6cm on average), based on an exerted pressure of 1,5 to 1,7N/cm² (Fonteyne, 2000). The trawl heads exert a pressure roughly ranging between 1 and 4 N/cm^2 (Fonteyne, 2000; Paschen et al., 2000). The pressure from the tickler chains or chain matrix elements is substantially lower than that exerted by the trawl heads, in the order of 0.5 N/cm² (Paschen et al., 2000), although the area covered is significantly larger. The penetration of the chains into the sediment, and hence the amount of physical disturbance caused by the beam trawl, depends on the weight of the gear, towing speed and sediment type. Reported values vary between 3 mm and 6 cm (Lindeboom & de Groot (1998a); Duplisea et al.(2002); Blom (1990) and Paschen (1999)). Based on these data, an average penetration of 2 cm was taken as an estimate for chain matrix and groundrope. Tickler chains penetrate deeper into the sediment than chain matrices according to Moore and Jennings (2000) and generally beam trawls with a chain matrix are used on harder substrates and therefore penetrate less deep. No quantified data are available but a difference of 10% was selected as a reasonable estimate. The data for 4 different beam trawl types are given in Table 3.6.

Table 3.6. The average penetration depth of the beam trawl, taking the penetration depth of the individual components and their relative width in relation to the total width of the gear into account.

	Penetration depth (cm)		Width (m)		Penetration depth of the gear (cm)
	Trawl head	Ticklers and groundgear	4 trawl shoes	Groundgear for 2 trawls	
4m beam trawl (chain mat)	6.0	2.0	1.08	7.0	**2.6**
4m beam trawl (tickler chains)	6.0	2.2	1.24	7.0	**2.7**
12m beam trawl (chain mat)	6.0	2.0	1.56	21.0	**2.3**
12m beam trawl (tickler chains)	6.0	2.2	2.52	22.0	**2.6**

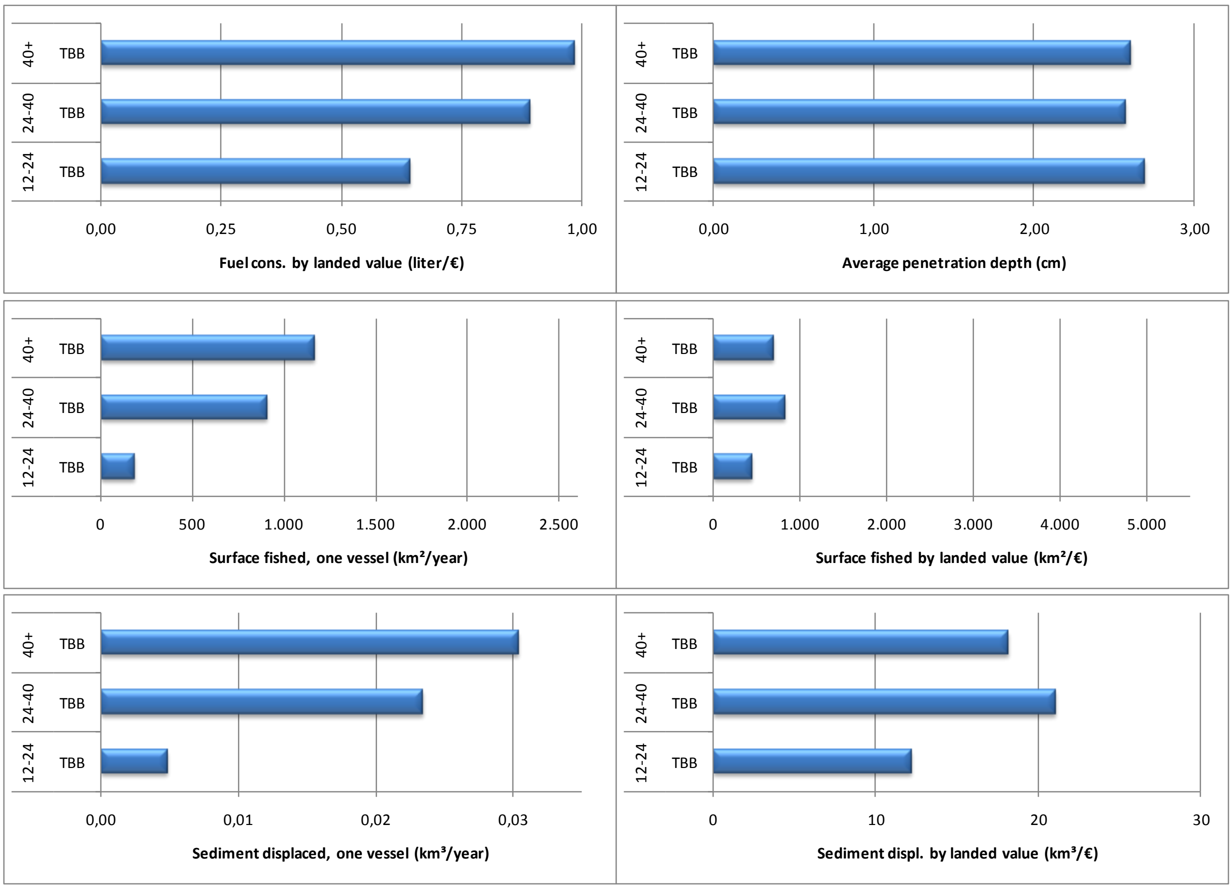


Figure 3.11. Impact related parameters for the beam trawl based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5).

3.11.1.2. The shrimp beam trawl

Paschen et al. (2000) report a bottom pressure of the trawl head of 0.8 N/cm² for the shrimp beam trawl.

3.11.1.3. The flatfish pulse trawl

The physical contact of a pulse trawl with the seabed is split up in the contact by the trawl heads and the groundrope, the tickler chains have been replaced by electrodes. With the PulseWing also the trawl heads have been removed and replaced by the SumWing nose.

The average penetration depth of the pulse trawl has been reduced to 0.9 cm en 0.8 cm for a Eurocutter and large beam trawler respectively. In the case of the PulseWing this penetration depth has been further reduced with 11.5% for a 4m trawl and 10% for a 12m trawl. Since the towing speed with the pulse trawls has been reduced to 4.5 and 5.5 kn for a Eurocutter and large beam trawler respectively, the surface fished has been reduced. Also the sediment displaced is markedly less.

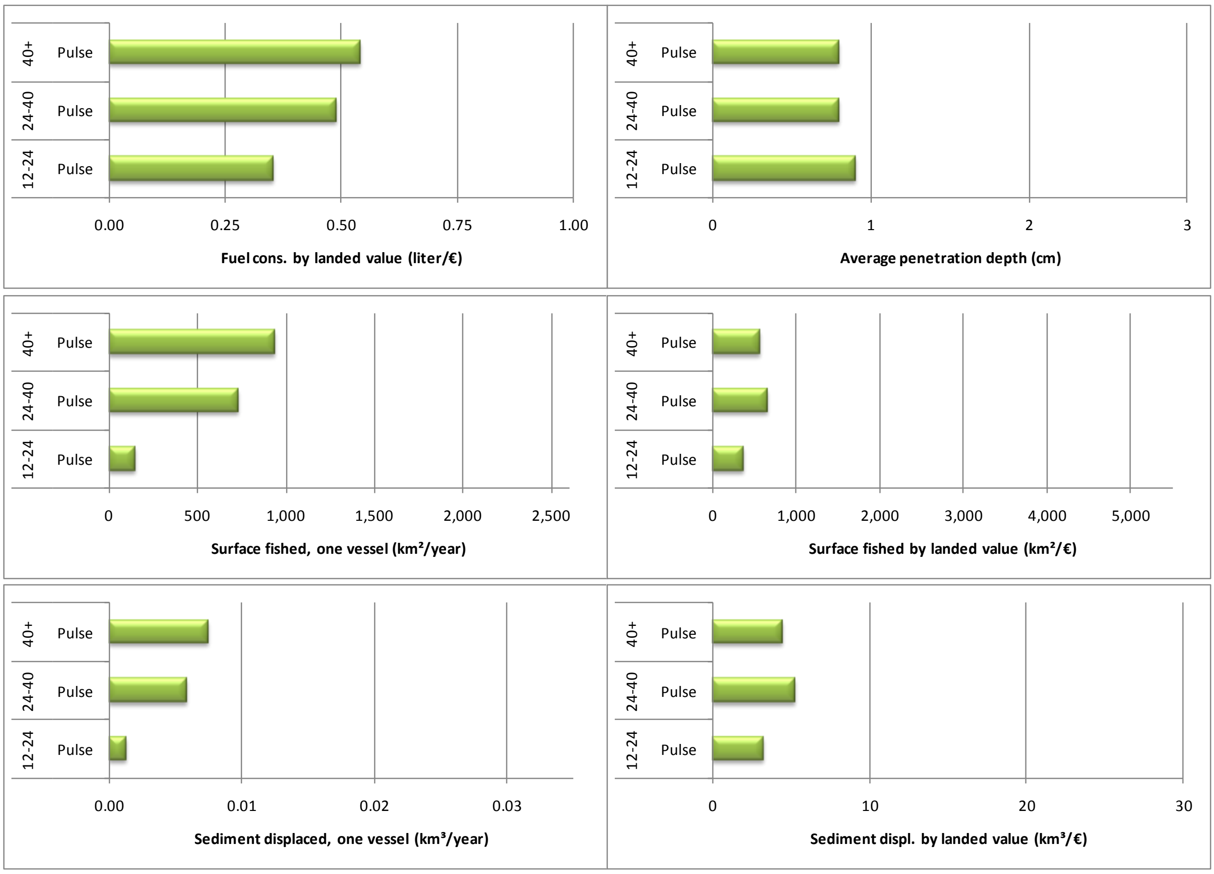


Figure 3.12. Impact related parameters for the pulse trawl (Verburg).

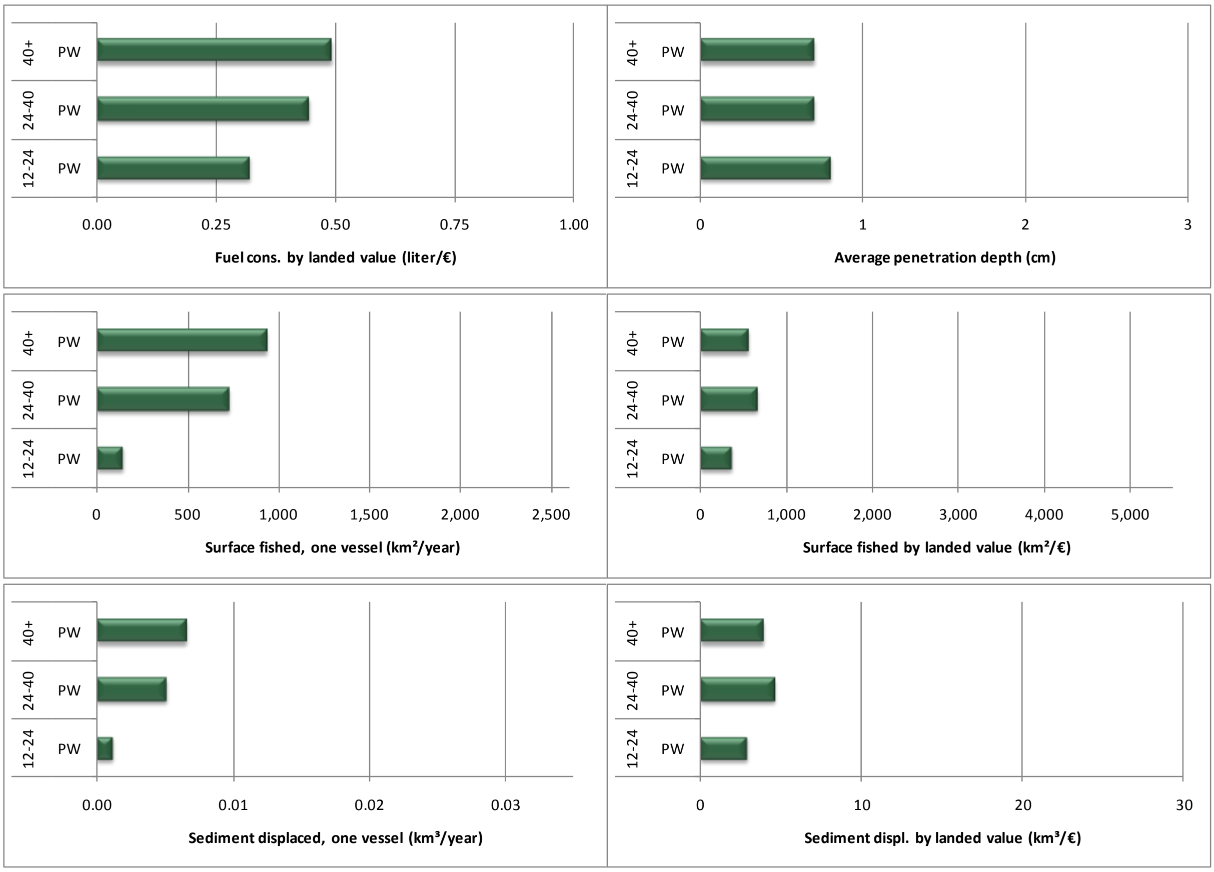


Figure 3.13. Impact related parameters for the PulseWing trawl (HfK Engineering).

3.11.1.4. The Sumwing

With the Sumwing, the beam trawl heads have been replaced with a nose that touches the seafloor. The rest of the gear (ticklers chains and groundgear) has remained the same. There is no information available on the penetration depth of the nose, so a conservative approach was chosen and it was kept the same as for the beam trawl shoe. Based on expert judgement, claiming that the hydrodynamics of the Sumwing are such that the nose contact is very light, the penetration depth estimate is likely to be less. Except for the replacement of the trawl heads with the nose, in terms of seafloor contact, the rest of the gear has remained the same. The data for 4 different beam trawl types are given in Table 3.7.

Table 3.7. The average penetration depth of the Sumwing, taking the penetration depth of the individual components and their relative width in relation to the total width of the gear into account.

	Penetration depth (cm)		Width (m)		Penetration depth of the gear (cm)	% reduction
	Nose	Ticklers and groundgear	4 trawl shoes	Groundgear for 2 trawls		
4m beam trawl (chain mat)	6.0	2	0.48	7.0	**2.3**	13%
4m beam trawl (tickler chains)	6.0	2.2	0.48	7.0	**2.4**	10%
12m beam trawl (chain mat)	6.0	2	0.48	21.0	**2.1**	8%
12m beam trawl (tickler chains)	6.0	2.2	0.48	22.0	**2.3**	12%

On average the reduction in average penetration depth of a Sumwing gear is 11.5% for a 4m trawl and 10% for a 12m trawl. As for fuel consumption data are scarce but the available data indicate a minimum reduction of 10% and occasional reductions up to 23% have been recorded. For the presentation of the data in this report the 10% figure has been used, assuming equal catches.

Applying the Sumwing allows fishermen to trawl at the same towing speed as before, with a reduced fuel consumption, reduced CO2 production and less seafloor damage. This is assuming that speed is indeed kept constant. The reduced hydrodynamic resistance of the Sumwing would, however, also allow increasing the towing speed and fish with a similar amount of fuel but sweep more ground and probably catch more fish. Data is lacking but anecdotal information also points at shorter heave-in times.

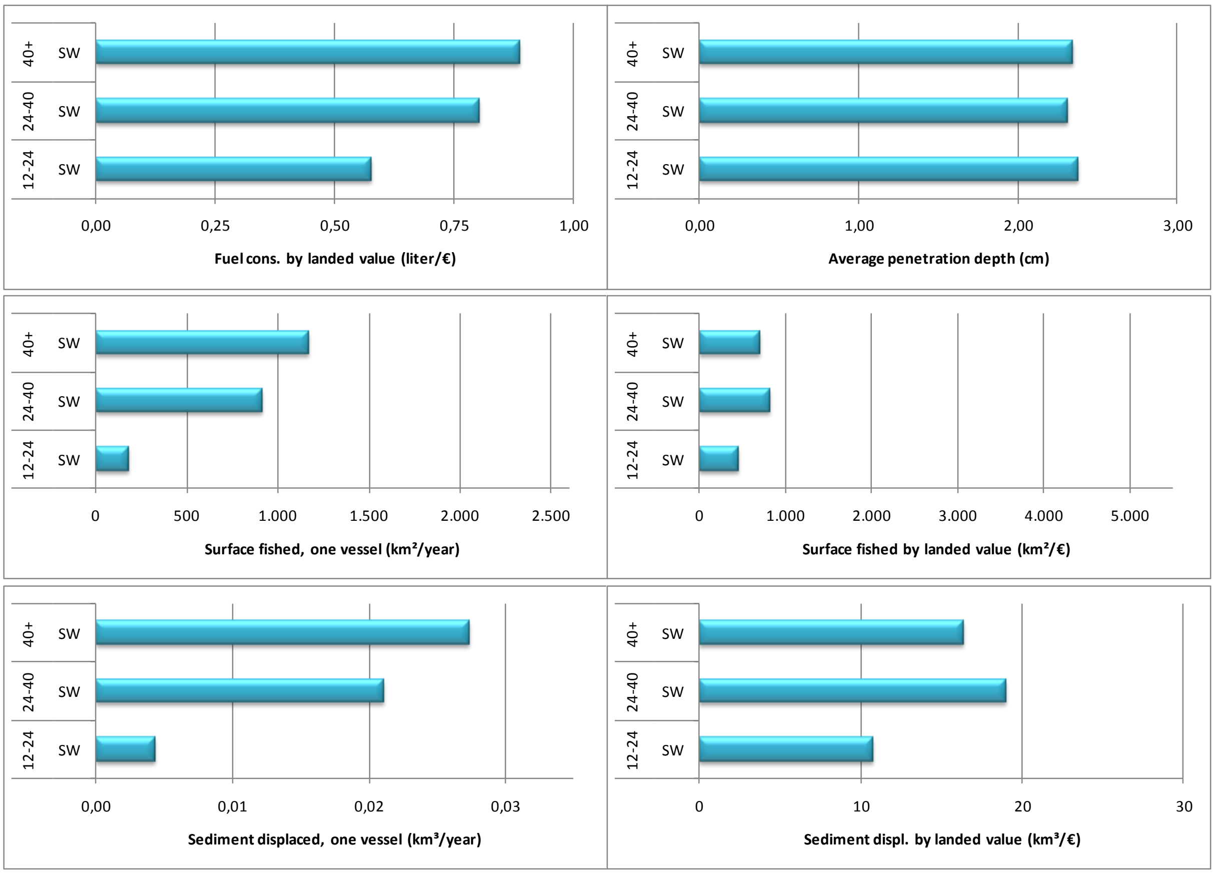


Figure 3.14. Impact related parameters for the beam trawl based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5).

3.11.1.5. Hydrorig

Since the Hydrorig is still in the experimental phase and several new designs have been tested, no results are available yet.

3.11.1.6. Demersal otter trawls (outrigger, single, twin and pair trawls)

The penetration depth of otter boards is reported in several studies and an average was taken as a proxy for penetration depth of an otter boards used for the demersal trawls (Table 3.8). This averaged value is 8.4cm (Brylinsky et al., 1994; Humborstad et al., 2004; Løkkeborg, 2005; O'Neill et al., 2009). It must be taken into account that these values are proxies. The penetration depth depends on the weight and performance of the doors (type, angle of attack, speed) and on sediment grain size and hardness, being deeper in mud than in sand (Churchill, 1989; Krost et al., 1990; Tuck et al. (1998)). A generally held view is that trawl doors inflict more damage per unit area of seabed than other gear components although the footgear sweeps a larger area (Gilkinson et al., 1998). The sweeps are not expected to penetrate the seabed, although they can flatten the topography. Therefore a value of 0.1cm has been attributed to the sweeps. Depressions probably resulting from rollers attached to the foot rope of otter trawls may penetrate to a depth of 2-5 cm (5NSC, 1997; Linnane et al., 2000a). Approximately half of the footrope consists of rollers (penetration between 2 and 5cm) and half of the width is expected not to penetrate the surface. An approximate penetration depth of 1.8cm is thus used. Twin trawls have an extra gear component, the roller clump, which penetrates on average 9.7cm (Cotterell and Stevens, 2007; O'neill et al.,(2009)).

The average penetration depth of the demersal trawls depends largely on the width of the different gear components and the total spread of the gear. The total spread of the gear differs from fishery to fishery, but for the width of each gear component, the same ratio has been used. For outrigger trawls, the area fished by the ground gear, is set to 80% with a given spread between the doors of 8m for outrigger trawls of small beam trawlers and 16m for outrigger trawls of large ones (Vanderperren, 2008). The towpath width taken by 1 otter board is averaged to 0.55m. For a twin trawl operated from a large beam trawler, the experimental values were used (Vanhee, 2008), which result in a door spread of 185m and a width of the ground gear of 29m.

For demersal trawls, towed from the stern of otter trawlers, the area between the doors is a given experimental value (pers. comm.. fishing industry). The ratio which gives the width of the sweeps and of the ground gear is taken from the ratio reported by Sangster and Breen (1998), namely 40.6m for the ground gear, 83m for door spread, which results in 42.4m for the width of the sweeps. For a twin trawl, the width of the ground gear is 48m, which is the average of the values reported by Sangster and Breen (1998), Graham and Kynoch (2001) and Graham et al. (2003). The door spread is 110m, which results in a width of 62.6m for the sweeps (Sangster and Breen, 1998; Graham and Kynoch, 2001; Graham et al., 2003). As exact values are not retrieved, the ratios reported by Sangster and Breen (1998), Graham and Kynoch (2001) and Graham et al. (2003) are used as an approximation for single and twin trawls operated from the stern. For a pair trawl, the width of the ground gear is assumed the same. However, the width of the sweeps is not. This is calculated from the “door” spread, i.e. the spread between the end parts of the sweeps. This spread is 250m, which implies a “door” spread of 209.4m. The sweeps are heavier to keep them better on the ground, at least for a distance of 225m (Seafish, website 19 November 2009). This penetration depth is set to 0.4cm, whereas the penetration depth of the lighter part of the sweeps is the same as for sweeps of a single trawl.

The data given in the 2 latter paragraphs will differ according to the size of the vessel although it is assumed that the ratios between the different gear components are quite constant, which is what counts in the calculations made for the data given in Table 3.8.

Table 3.8. The average penetration depth of demersal trawling, taking the penetration depth of the individual components and their relative width in relation to the total width of the gear into account. This example is applicable to Belgium, but the same ratios of width of different gear components are used for Denmark, the Netherlands and the UK.

	Penetration depth (cm)				Width (m)				Penetration depth of the gear (cm)
	Otter boards	Sweeps	Groundgear	Clump	Otter boards*	Sweeps	Groundgear	Clump	
2 outrigger trawls, operated from a large beam trawler (>24m)	8.4	0.1	1.8	9.7	2.3	6.4	25.6	/	**1.888**
Twin trawl, operated from a large beam trawler (>24m)	8.4	0.1	1.8	9.7	1.2	127.0	58.0	0.6	**0.693**
Twin trawl, operated from a stern trawler (>24m)	8.4	0.1	1.8	9.7	1.2	62.2	47.8	0.6	**0.941**
Demersal trawl, operated from a stern trawler (>24m)	8.4	0.1	1.8	9.7	1.2	42.4	40.6	/	**1.010**

* The width of an otter boards is the same for all gears (as a proxy), but the number of otter boards used are not, e.g. 4 otter boards for outrigger trawling, whereas only 2 for twin trawling.

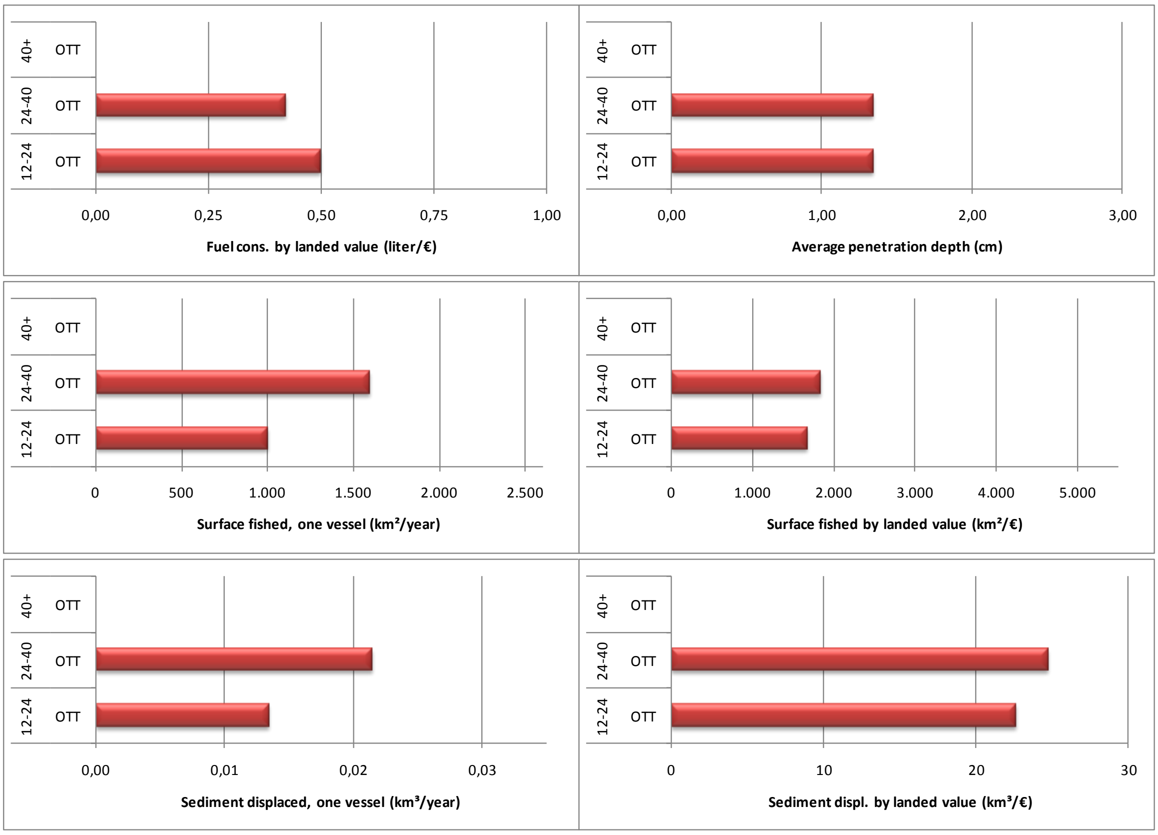


Figure 3.15. Impact related parameters for the twinrig otter trawl based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5)

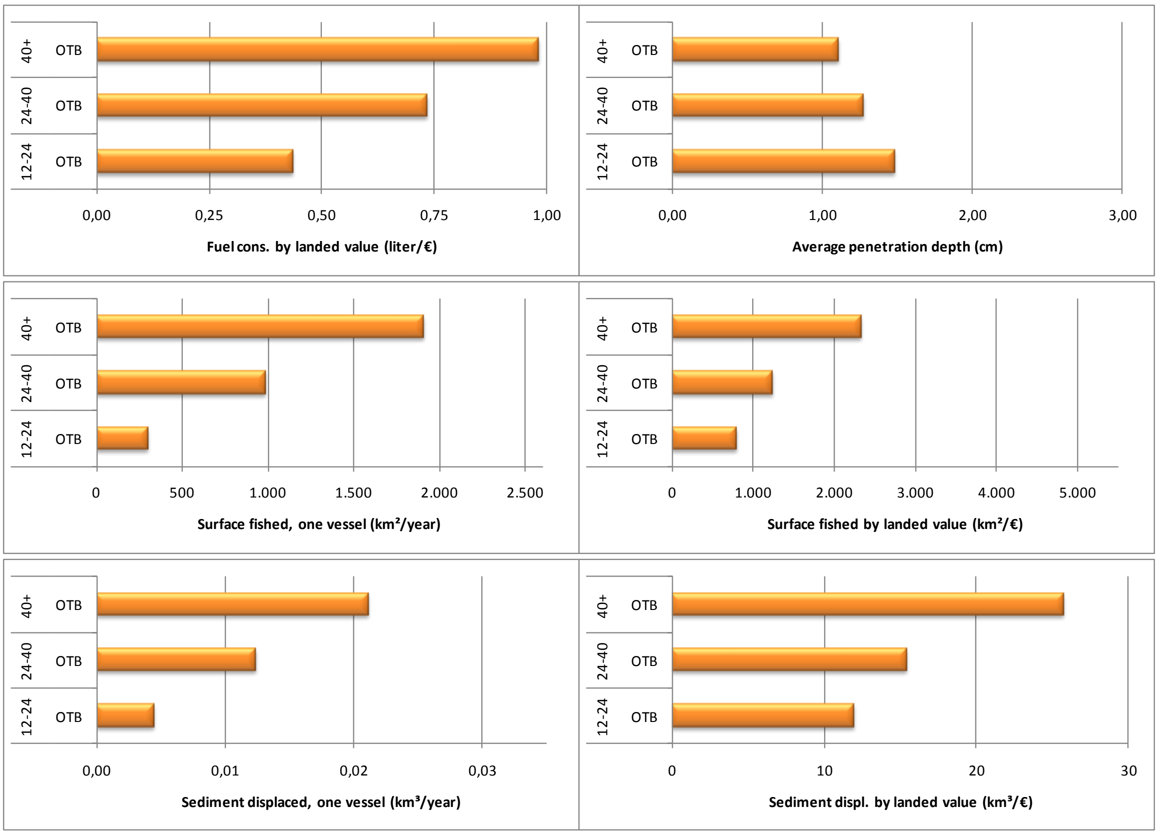


Figure 3.16. Impact related parameters for the single otter trawl based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5)

3.11.1.7. Demersal seines, flyshooters

The gear components in physical contact with the seabed are the sweeps and the ground gear. The penetration depth and the width of the ground gear is approximately the same as for an otter trawl. The width fished by the sweeps is approximated by assuming that the fished area of a demersal seine has a circular shape with a fished area of 3.4km², which implies a diameter of 2.08km. The penetration depth is assumed to be the same as for the sweeps of an otter trawl, i.e. 0.1cm. The width of the ground gear is 16m with an penetration depth of 1.8cm, similarly as for otter trawls. The average penetration depth of the total fishing gear is therefore 0.11cm.

This accounts for the demersal seiners active in the North Sea in 2006. Recently, several Dutch and French so called flyshooters (Scottish seine) have become active in the English Channel and the North Sea, mainly targeting non-quota species like red mullet and gurnards. These are state of the art modern vessels with modern and very efficient equipment on board. They use heavier and thicker sweeps, fish a larger surface and haul the gear quicker compared to the traditional seiners. Data are lacking to make any assessment on these vessels. It is expected that the environmental impact of these type of vessels is also low but fishing power is perceived to be very high.

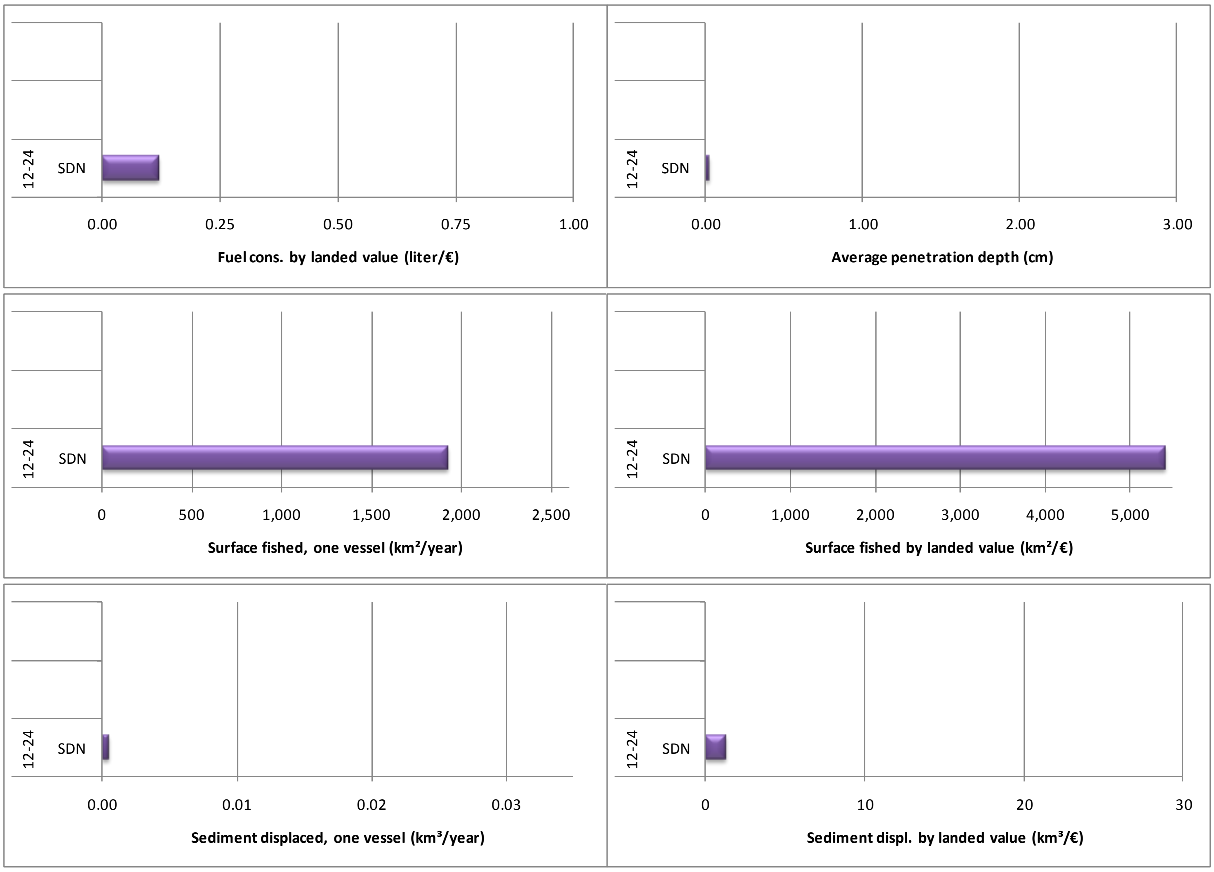


Figure 3.17. Impact related parameters for the demersal seine based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5).

3.11.1.8. Static gear

There is a great variation in static gears used, e.g. Guitton et al. (2003); Depestele et al. (2008). A generic static gear for catching sole and plaice is used in this approach. The gear components in contact with the seabed are the anchors and the leadline. To the best of our knowledge, the penetration depth of a gill net has not been investigated and published. Therefore the impact has been estimated by an expert judgement. The anchors have a minor impact on the seabed, with a penetration depth of 2mm, whereas the leadline hardly penetrates the seabed (penetration depth of 0.1mm). The width disturbed by 1 anchor is 0.3m and the assumption is that there are 4 anchors over a distance of 1000m. The width of the leadline is 2cm for a distance of 998 per 1000m net. This results in a penetration depth of 0,012cm for 1000m net.

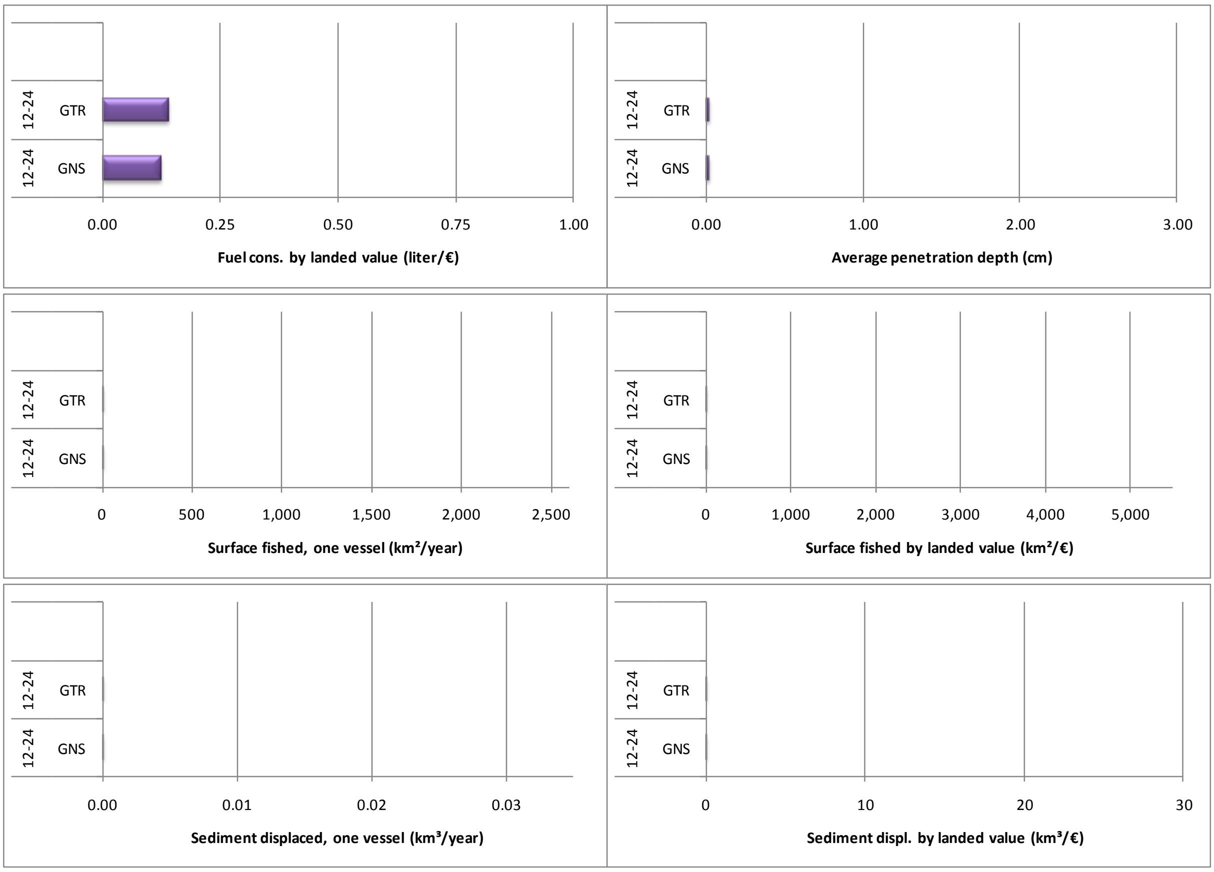


Figure 3.18. Impact related parameters for static gear based on the fishery in the North Sea in 2006 (B, Dk, Nl, Eng) (source see Table 3.5).

4. FISH DISCARDS

Discard data are available from observer programs, for which observers join a single trip of a commercial vessel and sample the discard fraction of the catch. For these programs it is impossible to join each individual fishing trip as funds and manpower are not sufficient. The main observer program delivering data for the North Sea covers less than 1% of the fishing trips whereas the European Commission has already expressed the need to increase the coverage to 15%. The observer program in 2006 showed that the major fish species in the discards were dab (*Limanda limanda*) and plaice (*Pleuronectes platessa*). The percentage plaice discards for the beam trawlers was on average 86% of the total catch in numbers and 54% in weight. For the bottom otter trawler the percentage plaice discards was 74% in numbers and 46% in weight. The percentage discards for sole was on average 29% in numbers and 13% in weight for the beam trawl vessels and less than 1 kg sole per hour was discarded by the otter bottom trawl.

Discard data for the Kattegat, North Sea and Eastern English Channel were provided by STECF (2010) for the years 2003-2008. The data are graphically presented in Figure 4.1. The abbreviations for the gears are:

Bottom trawls and seines (OTB, OTT, PTB, SDN, SSC, SPR) of mesh:

- TR1 equal to or larger than 100 mm,
- TR2 equal to or larger than 70 mm and less than 100 mm,
- TR3 equal to or larger than 16 mm and less than 32 mm;

Beam trawls (TBB) of mesh:

- BT1 equal to or larger than 120 mm
- BT2 equal to or larger than 80 mm and less than 120 mm;

Gill nets, entangling nets (GN);

Trammel nets (GT);

Longlines (LL).

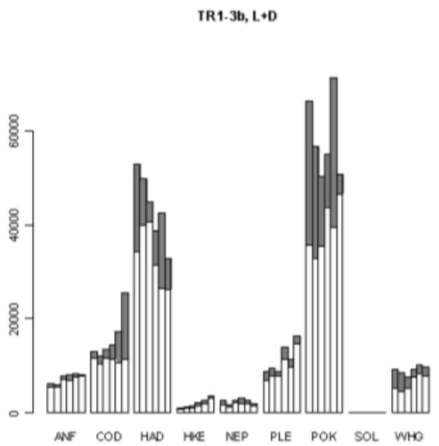


Figure 6.3.2.1. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings (white) and discards (grey) in weight 2003-2008 by TR1 gears .

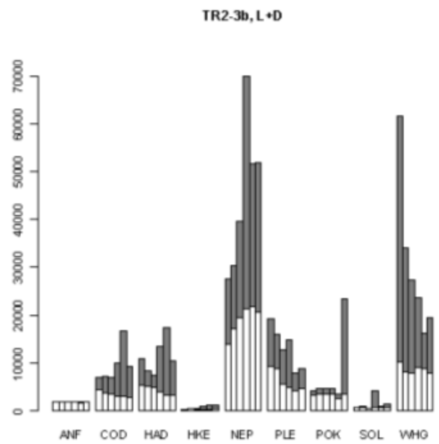


Figure 6.3.2.2. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings (white) and discards (grey) in weight 2003-2008 by TR2 gears .

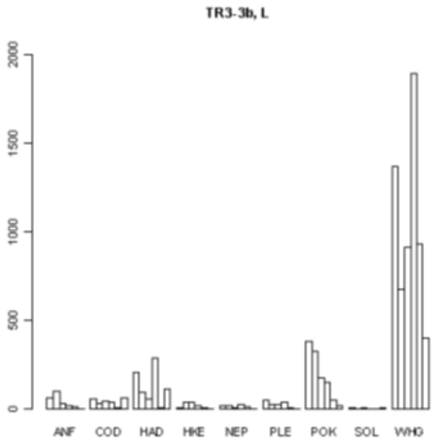


Figure 6.3.2.3. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings in weight 2003-2008 by TR3 gears (no discards data available) .

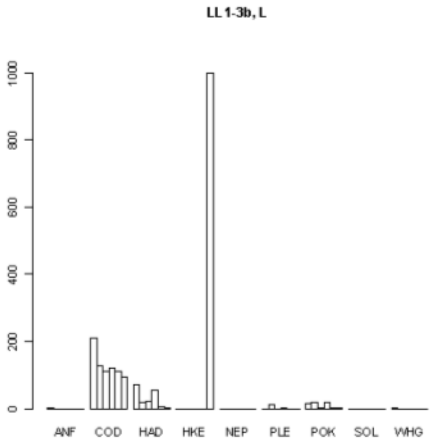


Figure 6.3.2.4. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings in weight 2003-2008 by LL1 gears (no discards data available) .

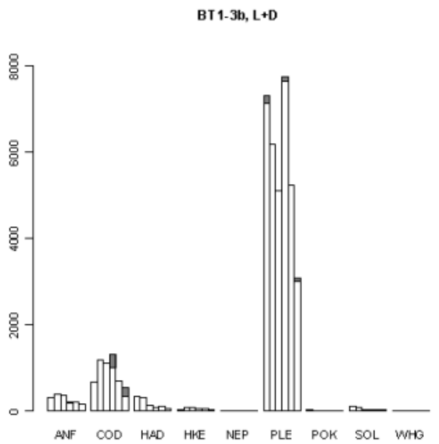


Figure 6.3.2.5. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings (white) and discards (grey) in weight 2003-2008 by BT1 gears .

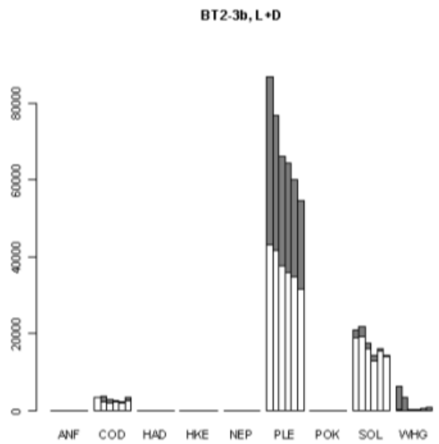


Figure 6.3.2.6. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings (white) and discards (grey) in weight 2003-2008 by BT2 gears .

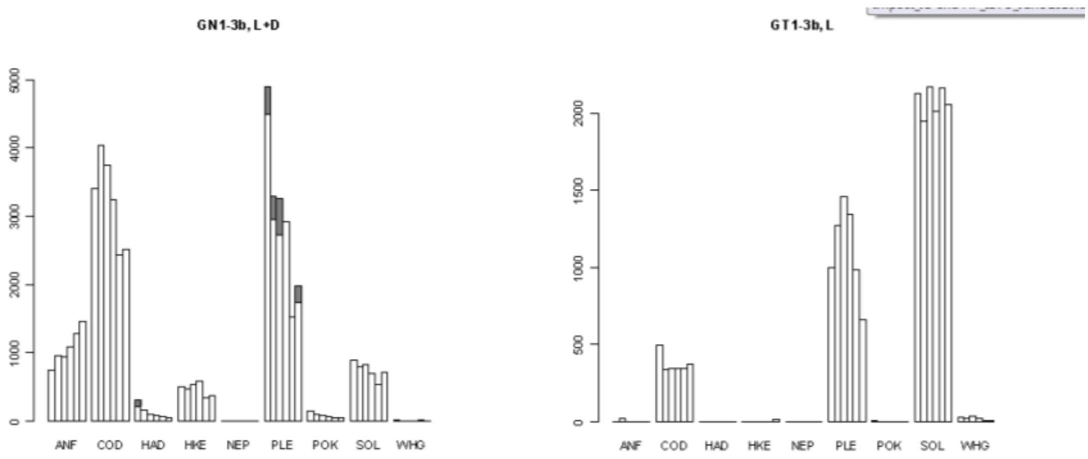


Figure 6.3.2.7. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings (white) and discards (grey) in weight 2003-2008 by GN1gears .

Figure 6.3.2.8. Area 3b (Skagerrak, North Sea & Eastern Channel), total landings in weight 2003-2008 by GT1 gears (no discards data available) .

Figure 4.1. Discard data for the Kattegat, North Sea and Eastern English Channel (STECF, 2010) for the years 2003-2008.

In the report attention is paid to the quality of the data and data deficiencies are made clear. Remarks are made like " These results are to be treated with caution at the present time considering the high degree of uncertainty arising from the low sampling level. Furthermore, these results do not take into account the possible differences between metiers." Some countries delivered incomplete data.

These values are an indication of a discarding practice at a moment in time. A moment with fish stocks with quickly changing characteristics and a fishery in transition. In order to serve the needs of this study we need to know the selective properties of the gears to assess the level of discarding on a certain fishing ground in a certain season. The discard ratio depends on the time of fishing (season) and the location of the fishing activity (coastal, offshore, rocky sediment or sandy bottom etc.). Furthermore the discard percentage depends on the recruitment of the years before. A good year class will increase the discard percentage in the following years, depending on the time it takes this species to grow above the minimum landing size. Especially, the low number of trips sampled limits their use for estimates of the total North Sea discards. Therefore in this report, where the aim is to compare fishing gears, the discards have been *calculated* based on recent selectivity parameters for the gears. These selectivity parameters have been applied to two length frequency distributions (one with ample young fish and one with the youngest age classes removed or reduced) of sole, plaice, cod, haddock and whiting. These distributions were based on the North Sea IBTS and BTS survey program for 2006 (provided by Imares, Nl). This method allows a more objective comparison of gears. The reason for incorporating two types of length frequency distribution, one with ample and one with young fish reduced, was to indicate the effect of the size composition of the fish on the fishing ground and to demonstrate the importance of managing the geographical and seasonal spread of fishing effort and the effectiveness of management tools like real time closures.

4.1. Beam trawls, otter trawl, set nets

The selectivity ogives for the different fishing gears and mesh sizes are given in Figure 4.2, Figure 4.3 and Figure 4.4 and were calculated and provided by Niels Madsen (DTU-Aqua, Denmark) in the frame of a collaborative EU project.

The set net parameters account for gillnets. Similar selective properties can be expected for trammel nets although the catching mechanism may lead to a wider selection ogive.

The length frequency distributions for plaice, sole, cod, whiting and haddock are given in Figure 4.5 for the option including young fish in the population and Figure 4.6 for the option excluding young fish in the population. The numbers of fish in the catch, above and below Minimum Landing Size (MLS), for three types of fishing gear, i.e. beam trawls, otter trawl and set nets, are given in Figure 4.7 for the option including young fish in the population Figure 4.8 for the option excluding young fish in the population.

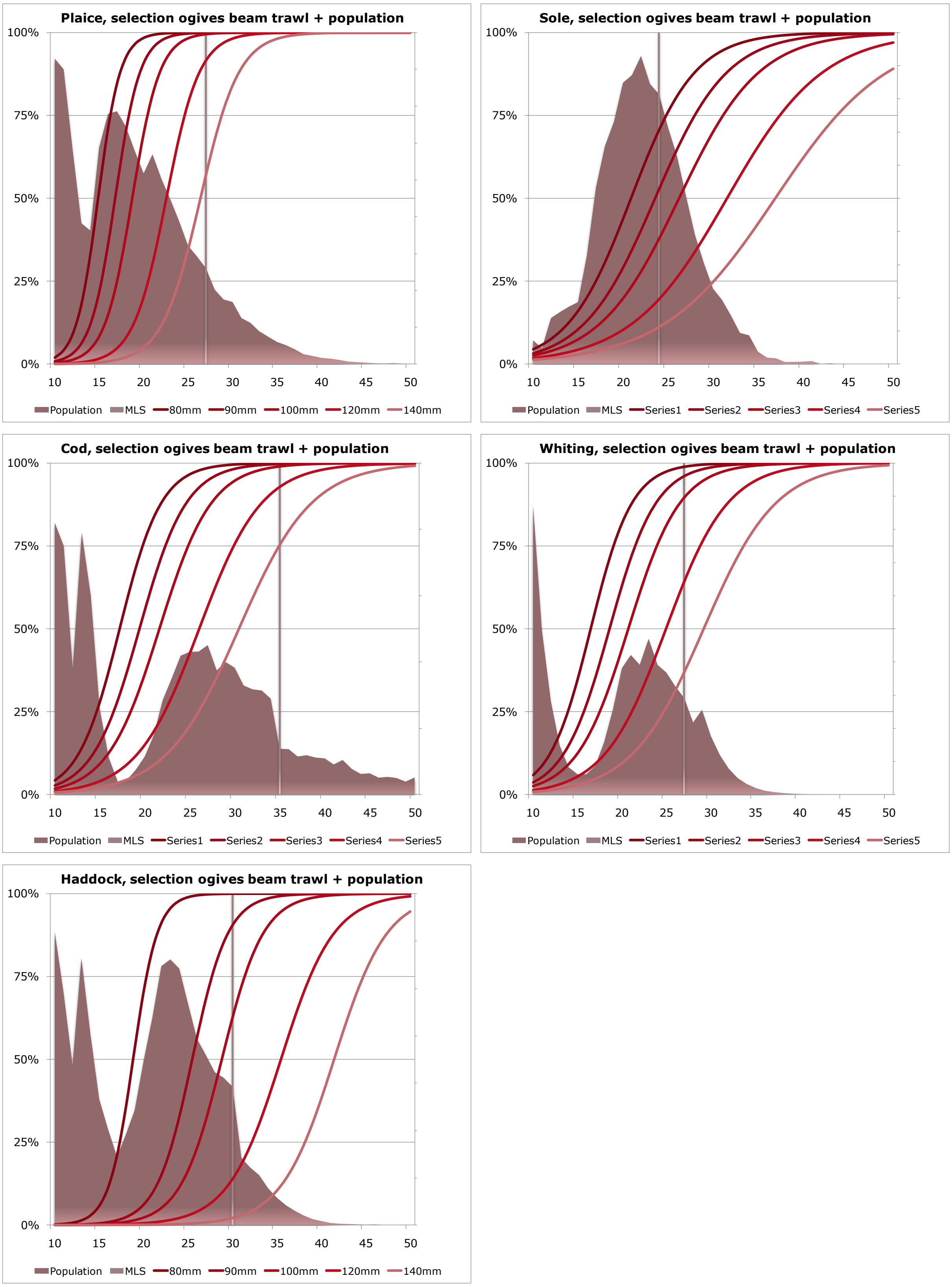


Figure 4.2. The beam trawl selectivity ogives for sole, plaice, cod, haddock and whiting, conditionally applicable for Sumwing, pulse trawl, Hydrorig.

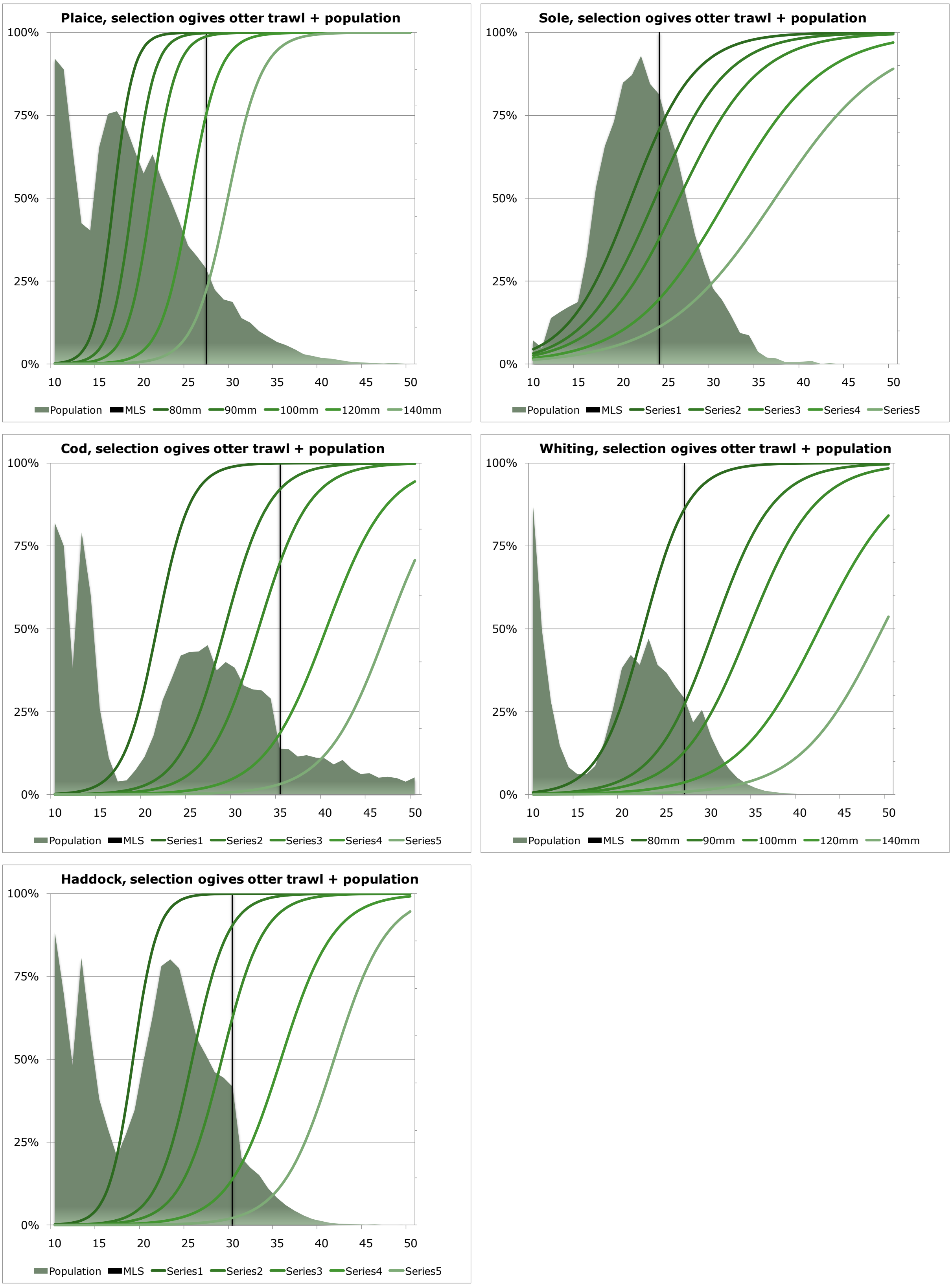


Figure 4.3. The otter trawl selectivity ogives for sole, plaice, cod, haddock and whiting, also applicable to twinrig and outrig.

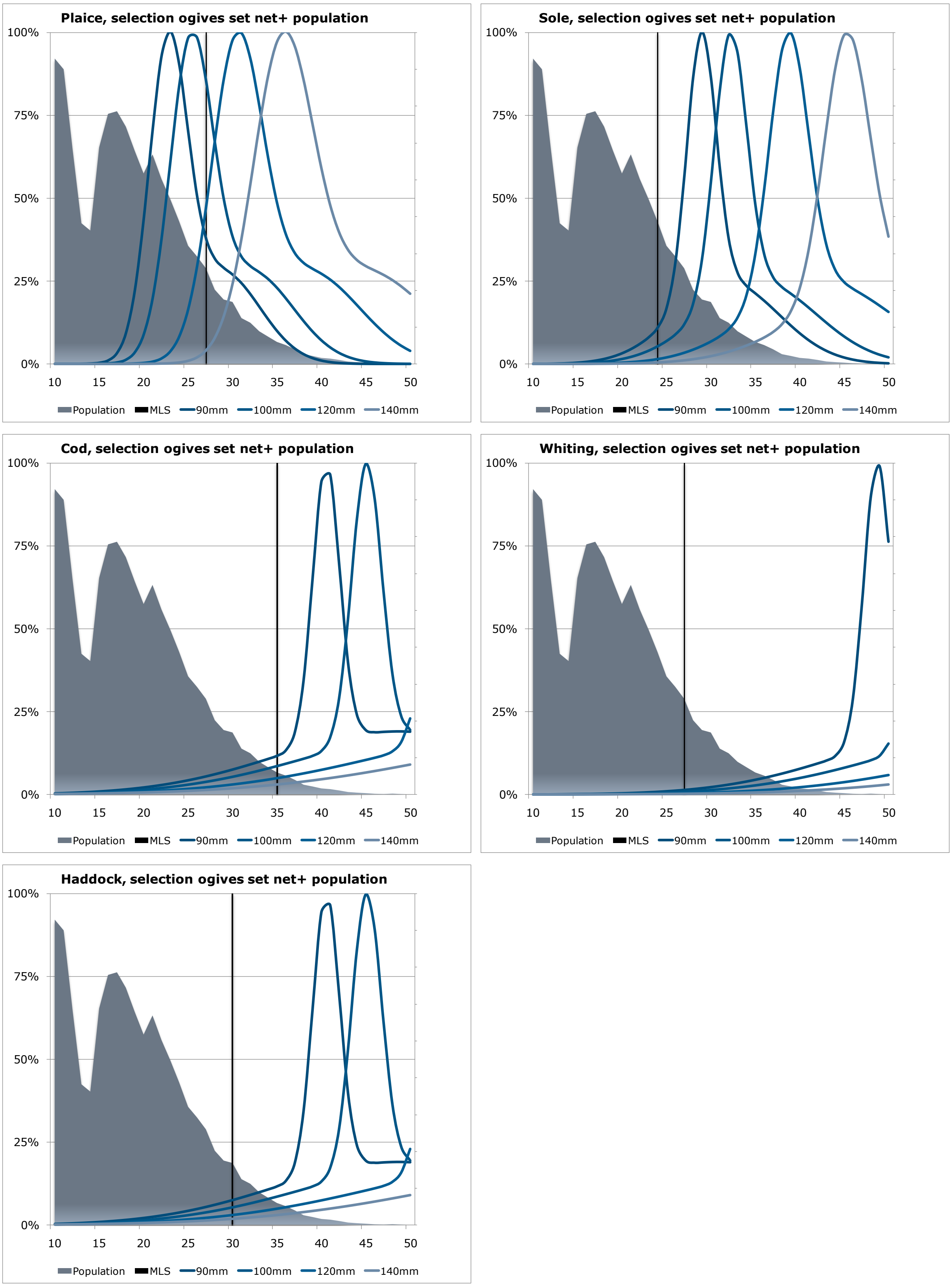


Figure 4.4. The set net selectivity ogives for sole, plaice, cod, haddock and whiting.

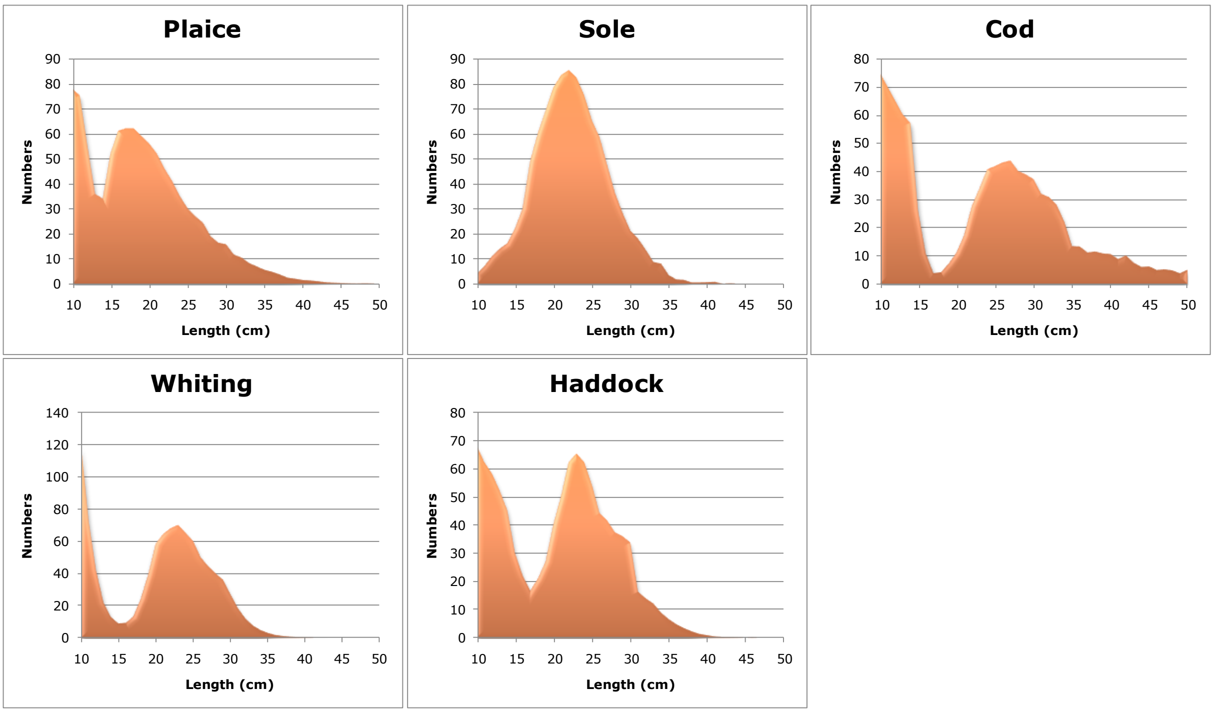


Figure 4.5. The length frequency distributions for plaice, sole, cod, haddock and whiting, including young fish, standardized to 1,000 fish, as used for the selectivity simulation.

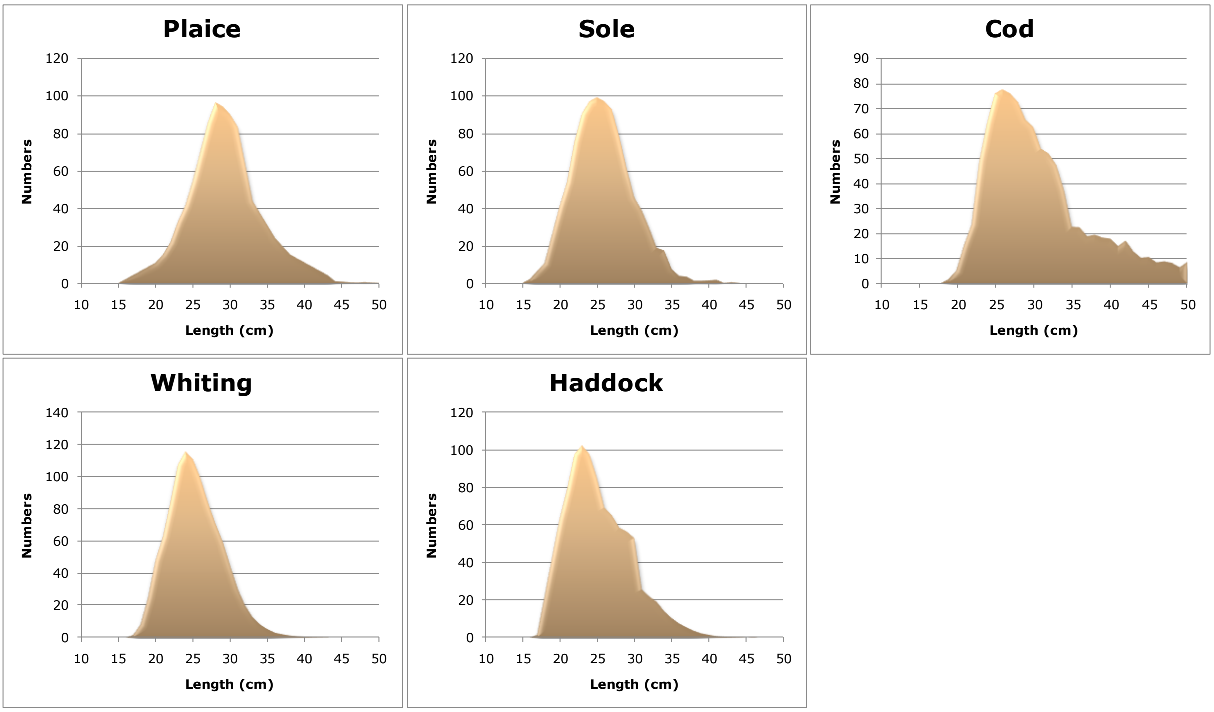


Figure 4.6. The length frequency distributions for plaice, sole, cod, haddock and whiting, excluding young fish, standardized to 1,000 fish, as used for the selectivity simulation.

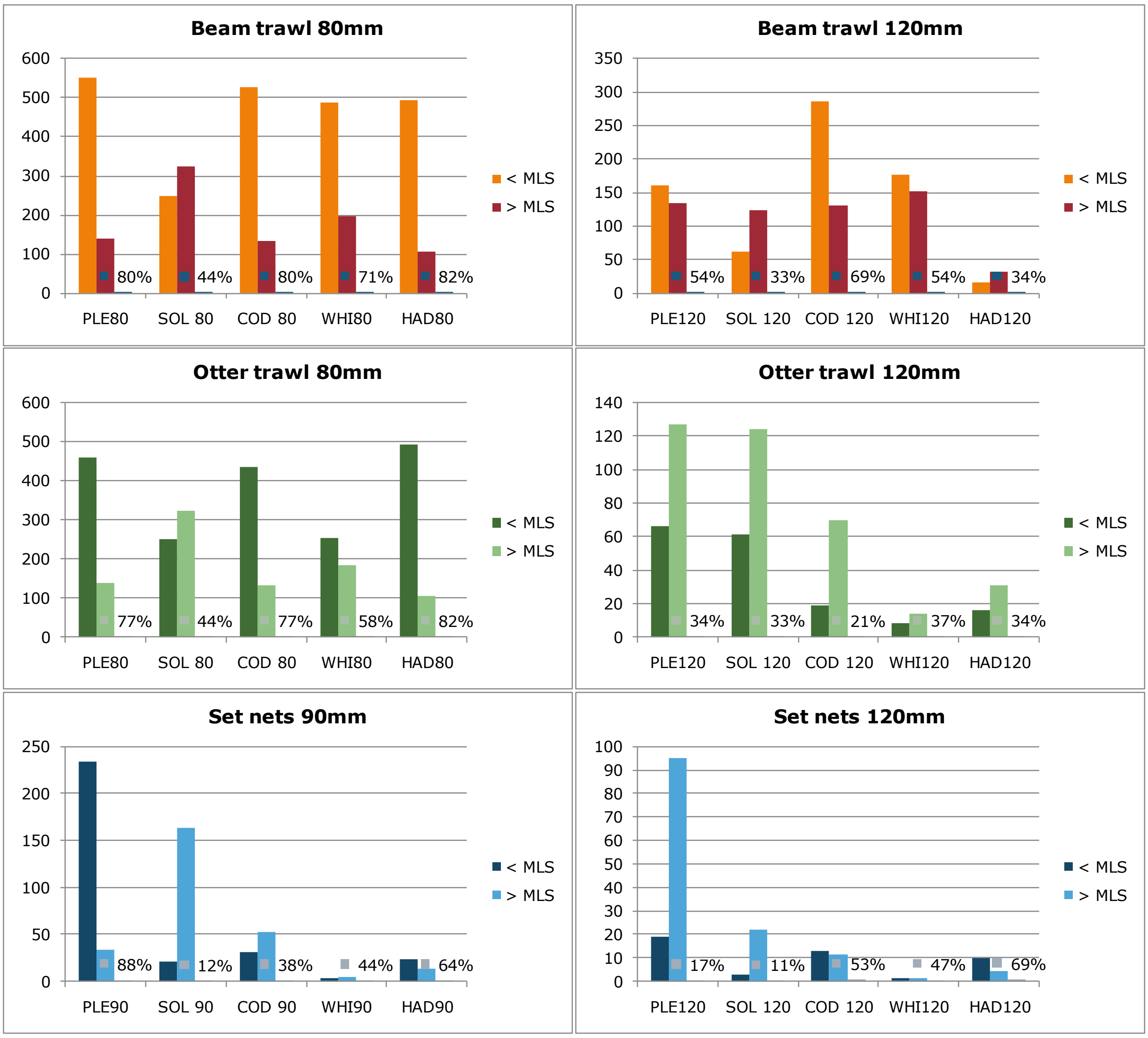


Figure 4.7. Numbers of fish in the catch "above Minimum Landing Size" and "below Minimum Landing Size", out of a total of 1,000 entering the net, for the option "including young fish in the population". The data label on the graph indicates the discard ratio (defined as % discards in the catch). These results are not obtained from observation at sea but are the outcome of a simulation.

All three types of fishing gear studied clearly have very high discard ratios for plaice when a small mesh size (80 or 90 mm) is being used. The small meshed trawls also have high discard rates for roundfish like cod, haddock and whiting and moderate discarding for sole. The selectivity of small mesh set nets is clearly better compared to trawls for sole, cod, whiting. Increasing the mesh size to 120mm improves the discard problem for all species although cod, whiting and plaice are still discarded at rates > 50%. Otter trawl selectivity has clearly improved compared to the smaller meshes. The set net discard ratios for cod, haddock and whiting are high but this is caused by reduced commercial catches compared to similar undersized catches.

Figure 4.8. Numbers of fish in the catch "above Minimum Landing Size" and "below Minimum Landing Size", out of a total of 1,000 entering the net, for the option "excluding young fish in the population". The data label on the graph indicates the discard ratio (defined as % discards in the catch). These results are not obtained from observation at sea but are the outcome of a simulation.

If the fishery targets large fish and the younger age classes are not present on the fishing ground discarding of flatfish like plaice and sole is low. For roundfish like cod, haddock and whiting, the situation has not improved. With the larger mesh size the discard problem has been further reduced to a low level for set nets and otter trawls and a low level for flatfish in beam trawls and a moderate level for roundfish in beam trawl.

4.2. Sumwing, pulse trawl, Hydrorig

The selectivity parameters have been collected in the beam trawl, otter trawl and set net fisheries but can conditionally be applied for other fishing gear as well. For the Sumwing trawl, similar catches are expected as for the beam trawl and operational characteristics such as towing speed can be expected to be the same so the same selectivity parameters can be used. For the pulse trawl, the netting material is the same as in the traditional beam trawls so similar selective characteristics can be expected. Smaller catch weights, however, can be expected due to the lower towing speed and the absence of tickler chains which can influence the selectivity (O'Neill and Kynoch, 1996; Madsen et al., 2002). The same accounts for the Hydrorig trawl which uses the same netting but which can obtain a different catch composition.

The selectivity parameters for the otter trawl can be used for the twinrig and the outrigger trawl.

4.3. Demersal seines

The ICES WGFTFB group (ICES, 2010) found evidence of high discarding in a number of seine net fisheries. Alverson et al (1994) identified the North Atlantic seine net fisheries for cod, haddock and whiting as being among the top twenty fisheries giving the highest discard ratios by number of fish (i.e. discard number per landed target species catch number). For cod the ratio was 0.79, for haddock 0.70 and for whiting 0.64. STECF (2006) reported discarding in seine net fisheries in the North Sea of approximately 20% for all species. Discarding/high grading by seiners in the North Sea is put down to low prices for round haddock and also due to quota restrictions but can vary from zero to around 30% depending on area (Mair, pers. comm.). STECF (2008) also report discarding of haddock to be high in the Irish seine net fishery in the Celtic Sea, with observed discarding of haddock at over 50% by total catch weight and at 10%, 16% and 32% for whiting, cod and hake respectively. STECF concluded that as for the North Sea, haddock and whiting discarding was due largely to poor selective properties of the gear and lack of a market for fish at or just above MLS. Pálsson (2003) identified significant discarding of haddock in Danish seine fisheries in Iceland. A later Icelandic study reported by Einarsson (2008) showed discard rates in Danish seine fisheries in terms of weight of cod and haddock over the period 2001-2007 had the highest (~12%) and lowest (0%) rates of measured discard rates of any fisheries in Iceland. In Norway, even with a discard ban in place, Valdermarsen and Nakken (2002) estimated discarding in the Norwegian Danish seine net fisheries to be in the order of 5-9%, mainly due to illegal high grading. This was quite high compared to similar estimates made for trawling (1-5%) and purse seines (3-9%). In Australian Danish seine fisheries, as reported by Wayte et al (2004), have very low discard rates for quota species in this case flathead and whiting, but high discards rates up to 100% for some non-quota species.

With respect to selectivity data for seine net gear, the group carried out an initial assessment and identified a number of studies that had attempted to measure seine net selectivity. However, most of these reports indicated that measuring selectivity of was problematically given the way seine net gear is operated. Codend covers (Coull and Robertson, 1985), alternate haul (Anon., 1990; Anon 1991) and trouser codends (Anon., 1991; Anon; 2006) have all been used to measure selectivity but none have proven to give completely satisfactory results.

A number of different selectivity devices have been tested to improve seine net selectivity in addition to simple increases in mesh size (Spingle 2001). These include the use of square mesh panels (Arkley, 1990; Ashcroft, 1991; Anon., 2002 Anon., 2003), grids (ICES, 1998; Anon., 2008) and coverless trawls with reduced top sheets (Anon., 1997). The results from these studies are varied and all of them indicated that while there appeared to be ways of improving selectivity, in practice it is difficult to obtain definitive results as indicated previously.

5. EFFECTS ON BENTHIC HABITATS

5.1. Introduction

Reiss et al. (2009) summarizes the two approaches, generally used to examine the impact of fishing on the benthic invertebrate component of marine ecosystems. Their description of the two approaches has been our guideline to investigate the effects of fishing upon benthic invertebrates. The first approach, the experimental studies, which have revealed effects at both species and community levels, have recently been comprehensively reviewed in 2 meta-analyses that have derived broad overviews of the immediate direct impact of fishing disturbance on benthic invertebrate communities (Collie et al. 2000, Kaiser et al. 2006). The short-term effects due to a particular fishing gear, are described in section 3.1 on "Tow path mortality". The second approach describes the impact upon benthic habitats, invertebrates by another methodology, namely by comparing fishing grounds with different levels of disturbance, generally expressed as fishing effort of bottom trawling. These studies are given in more detail in the section "3.4 Productivity and fishing intensity". Next to these sections, special attention will be given to habitats in "3.3 habitat impacts (incl. physical and biological), although habitat impacts are not ignored in other sections. The final section "3.5 Recovery and long-term impacts" includes long-term studies that have evaluated the trends in benthic communities and assessed the link with fisheries.

5.2. Tow path mortality: changes in densities and abundance

5.2.1. Introduction

The effects of mobile fishing gears on benthic invertebrates, communities and habitats have been studied in numerous publications (e.g. (Allen and Clarke, 2007; Auster and Langton, 1999; Auster et al., 1996; de Juan et al., 2008; Gilkinson et al., 2006; Gordon et al., 2006; Hall, 1999; Hinz et al., 2009; Jennings et al., 2001a; Kaiser, 1998; Kaiser and de Groot, 2000; Kenchington et al., 2007; Pitcher et al., 2009; Rabaut et al., 2008; Rabaut et al., 2009; Reiss et al., 2009; Rice, 2006; Schratzberger and Jennings, 2002; Schratzberger et al., 2009; Thrush and Dayton, 2002; Thrush et al., 1995; Turner et al., 1999; Watling, 2005; Watling and Norse, 1998a; Watling and Norse, 1998b). However, general conclusions will be based on the two meta-analyses which have examined the changes in abundance due to beam trawling or otter trawling. Twinrig trawling is technologically different from otter trawling because of the larger horizontal spread of the gear (for the same vessel engine power) and the presence of the roller clump. The severity of impact of a twin-rigged trawl is therefore at least that of an otter trawl. This analysis investigates the effect of trawling on abundance and the factors that explain variability in these effects, e.g. habitat.

5.2.2. Beam trawl and twinrig trawl

5.2.2.1. First meta-analysis of trawling effects on benthos (Collie et al., 2000)

Collie et al. (2000) have tried to answer three questions:

1. Are there consistent patterns in the responses of benthic organisms to fishing disturbance?
2. How does the magnitude of this response vary with habitat, depth, disturbance type and among taxa?
3. How does the recovery rate of organisms vary with these factors?

The meta-analysis comprised 39 publications, implying 57 different impact manipulations. However, these include both trawling and dredging. Within the frame of this investigation, the focus is solely to the trawling part of the meta-analysis. This reduces the number of manipulations drastically to 29 (Table 5.1). Most of the studies were undertaken at depths less than 60m. The regime variable was used to distinguish experimental studies (acute disturbance) from the 12 studies comparing fished and unfished areas. The latter methodology is currently more frequently applied (see section on productivity). 21 manipulations focus on otter trawling, whereas 8 on beam trawls. The impact of otter trawls has been investigated for sand and mud habitats, whereas the impact of beam trawls is studied in gravel, muddy sand and sand habitats.

Table 5.1. Summary table showing the 57 fishing impact studies used in the analysis, sorted by fishing gear, habitat and region. Some publication appear more than once because they incorporated distinctly different experimental manipulations. Missing values indicate that the information was not provided in the original publication. The "use"-column indicates whether the data was used for the formal statistical analysis (values in brackets denote use in the recovery analysis). Recovery denotes the period in days over which recovery was followed. An asterisk in the regime column denotes a study on a fishing ground, where the level of disturbance was unknown. (Modified from Collie et al. (2000)).

Reference	Use	Gear	Habitat	Region	Scale (m)	Depth (m)	Regime	Recovery period (days)
Kaiser & Spencer (1996)	x	Beam trawling	Gravel	Northern Europe	40	40	1	
Kaiser *et al.* (1998)	x	Beam trawling	Gravel	Northern Europe	40	40	1	180
Kaiser & Spencer (1996)		Beam trawling	Gravel	Northern Europe	40	40	1	
Lindeboon & de Groot (1998)	x	Beam trawling	Muddy sand	Northern Europe	60	43	1	
Lindeboon & de Groot (1998)	x	Beam trawling	Sand	Northern Europe	60	20	1	
Bergman & Hup (1992)		Beam trawling	Sand	Northern Europe	200	30	1	
Kaiser & Spencer (1996)	x	Beam trawling	Sand	Northern Europe	40	27	1	
Kaiser *et al.* (1998)		Beam trawling	Sand	Northern Europe	40	27	1	180
Ismial (1985)		Hydraulic dredging	Muddy sand	East North America	150	3	1	300
Peterson *et al.* (1987)		Inter-tidal dredging	Biogenic	East North America	35	1	2	730
Brown & Wilson (1997)	x	Inter-tidal dredging	Mud	East North America	1	0	4	
Kaiser *et al.* (1996)		Inter-tidal dredging	Mud	Northern Europe	2	0	1	210
Kaiser *et al.* (1998)	x (x)	Inter-tidal dredging	Muddy sand	Northern Europe	1·5	0	1	365
Wynberg & Branch (1994)		Inter-tidal dredging	Muddy sand	South Africa	3	0	1	606
Peterson *et al.* (1987)		Inter-tidal dredging	Sand	East North America	35	1	2	730
Hall & Harding (1997)	x (x)	Inter-tidal dredging	Sand	Northern Europe	45	0	1	56
Cryer *et al.* (1987)		Inter-tidal dredging	Sand	Northern Europe	5	0	1	180
McLusky *et al.* (1983)	x (x)	Inter-tidal dredging	Sand	Northern Europe	1	0	1	140
Heiligenberg (1987)	x (x)	Inter-tidal dredging	Sand	Northern Europe	7	0	1	140
Heiligenberg (1987)	x (x)	Inter-tidal dredging	Sand	Northern Europe	1	0	1	180
Heiligenberg (1987)	x (x)	Inter-tidal dredging	Sand	Northern Europe	1	0	1	140
Hall *et al.* (1990)		Inter-tidal dredging	Sand	Northern Europe	50	7	1	40
Brown & Wilson (1997)	x	Inter-tidal raking	Mud	East North America	1	0	2	
Cotter *et al.* (1997)	x (x)	Inter-tidal raking	Sand	Northern Europe	20	0	1	400
Hall & Harding (1997)	x (x)	Inter-tidal raking	Sand	Northern Europe	45	0	1	56
Kaiser *et al.* (1998)	x	Otter trawling	Biogenic	East Australia	40	25	1	
Kaiser *et al.* (1998)	x	Otter trawling	Biogenic	East Australia	40	50	1	
Van Dolah *et al.* (1987)	x (x)	Otter trawling	Biogenic	East North America		20	1	365
Bradstock & Gordon (1983)		Otter trawling	Biogenic	New Zealand		10	*	
Magorrian *et al.* (1995)		Otter trawling	Biogenic	Northern Europe			*	
Sainsbury (1987)		Otter trawling	Biogenic	North-western Australia		50	*	
Guillen *et al.* (1994)		Otter trawling	Biogenic	Southern Europe			*	1095
Kaiser *et al.* (1996)		Otter trawling	Gravel	East North America		94	*	
Freese *et al.* (1999)		Otter trawling	Gravel	West North America	5	206	1	
Lindeboon & de Groot (1998)	x	Otter trawling	Mud	Northern Europe	40	35	1	
Tuck *et al.* (1998)	x (x)	Otter trawling	Mud	Northern Europe	200	30	16	540
Lindeboon & de Groot (1998)	x	Otter trawling	Mud	Northern Europe	40	75	1	
Sanchez *et al.* (in press)		Otter trawling	Mud	Southern Europe	100	20	1	180
Brylinsky *et al.* (*1994*)	x	Otter trawling	Sand	East North America			1	
Van Dolah *et al.* (1991)	x (x)	Otter trawling	Sand	East North America	500	8	*	180
Auster *et al.* (1996)		Otter trawling	Sand	East North America		30	*	3650
Van Dolah *et al.* (1991)	x (x)	Otter trawling	Sand	East North America	200	20	*	180
Pitcher *et al.* (1996)		Otter trawling	Sand	Eastern Australia	1200	25	1	1440
Pitcher *et al.* (1996)		Otter trawling	Sand	Eastern Australia	20	25	13	1440
Gibbs *et al.* (1980)		Otter trawling	Sand	Eastern Australia		10	1	
Engel & Kvitek (1998)		Otter trawling	Sand	West North America	3700	180	*	
Fonseca *et al.* (1984)		Scallop dredging	Biogenic	East North America			1	
Hall-Spencer (1995)		Scallop dredging	Biogenic	Northern Europe				
Collie *et al.* (1997)	x	Scallop dredging	Gravel	East North America	5000	42	*	1275
Collie *et al.* (1997)	x	Scallop dredging	Gravel	East North America	5000	83	*	1275
Bradshaw *et al.* (1999)	x (x)	Scallop dredging	Gravel	Northern Europe				
Watling *et al.* (unpublished)	x (x)	Scallop dredging	Muddy sand	East North America	50	15	1	180
Currie & Parry (1996)	x (x)	Scallop dredging	Muddy sand	South Australia	600	12	2	420
Thrush *et al.* (1995)	x (x)	Scallop dredging	Sand	New Zealand	20	24	1	90
Thrush *et al.* (1995)	x (x)	Scallop dredging	Sand	New Zealand	20	24	1	90
Eleftheriou & Robertson (1992)	x	Scallop dredging	Sand	Northern Europe			1	
Langton & Robinson (1990)	x	Scallop dredging		East North America			*	

The effects of the trawling on the number of individuals and the number of species have not shown a statistical significant pattern. This lack of significance is largely due to the low statistical power, but Collie et al. (2000) also suggest that it may also be that negative responses of some taxa are counteracted by positive responses of others. The authors conclude that the immediate impact of trawling is high although strongly variable with gear type, habitat and taxa. Otter trawling and beam trawling have the least impact in comparison with different types of dredging. However, the lack of effect from beam trawling might be due to the relative paucity of data and the fact that most studies were conducted in relatively dynamic sandy areas. The responses in sand habitats seem less negative as in other habitats, although a clear ranking of the severity of impacts have not emerged. This is mostly likely due to the unbalanced nature of the data. Kaiser et al. (2006) have therefore also included "habitat" as an important explanatory variable for variation differences in density changes. The recovery patterns are not discussed as these are widely under examination by Kaiser et al. (2006) and are more clearly given further.

5.2.2.2. Second meta-analysis of trawling effects on benthos (Kaiser et al., 2006)

Kaiser et al. (2006) extended the database by Collie et al. (2000) and re-analyzed it as the lack of studies in Collie et al. (2000) resulted in some inconsistent conclusions, especially concerning the recovery potential of benthic organisms. The number of manipulations in Kaiser et al. (2006) were 40 for otter trawling and 17 for beam trawl treatments. The habitats investigated were split into sand, muddy sand, mud, gravel and biogenic habitats. There were no data of beam trawling in muddy or biogenic habitats. We are also unaware of any study on the effects of commercial beam trawling on muddy fishing grounds. However, concerning biogenic reefs, we refer to Rabaut (2009), who concludes that there are some pointers which indicate that the tightly associated species of *Lanice conchilega* reefs will be impacted significantly when beam trawling occurs. The aim of the study by Kaiser et al. (2006) was specifically to analyze

1. The direct effects of a certain fishing gear in a habitat type
2. The effect of habitat and gear combinations to the total number of individuals and species (this analysis could not effectively be fulfilled due to data limitations)
3. The recovery of individual phyla for certain habitat/gear combinations
4. The recovery of functional groups for certain habitat/gear combinations

The response variable has been calculated as % difference $X = [(A_f – A_c)/A_c] * 100$

where A_f = abundance in experimental fished areas (abundance prior to fishing)

A_c = abundance in unfished control area (abundance after fishing)

1. To investigate the direct effects, information was split up in four discrete time intervals for otter trawls and beam trawls. The initial impact of beam trawl disturbance is most severe in sandy and gravel habitats. There is a rapid recovery from beam trawl disturbance in a sandy habitats. In muddy sand the abundance even increases after a considerable time period. However, it must be noticed that Kaiser et al. (2006) have not distinguished the difference between meio- and macrofauna in their analysis. The decrease in abundance after otter trawl disturbance is only apparent in muddy sand (taken into account a time lag) and in biogenic habitats. In muddy habitats, the abundance seem to increase over a longer time span.

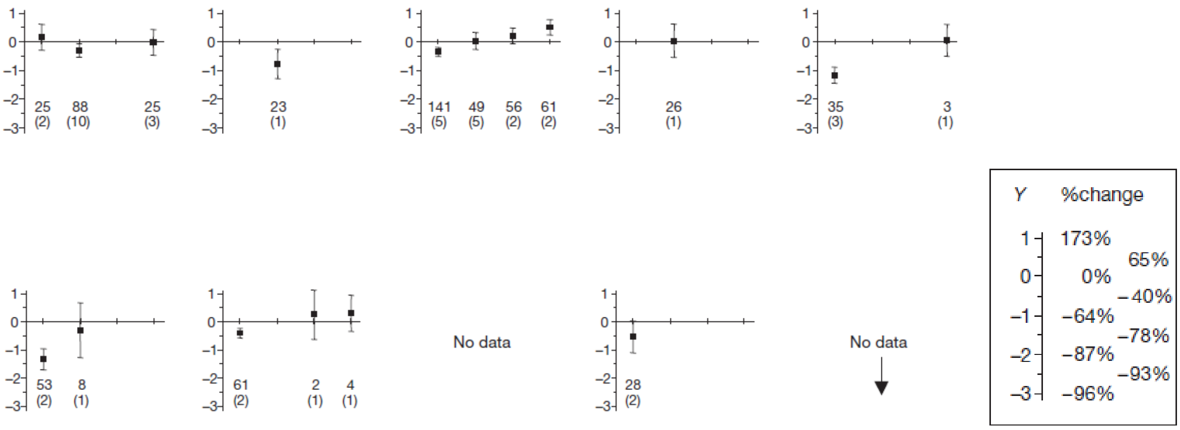


Figure 5.1. Response Y of benthic taxa to disturbance by otter trawls (above) and beam trawls (below) in different habitat categories. Y is log-transformed percentage change inabundance of each taxon in relation to control conditions (Y = -4.6: complete removal; -2.2 = 90% reduction; -0.7 = 50% reduction; -0.22 = 20% reduction; 0 = no change; +0.22 = 25% increase; +0.7 = 100% increase). The response is shown for 4 time categories (0-1, 2-7, 8-50 and >50d); note that the final time bin varies between Days 50 and 1460 after a disturbance event. Data are means +/- 2 SE (from pooled SD for each plot); hence, there is no significant difference from a zero-response (no impact of trawling) if the error bar intersects the X-axis. For certain combinations of fishing gear and habitat, there were either insufficient or no data. Numbers at the bottom or top of each graph: number of data point for that time interval and (parentheses) number of different studies contributing data points. (Modified from Kaiser et al., 2006).

2. The effect of trawling on whole community descriptors have not been reported for beam trawls, but for otter trawls no significant differences could be found in total number of species or number of individuals nor for sandy, nor for mud habitats. Kaiser et al. (2006) indicate why many studies may have failed to report effects for univariate community metrics. They stress that many of the experimental studies undertaken to date have examined the response of species richness to fishing disturbance at an inappropriately small scale in a bid to maximise replication within a given sampling effort. Fishing disturbances are large-scale in nature, and require sampling effort to appropriately match the scale of the impact; hence many previous studies may have failed to report effects due to an inappropriate scale of sampling for univariate community metrics.

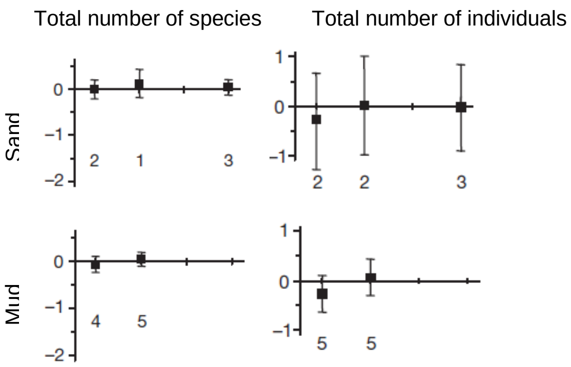


Figure 5.2. Response of total number of species and total number of individuals (I) to otter trawls in sandy and muddy habitats after an initial disturbance event, recorded over 4 time intervals. Intersection of 95% confidence intervals with the zero-response line indicates no impact of trawling.

3. The recovery of individual phyla for certain habitat/gear combinations is examined, taking time as a continuous variable . A simple linear regression is performed for each habitat/gear combination on the pooled taxa or for individual phyla. Pooled data only revealed sufficient data for the “muddy sand” habitat for beam trawls and for “biogenic” and “mud” habitats for otter trawls. Table 5.2 indicates for different habitats what the changes in response variable are after 1 day. These values are illustrative for indications of how long recovery time might last. Conclusions for beam trawls are based upon very limited data points.

Table 5.2. Impact and recovery summaries for the combinations of beam trawl and otter trawl with investigated habitats, (ex: extrapolation beyond longest time for which data were available). Initial impact: linear regression of loge(1+[% change from control]/101) against loge(1+[time after impact, d]) used to predict initial impact (where times are now on continuous scale), provided there are points in third and fourth time groups. This is used whether or not the regression is ‘significant’, provided the F ratio is >1; otherwise, initial impact is estimated from all values, irrespective of time, by simple mean and CI. Comments: emphasises paucity of data, or when linear regressions are borderline significant or not significant. Note: Caution should be exercised in interpreting any predictions, whether extrapolated or interpolated, since they can be strongly dependent on the linearity assumption (Modified from Kaiser et al., 2006).

Habitat	Change in response after 1 day (%)		Time to –20% recovery		Time to –10% recovery	
Beam trawl						
	Mean	Min.	Mean	Max.	Mean	Max.
Gravel	-42	-22	No data on recovery but a significant initial drop			
Muddy sand	-38	-28	5d	29d	11d	236d
Sand	-37	-55	No data on recovery but a strong initial drop			
Otter trawl						
	Mean	Min.	Mean	Max.	Mean	Max.
Biogenic	-74	-63	112d	>8yr ex.	188d	>8yr ex.
Gravel	+3	0	No data on later times but no initial drop at all			
Mud	-29	-17	1d	4d	4d	8d
Muddy sand	-51	-19	No data on recovery but a significant initial drop			
Sand	-15	0	No good evidence for drop or subsequent change			

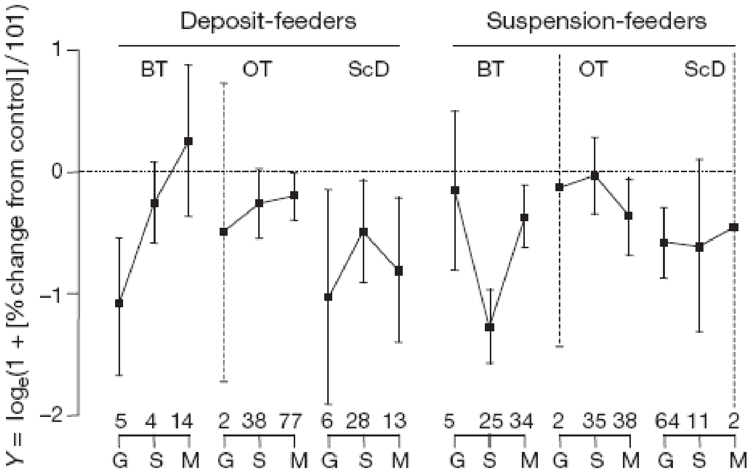


Figure 5.3. Mean initial response (up to 7 d after impact), with 95% confidence intervals of deposit- and suspension-feeding fauna to (BT) beam-trawling, (OT) otter-trawling and (ScD) scallop-dredging in (G) gravel, (S) sand and (M) muddy sand/mud habitats combined. Dashed lines: CI where only 2 points available for mean calculation, and hence some intervals extend outside plotted range). Values above x-axis: number of data points in each mean calculation. Adequate test for a significant initial impact: whether 95% confidence interval crosses zero-response line.

4. Kaiser et al. (2006) also undertook the considerable task of identifying broad functional types for as many of the taxonomically-based data values as possible. They examined the recovery of functional groups. Consistent trends were apparent for deposit- and suspension-feeding fauna in the short-term response to fishing disturbance. Otter trawls had a negative response on deposit- and suspension feeders, uniformly over all different habitat types. The greatest impact was on suspension feeders in muddy habitats. The effects of beam trawls were highly variable among habitats, with the most negative effect on deposit feeders in gravel habitats. Suspension feeders were most negatively affected in sand habitats (Figure 5.3).

5.2.3. Fly-shoot

Only one recent study has been detected, namely Thórarinsdóttir et al. (2010). Data obtained from analysis of grab samples revealed no significant differences in the species composition between fished and unfished areas although the abundance of benthic organisms tended to be greater within the closed area than in the fished area. Findings from samples obtained with epibenthic dredge were consistent with those of the grab samples. To compare species composition of the larger bodied invertebrates and fish between fished and unfished grounds, tows were taken with fly-dragging. Due to several practical constraints, it was not possible to collect sufficient number of samples to compare statistically abundances among locations.

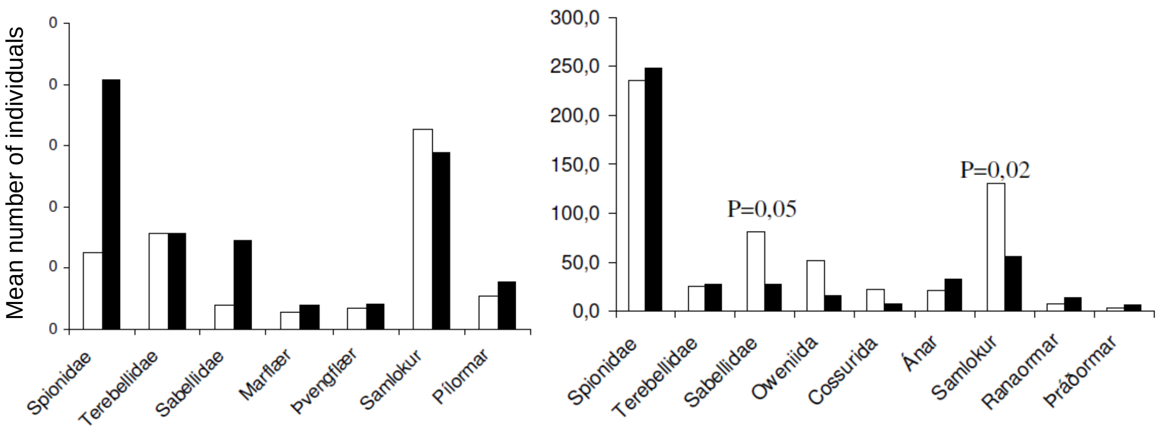


Figure 5.4. The mean number of the most common animal groups in the sledge (left) and grab (right) samples from the preserved area (open bars) and from the fishing area (closed/black bars). The first 3 (left) and 5 (right) groups are polychaeta species. Marflær = amphipoda, þvengflær = tanaidacea, Ánar=oligochaeta, samlokur=bivalvia, ranaormar=nemertinea, þráðormar=nematoda (Modified from Thórarinsdóttir et al. (2010)).

5.2.4. Hydrorig, sumwing and pulse trawl

Scientific conclusions cannot be drawn yet on tow path mortality in an area fished where pulse trawling, hydrorig and sumwing fishing takes place. This is because the fishing gear is only recently developed or still in the developmental phase. Moreover, as accounts also for fly-shoot fishing, this type of impact studies is complex and expensive, which might explain why they are, to the best of our knowledge, not conducted. Some comments are given in Section 3.11.1.4, 3.11.1.5 and 3.11.1.6.

5.3. Productivity and fishing intensity

5.3.1. What is productivity?

The Ecosystem Approach to Fisheries (EAF) and Fisheries Management (EAFM) recognizes that the ocean's living marine resources do not live in isolation from other ecosystem components. The major question is thus: "What types of fisheries and effort can be sustained without compromising the structure and functioning of the ecosystem?" (Pitkitch et al., 2004).

Productivity can be defined as the rate at which biomass is generated in an ecosystem (units of mass per spatial unit per temporal unit). It is an essential measure in the estimation of changes in the ecosystem structure and especially functioning. Fishing may result in positive and/or negative changes in productivity of resources (changes in ecosystem functioning) and affects associated species (ecosystem structure) (FAO, 2003). The key questions are therefore:

"Does the removal of top predators affect lower trophic levels?"

"Does the removal of forage species (prey) affect lower trophic levels?"

"Does the effects upon other non-commercial ecosystem components affect other trophic levels in changing the structure and the functioning of the ecosystem?"

The decline of primary productivity of consumers low in the food chain removes important forage species needed higher in the food web, with cascading effects for the ecosystem. Conversely, the removal of top predators may release an unusually large abundance of preys at lower levels with cascading and feedback effects on the food chain and species composition (Cury et al., 2003). The changes in abundance of commercial fish species has been of concern since decades. However, the effects of fishing upon productivity of other ecosystem ecosystem components has only been a topic in recent years. These effects result in changes in productivity of other ecosystem components (positively or negatively). This energy flow has been described according to different theories: bottom-up, top-down or wasp-waist (Cury et al., 2003). No general theory is able to totally predict the ecosystem's behaviour, although tentative generalizations should be proposed and investigated (Cury et al., 2003; 2008), including the driving factors (e.g. Heath et al., 2005). As changes in production have only recently gained research focus (Jennings et al., 2001b), the impact of different fishing techniques and upon different habitat types is fairly difficult to discriminate. However, impact of "bottom trawling" has been under attention and linking these research outputs with other chapters in this document may lead to tentative hypotheses.

5.3.2. Primary productivity

Primary productivity is the production of organic matter (aquatic plants, mainly algae, phyto-plankton) from carbon dioxide and other chemical compounds. Limiting factors are light and mineral nutrients. The effects of beam trawling and otter trawling (incl. twin-trawling) on plankton was topic of investigation in the ICES Working Group on Ecosystem Effects of Fishing (WGECO) in 2006. Up till then, they were not aware of any study reporting the effects of either of these fishing methods. General conclusions of the potential effects were deducted from general ecological theory and known effects: Changes in the abundance of fish and benthos, from the direct and indirect effects of fishing (see other sections of this document), will alter the total amount and spatial distribution of larvae produced. In many regions, the seasonal input of mero-planktonic larvae comprises a major part of the zooplankton and this can influence system dynamics through their consumption of phytoplankton and micro-zooplankton (ICES, 2006). One essential part of understanding how fishing affects primary productivity is thus through the changes in benthic and fish communities (e.g. Baum and Worm (2009). Herefore, one must understand how ecosystem function of benthic communities is altered by trawling, which includes the understanding of the function of species and their sensitivity to trawling (Larsen et al., 2005).

Next to the indirect effects on phyto-plankton through altered consumption patterns, fishing may also induce a physico-chemical bottom-up forcing. This bottom-up forcing has been considered to be the main mechanism in structuring the marine ecosystem (e.g. Heath (2005)), although some field observations and empirical correlations support the top-down modulation (e.g. mentioned by ICES, 2006) (Reid et al., 2000). The bottom-up forcing implies that nutrient fluxes from the sediment to the euphotic zone are affected. The remineralization process, through fluxes of nutrients, ultimately fuels new algal production in the euphotic zone. These effects on the nutrient balance are especially apparent in continental shelf and coastal areas. Trawling might affect nutrient fluxes in direct and indirect way.

In a direct way, bottom trawling may trigger off considerable productivity pulses due to the rate of dissolved and particulate nutrient releases from seabed disturbance (Dounas et al., 2007). These releases may be transported to the euphotic zone to support new production, which is in support of the bottom-up mechanism for increasing the amount of food available to planktivorous fish (Dounas et al., 2007). The effects of different fishing techniques on the physical environment are specific to each gear (clouds of suspended sediment, resuspension and bury of biologically recyclable organic material). Tentative hypotheses on nutrient releases can be made in this sense as direct measurements of nutrient releases are limited in the North Sea (e.g. Durrieu de Madron et al. (2005) in the Gulf of Maine; Pusceddu et al. (2005) in the Thermaikos Gulf). Durrieu de Madron et al. (2005) conclude that bottom trawls produce significant resuspension, whilst the near-bottom and mid-water pelagic trawls have no impact upon the sediment. The sediment clouds at several hundred meters astern of the bottom trawls are 3–6m high and 70–200m wide; they were generated both by the otter doors and the net. The average suspended sediment concentrations measured in the plumes reach 50 $mg*l^{-1}$. Pusceddu et al. (2005) conclude that trawling activities in Thermaikos Gulf determined a significant increase in suspended POM concentrations and important changes in its biochemical composition.

In the surface sediment system the macrofauna is an important component for the benthic-pelagic coupling in terms of transport and exchange of solids and solutes in sediment and water through deposition and recirculation (Olsgard et al., 2008). Especially species which structure the habitat, such as *Lanice conchilega*, might be crucial in ecosystem function and community structure (Rabaut et al., 2007). The impact on bioturbators (e.g. the impact of **beam trawling** on *Lanice conchilega* (Rabaut, 2009)) might be inventoried and can indirectly indicate in which habitats trawling might affect primary production (see Box).

Box: bottom trawling impacts the abundance of bioturbators, which affects nutrient fluxes (modified from Olsgard et al., 2008)

Field observations confirmed that trawling reduced the density of important bioturbators in the study area, but revealed only weak effects of trawling on nutrient fluxes. The importance of the decline in bioturbators was demonstrated in the mesocosm experiments where the density of four key bioturbators (*Brissopsis lyrifera, Nuculana minuta, Calocaris macandreae* and *Amphiura chiajei*) showed significant correlations with nutrient flux. All four species caused an increase in the rate at which silicate was released from the sediment, but their effect on nitrogen cycling were species specific. Bioturbators that bulldoze through the sediment (B. lyrifera and N. minuta) increased the loss of dissolved inorganic nitrogen (DIN) from the sediment, whereas those that irrigate burrows within the sediment (C. macandreae and A. chiajei) caused increased uptake of DIN. This shows that the activities of the species present can determine whether the seabed acts as a source or a sink of nitrogen nutrients.

In the Southern North Sea a significant decline in silicate and increase in nitrogen concentrations has been observed over the last 30 years (Humborg et al., 2000; Sommer et al., 2002). In the central areas of the North Sea, the release of silicate from the sediment has been found to be much more important than river input, and recent 3-D models for the North Sea indicate that benthic efflux of silicate is the most important source of silicate for phytoplankton (Moll and Radach, 2003; Proctor et al., 2003). Through decimation of large bioturbators, trawling may affect the efflux of silicate to an extent that alters primary production and plankton dynamics.

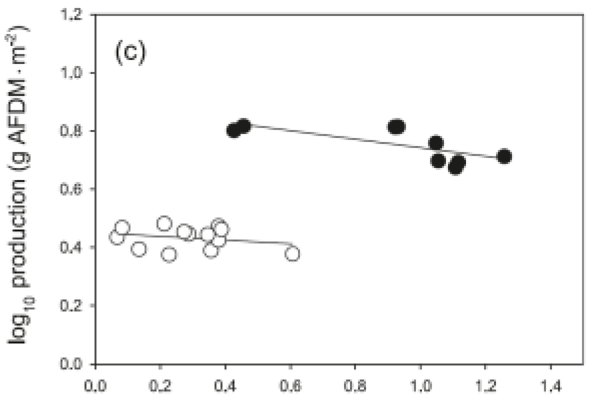
5.3.3. Secondary productivity

5.3.3.1. Benthic meiofaunal effects

The extent to which the observed changes in community structure reflect changes in the production of the nematode community was totally unknown until very recently (Schratzberger et al., 2002). One important reason might be the notion that meiofauna is considered to be less vulnerable to direct physical impacts of trawling, in contrast to macro- and megafauna (Hinz et al., 2008). However, nematodes, which are usually numerically dominant in the total meiofaunal composition (Coull, 1999), complete their life cycle in a few weeks, resulting in a much higher production to biomass ratio compared with macrofauna. Thus, since meiofauna make a significantly greater contribution to benthic production than the larger macrofauna, there are compelling reasons to assess their response to disturbance (Schratzberger et al., 2002; Hinz et al., 2008). Jennings et al. (2001) also suggest that effects of trawling upon production can be best examined by the production and dynamics of the meiofauna and the smallest macrofauna, because these groups, along with bacteria, are the only large groups of species that have sufficiently fast life cycles to proliferate in intensively trawled areas are process the carbon and nitrogen that cannot be processed by depleted populations of larger animals. While nematodes are an important ecosystem component in all habitats, they are probably more active in sediments with high amounts of organic matter, such as muddy sediments (Coull, 1999 in Hinz et al., (2008)).

Jennings et al. (2001a) conducted an experiment in **the Silver Pit and the Hills region of the North Sea**, comparing different levels of **beam trawl disturbances** in these North Sea regions. The range of trawling disturbance was low in the Hills region, resulting in non-significant effects on production. For the Silver Pit, they concluded that the relative infaunal production (production per unit biomass) rose with increased trawling disturbance, largely attributable to smaller animals in disturbed communities. They also had some evidence for the proliferation of small polychaetes at moderate levels of disturbance, whereas their production fell at higher levels of disturbance.

Another, more recent study by Hinz and colleagues (Hinz et al., 2008) has investigated the effect of **otter trawling** on two **muddy fishing grounds in the North Sea** (Fladen ground) and in the Irish Sea.



Log10 times trawled (year -1)

Figure 5.5. The relationship between production with trawling frequency for nematodes. Significant regression lines are drawn (p=0.05). Open circles indicate North Sea data; solid circles are data from the Irish Sea (modified from Hinz et al., 2008).

They conclude that otter trawling, inclusive of twin rigging, has a significant negative effect on nematode abundance, production and genus richness in both areas. Based on the results of the regression slopes in Figure 5.5, a tenfold increase in trawling intensity for 1 to 10 year^{-1} lead to a reduction in production by 25.7% in the Irish Sea and 16.3% in the North Sea. In the North Sea, for three of the genera, a significant response to trawling was detected. *Aponema* and *Sabatieria* had a positive response to increasing trawling frequency, while *Halalaimus* showed a negative response. Hinz et al. (2008) discussed a significant negative effect of otter trawls on nematode production in both the Irish Sea and muddy fishing grounds of the North Sea, which fishing grounds are characterized by a relatively low primary productivity of 90-100g C*m^{-2} (De Wilde et al, 1986 in Hinz et al. (2008)).

5.3.3.2. Benthic macro- and mega-faunal effects

Existing theory suggests that frequent trawling disturbance may lead to the proliferation of smaller benthic species (Duplisea et al., 2002) with faster life histories, because they can withstand the mortality imposed by trawling and benefit from reduced competition or predation as populations of larger species are reduced (see sections above). Since smaller species are more productive, trawling disturbance may “farm the sea”, with knock-on benefits for consumers, including fish populations (see following section) (Jennings et al., 2001). Therefore Jennings et al. (2001) examined whether larger organisms decline in response to trawling, while smaller ones proliferate. This would imply both the slope and intercept of the size spectra to be positively correlated with trawling disturbance and total production of the community would have risen as the increased production of smaller animals exceeds the loss of production in depleted populations of larger animals. However, Jennings et al. (2001) have drawn the following conclusions from their North Sea- experiments where trawling is most likely to have been **beam trawling**:

1. In the Silver Pit region (27-fold range in trawling disturbance), trawling led to significant decreases in infaunal biomass and production (see also above: meiofaunal effects). The abundance of larger individuals was depleted more than smaller ones. The effects of trawling disturbance were not significant in the epifaunal community (Figure 5.6).
2. In the Hills region (10-fold range in trawling disturbance), there were no significant effects on biomass or production.

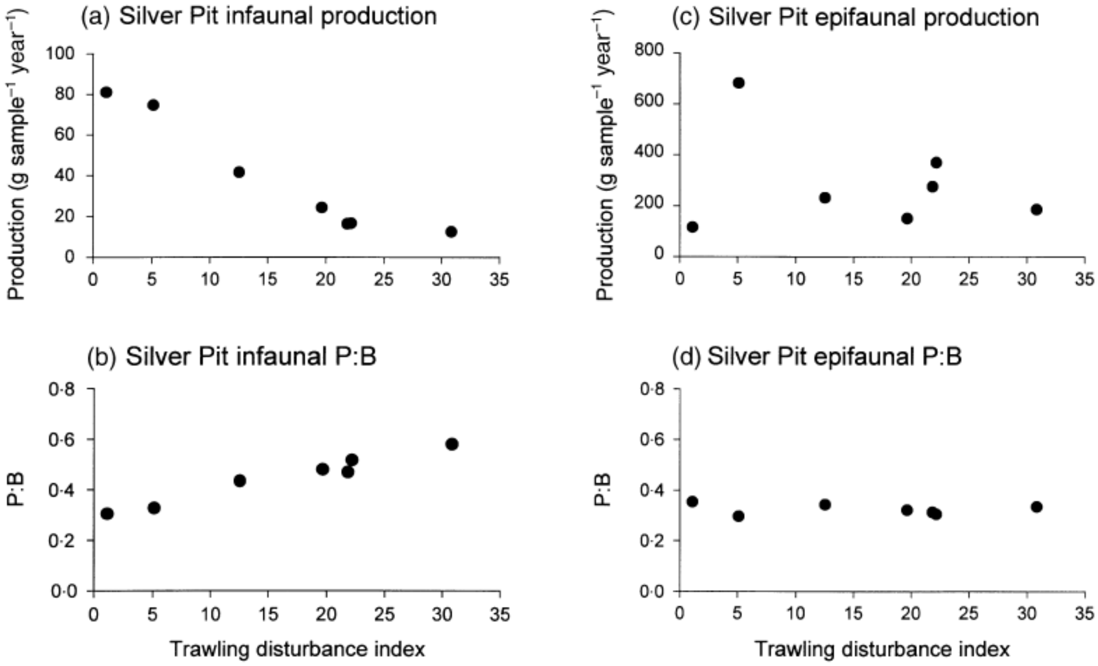


Figure 5.6. The relationship between trawling disturbance and (a) infaunal production, (b) infaunal P:B, (c) epifaunal production and (d) epifaunal P:B in the Silver Pit region (Modified from Jennings et al., 2001).

The hypothesis of "farming the sea" could not be proven, on the contrary. For the infaunal invertebrates in the more heavily trawled and deeper regions, there was a reduction in the production of larger infaunal invertebrates. This was due to the differential loss of large individuals rather than the proliferation of smaller ones, leading to a total loss of production. Moreover, Jennings et al. (2001) conclude that the increase in small infaunal invertebrates is largely due to changes in primary production (mostly likely due to climate change) and not to trawling. As explained in the section of meiofaunal effects, this is in contrast with the findings of Hinz et al. (2008). An explanation for the non-significance of changes in epifaunal production was attributed to the fact that epifaunal mobility might have masked the potential detection of any effects as the spatial separation between sites was limited.

Another investigation of the effects of trawling upon benthic secondary production was undertaken by a modeling exercise (Hiddink et al. 2006a, 2006b). A theoretical, size-based model was constructed, including habitat features. This model was validated by sampling 33 stations subject to a range of trawling intensities in four shallow, soft sediment areas in the North Sea. General conclusions (Hiddink et al., 2006b) were that both the model and the field data demonstrated that trawling reduced biomass, production and species richness. Hiddink et al. (2006a) have simulated the effects of closures of different sizes and in different locations. These could have both positive and negative effects, depending on the trade-off between recovery in the closed areas and additional trawling effects in the open areas that arose from displaced fishing activity. The details of their findings indicate the following (Hiddink et al., 2006b):

The effects of trawling were generally stronger on biomass than on production (Figure 5.7). The model predictions showed that the impact of the first passage of a trawl has the greatest effect, while an increase of trawling effort on communities that were already heavily trawled had little additional effect on production or biomass for all habitats. The model demonstrated that there was an interaction between natural disturbance and fishing disturbance; in situations of high natural disturbance (erosion), biomass, production, and species richness were low irrespective of fishing disturbance. Consequently, additional fishing disturbance had a much smaller effect on the benthos in situations with a high than with a low natural disturbance. At the same level of natural disturbance and trawling intensity, benthic communities on **mud** and **muddy sand** were less affected by trawling than those on **sand** and **gravel**. For epifauna (2m beam trawl samples), there was a significant negative effect of trawling on biomass and production; for small infauna (box corer and Hamon grab samples), there was a significant negative effect of trawling on biomass. They found no effect of trawling on the biomass and production of infauna sampled using dredges, and no significant interactions between the area and trawling intensity for any of the three sampling methods (Table 5.3). The comparison of the modeled results with the field data revealed that all correlations between the observed biomass in the North Sea and that predicted by the model were positive, except one. 8 out of 12 of these correlations were significant. Hiddink et al. (2006b) conclude that according to the model, benthic biomass in the Dutch and UK sector of the North Sea is currently 56% lower than would be expected in the absence of bottom trawling. Benthic production in the Dutch and UK sector of the North Sea was 21% lower, consistent with a shift in the benthic community towards smaller individuals and species with higher *P:B* (Production to Biomass) ratios. Hiddink et al. (2006b) discussed the simplifications of their model, such as species with different vulnerabilities that fill each others' niche, extinction of key species with important ecosystem functioning, etc. In conclusion, they state that this model helps to understand the spatial patterns and changes in production of benthic species according to trawling disturbance, which impacts the marine environment differently in different habitat types. A reduction of trawling can, according to Hiddink et al. (2006b), be achieved by redirecting trawling effort from vulnerable to more resilient habitats. Different management scenarios have been modeled and are presented in (Table 5.4 and Figure 5.8). Because they measured the effects of only a small proportion of the international beam trawl fleet, the estimated *status quo* impacts of trawling in 2002 (18.4% reduction in biomass, 4.6% reduction in production, and 12.4% reduction in cells with no species loss relative to no trawling) were smaller than those that have been estimated when the effects of the international **beam trawl** fleet were considered in the same area (56% reduction in biomass and 21% reduction in production, Hiddink et al., 2006b).

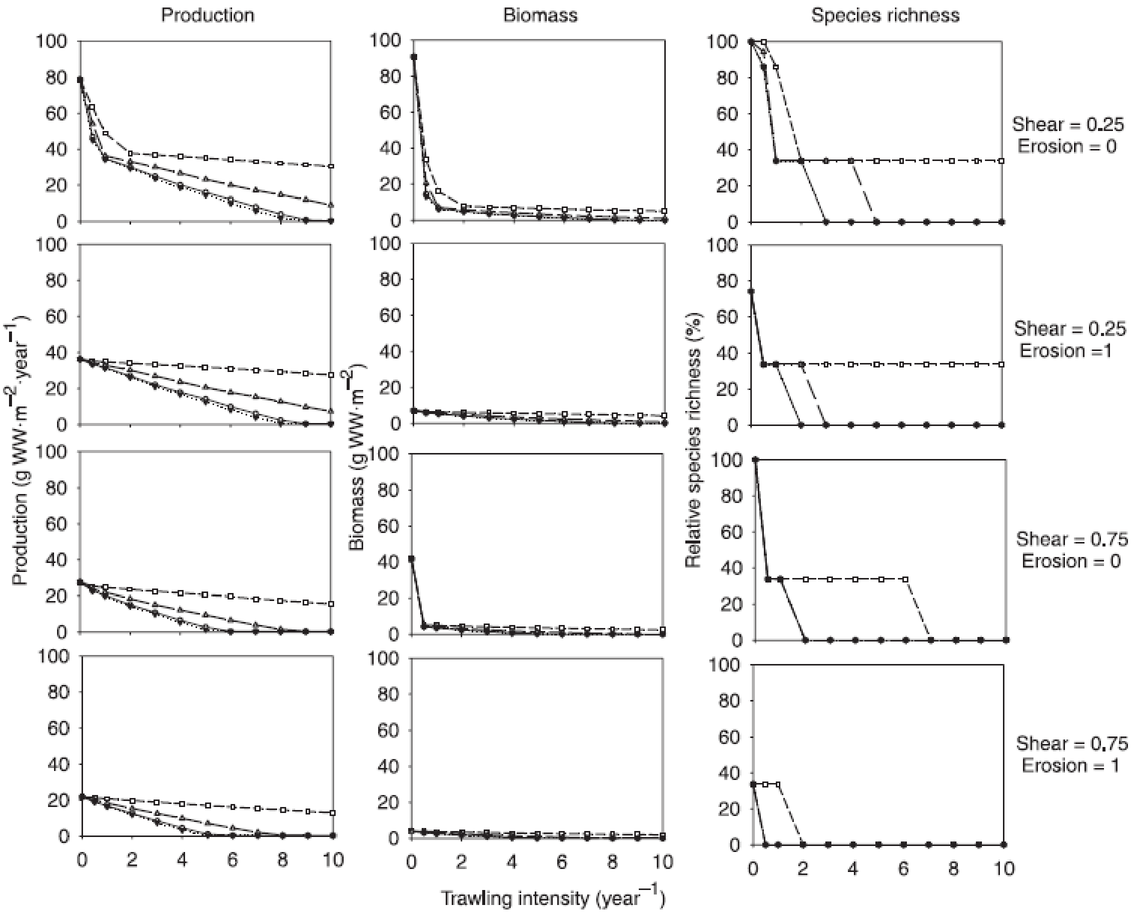


Figure 5.7. The relation among trawling intensity, production, biomass, and species richness of benthic communities on four sediment types as calculated by the model (Hiddink et al., 2006b). Production, biomass, and relative species richness are given for two levels of shear stress (Pa), two levels of erosion (cm), and four sediment types. Open circle, gravel; solid triangle, sand; open triangle, muddy sand; open square, mud. WW, wet weight. (modified from Hiddink et al., 2006).

Table 5.3. Statistical parameters of the regression relationships among biomass, production, and trawling intensity (all log10-transformed) for four locations and three types of sampling gear for biomass, production, and species richness. (modified from Hiddink et al., 2006b).

		Area			Trawling intensity			Area × trawling intensity			
	R^2	df	F	p	df	F	p	df	F	p	Residual df
Biomass											
2 m beam trawl	0.72	3	15.5	<0.001	1	14.29	0.0008	3	1.40	0.26	25
Dredges	0.95	3	162.1	<0.001	1	2.32	0.14	3	1.34	0.28	25
Corer–grab	0.87	1	176.0	<0.001	1	18.15	0.002	1	1.28	0.26	27
Production											
2 m beam trawl	0.75	3	20.7	<0.001	1	12.33	0.0017	3	0.80	0.50	25
Dredges	0.94	3	138.9	<0.001	1	0.89	0.35	3	0.44	0.072	25
Corer–grab	0.55	1	29.2	<0.001	1	3.74	0.064	1	0.06	0.80	27
Species richness											
2 m beam trawl	0.60	1	3.53	0.089	1	11.33	0.0071	1	0.10	0.75	10
Dredges	0.83	1	42.8	<0.001	1	2.81	0.12	1	2.76	0.13	10
Corer–grab	0.27	—	—	—	1	1.87	0.23	—	—	—	5

Table 5.4. Comparison of the effects of 11 management scenarios on biomass, production and species richness of benthic communities in the North Sea. Biomass and production are given as a percentage of biomass and production without trawling. For scenarios 1-7s, trawling effort in southern and central North Sea study area was standardized to 100% of pre-management levels.

			Biomass (B) (%)			Production (P) (%)			% cells with maximum species richness (%)
			Time (years)			Time (years)			
Scenario		Trawling effort relative to 2002 (%)	5	10	25	5	10	25	$t = 25$
	No trawling	0.0	100.0	100.0	100.0	100.0	100.0	100.0	75.3
	Current trawling	100.0	81.7	81.6	81.6	95.4	95.4	95.4	62.9
	Stop trawling	0.0	85.3	87.5	90.4	97.4	98.5	99.3	64.5
1	Close 40% cod catch	107.0	81.5	81.4	81.3	95.3	95.3	95.3	62.9
2	Close 60% cod catch	113.9	81.2	81.0	80.8	95.2	95.1	95.0	62.9
3	Close 80% cod catch	113.0	80.7	80.3	79.9	94.9	94.7	94.6	62.4
4	Close 40% plaice catch	107.0	81.2	81.1	81.0	95.3	95.3	95.3	62.7
5	Close 40% sole catch	102.5	81.5	81.4	81.3	95.3	95.3	95.3	62.9
6	Close <20% plaice catch	115.0	81.9	82.1	82.6	95.3	95.4	95.4	62.8
7	Low catches by any fleet	74.3	82.5	83.3	84.6	95.8	96.2	96.5	63.0
8	Days at sea 20% reduction	80.0	82.3	82.7	83.1	95.8	96.0	96.1	63.2
9	Days at sea 40% reduction	60.0	83.0	83.8	84.7	96.2	96.6	96.9	63.6
10	Decommission 20% most efficient boats	82.9	82.1	82.4	82.6	95.7	95.8	95.9	63.1
11	Decommission 20% least efficient boats	99.3	81.7	81.7	81.6	95.4	95.4	95.4	62.9
1s	Close 40% cod catch	100.0	81.7	81.8	81.8	95.5	95.5	95.5	63.0
2s	Close 60% cod catch	100.0	81.7	81.7	81.7	95.4	95.5	95.5	63.0
3s	Close 80% cod catch	100.0	81.2	81.0	80.8	95.2	95.1	95.1	62.7
4s	Close 40% plaice catch	100.0	81.5	81.4	81.5	95.4	95.5	95.5	62.8
5s	Close 40% sole catch	100.0	81.6	81.5	81.5	95.4	95.4	95.4	62.9
6s	Close <20% plaice catch	100.0	82.2	82.7	83.3	95.6	95.7	95.8	63.1
7s	Low catches by any fleet	100.0	81.8	82.3	83.3	95.3	95.5	95.8	63.3

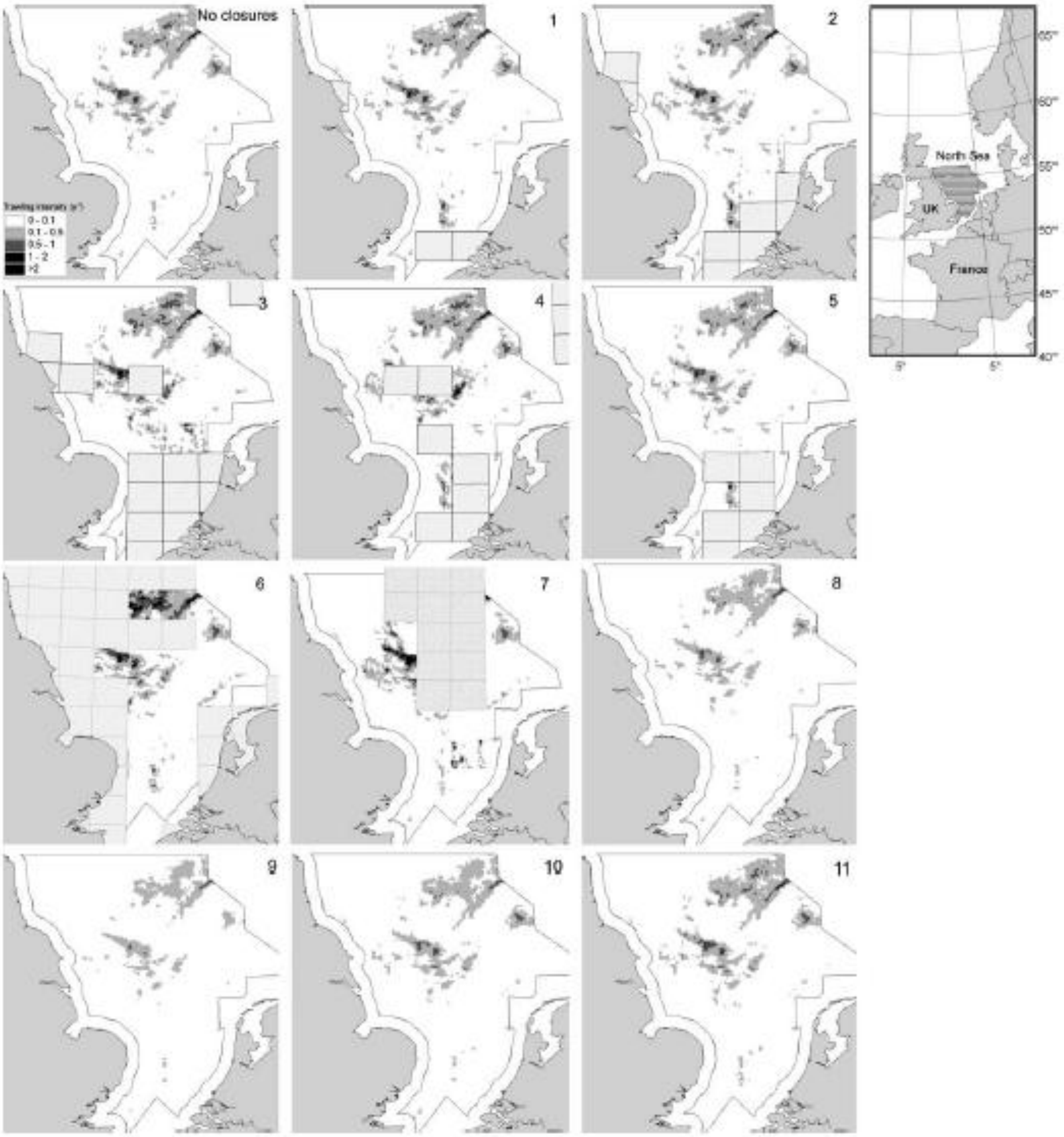


Figure 5.8. The study area - Dutch and UK North Sea south of 56°N, indicated by the solid line. The map in the top right-hand corner shows the position of the studied area in northwestern Europe. Trawling effort (y-1) of UK beam trawlers in the study area was calculated from VMS records and is indicated by grey shading. Numbers in the top right-hand corner of each map indicate the scenario number, and cross-hatched rectangles were those closed to trawling in the different scenarios. (Modified from Hiddink et al., 2006a).

The key results from the analysis of Hiddink et al. (2006a) are (i) that area closures in areas where existing fishing effort is low will lead to less effort displacement and are more likely to benefit benthic communities than closures in areas where fishing effort was high, and (ii) that effort reductions resulting from days at sea restrictions and decommissioning schemes are likely to reduce the spatial footprint of fishing activity and to provide benefits for benthic communities. These results apply when habitat types are relatively homogeneous, but they may not apply among habitats when there is significant variability in habitat type. Hiddink et al (2006a) also remarks that their approach takes account of trawling history and the existing state of the benthic community, the long- and short-term effects of area closures can be different. For example, with scenario 4s, the short-term effect of the area closure is negative, with minimum benthic biomass after about 15 years, but after 55 years the closure starts to have a net positive effect. This pattern suggests that previous trawling history should not be ignored when choosing closed areas. The pattern is also relevant because it implies that temporary or rotating area closures, which are unlikely to allow time for recovery and effectively lead to greater homogeneity of trawling disturbance (Dinmore et al., 2003 in Hiddink et al., 2006a) are likely to have a more negative effect on benthic communities than no closure. The results of their study also show that creating areas that are closed to fishing without reducing overall trawling effort may or may not have conservation benefits, depending on the areas closed. To identify management solutions that are optimal/least costly for both the fishery and the ecosystem, areas that are most and least sensitive to trawling have to be identified.

Quierós et al. (2006) conclude a negative impact of "chronic trawling" on the biomass and production of benthic communities in the **muddy habitat**, while no impact was identified on benthic communities from the **sandy habitat**. These differences are the result of differences in size structure within the two communities that occur in response to increasing trawling disturbance. Trawling intensity varied between 0.00 and 1.55 y^{-1} in the Dogger Bank, mostly fished by **beam trawlers** that target plaice (Rijnsdorp et al. (1998) in Quierós et al. (2006)) and between 0.10 and 3.53 y^{-1} in the Irish Sea, intensively exploited by **otter trawlers** that target the Norway lobster. Figure 5.9 shows the variation in community biomass and production with trawling intensity and the silt-clay fraction in the two study areas (the Irish Sea and the Dogger Bank, North Sea).

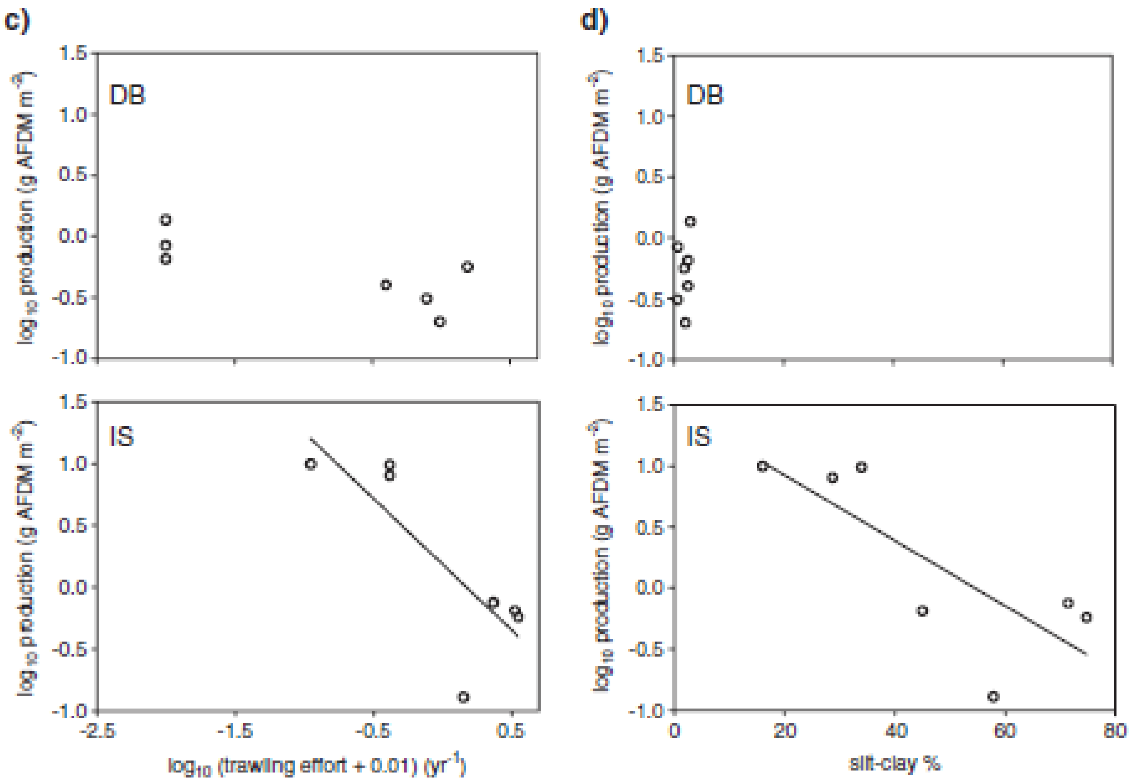


Figure 5.9. Production estimates. (c) the relationship between production and trawling intensity; (d) the relationship production and the silt-clay fraction in the sediment. "IS": Irish Sea; "DB": Dogger Bank (Modified from Queirós et al. (2006).

Reiss et al. (2009) have focused on the infaunal production of the Dutch **beam trawlers** in the Southern North Sea (German Bight), which comprised ~75% of the international trawl effort in the area. Reiss et al. (2009) concluded the following:

For all the time periods considered, fishing intensity (≈fishing effort) of the spatial units ranged from a frequency of 0 to 4.4 times trawled yr^{-1}. Within the entire German Bight region, 73% of 1 × 1 n mile spatial subunits were fished with an intensity lying between these lowest and highest values observed at the sampled stations. Only 2% of the German Bight region was more intensively fished than the most heavily fished station. Infaunal mean total biomass, secondary production and species number decreased significantly with increasing fishing effort (Figure 5.10). In terms of biomass, the duration of the fishing effort period considered made no difference to the result, but the effect of fishing intensity on secondary production and species number was apparent only for the short-term fishing effort period (Figure 5). Variations in fishing effort had no significant effect on mean total abundance, or on either of the diversity measures (the Shannon-Wiener and evenness index) that took species relative abundance into account. Despite the relatively homogeneous environmental characteristics for which the study area was selected, some covariance between fishing intensity and some environmental variables was apparent. This raises the possibility that the changes in the infaunal community that are related to fishing intensity in Figure 5 might instead have been caused by differences in sediment characteristics between the stations. This alternative explanation seems unlikely, however, considering the fact that no significant relationships were observed between infaunal biomass, production and species richness and any of the environmental variables examined. On the other hand, infaunal abundance was significantly negatively related to sediment mud and TOC content (Figure 5.11). Separate analysis of the different size fractions revealed that fishing disturbance induced reduction in infaunal secondary production, mainly for the larger-sized animals in the community, i.e. those retained in the 4 mm sieve. Among the animals retained in the 1 mm sieve, there was an apparent positive effect of fishing intensity on production. The results by Reiss et al. (2009) suggest that even in areas that have been heavily fished for decades, infaunal benthic invertebrate communities may remain sensitive to increases in fishing intensity. Thus, although a baseline shift in benthic communities due to chronic fishing disturbance has probably occurred in some areas of the North Sea during the last century, both infaunal community structure and parameters such as production, biomass and species number were still affected by disturbance due to trawling. This finding contrasts with the assertion that increased trawling effort in already heavily trawled areas would have little (if any) additional impact on benthic communities (e.g. Hiddink et al. 2006b), and may have important consequences for management.

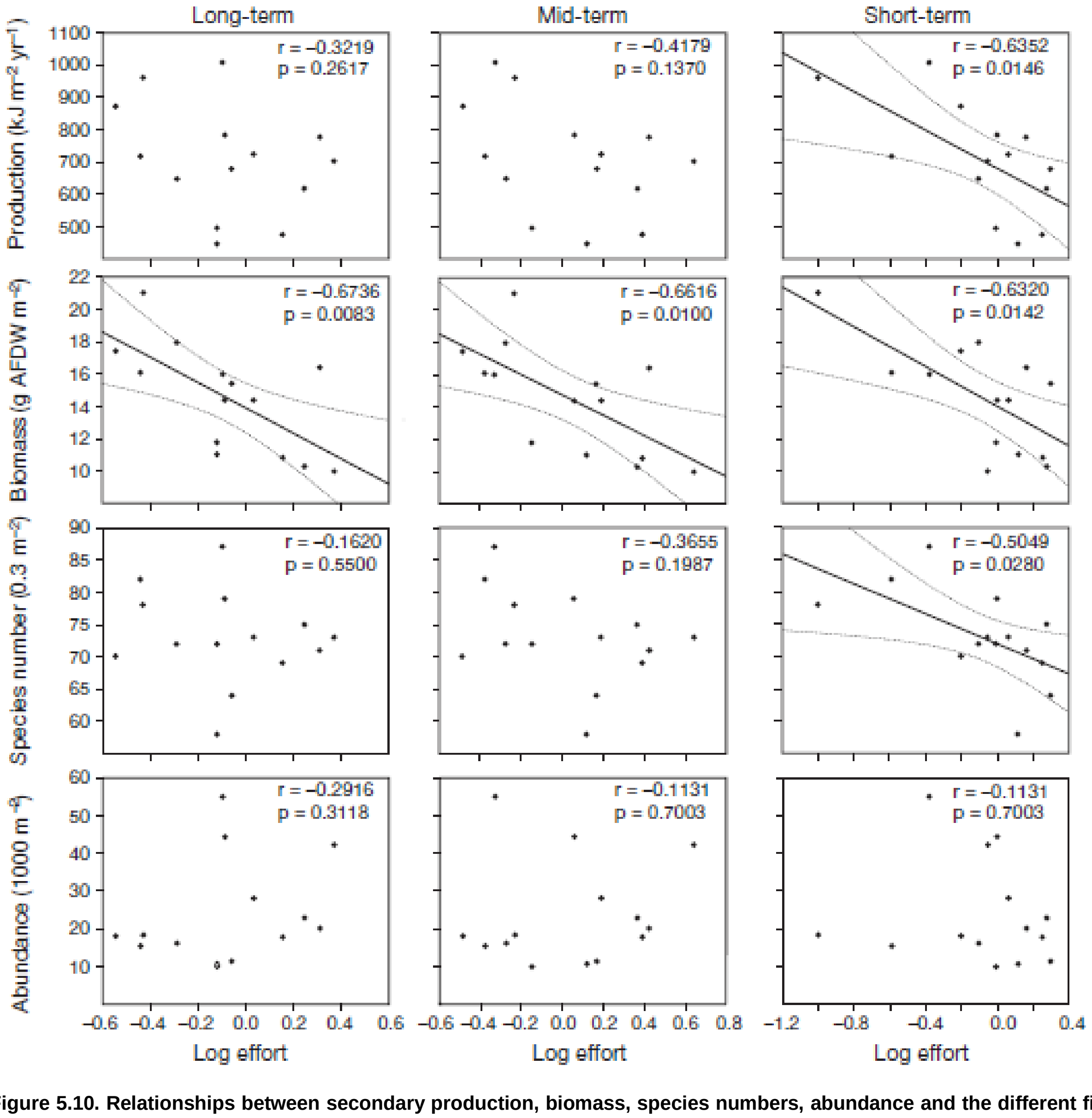


Figure 5.10. Relationships between secondary production, biomass, species numbers, abundance and the different fishing effort regimes. Trend lines and 95% confidence limits are given for significant linear relationships (Modified from Reiss et al. (2009).

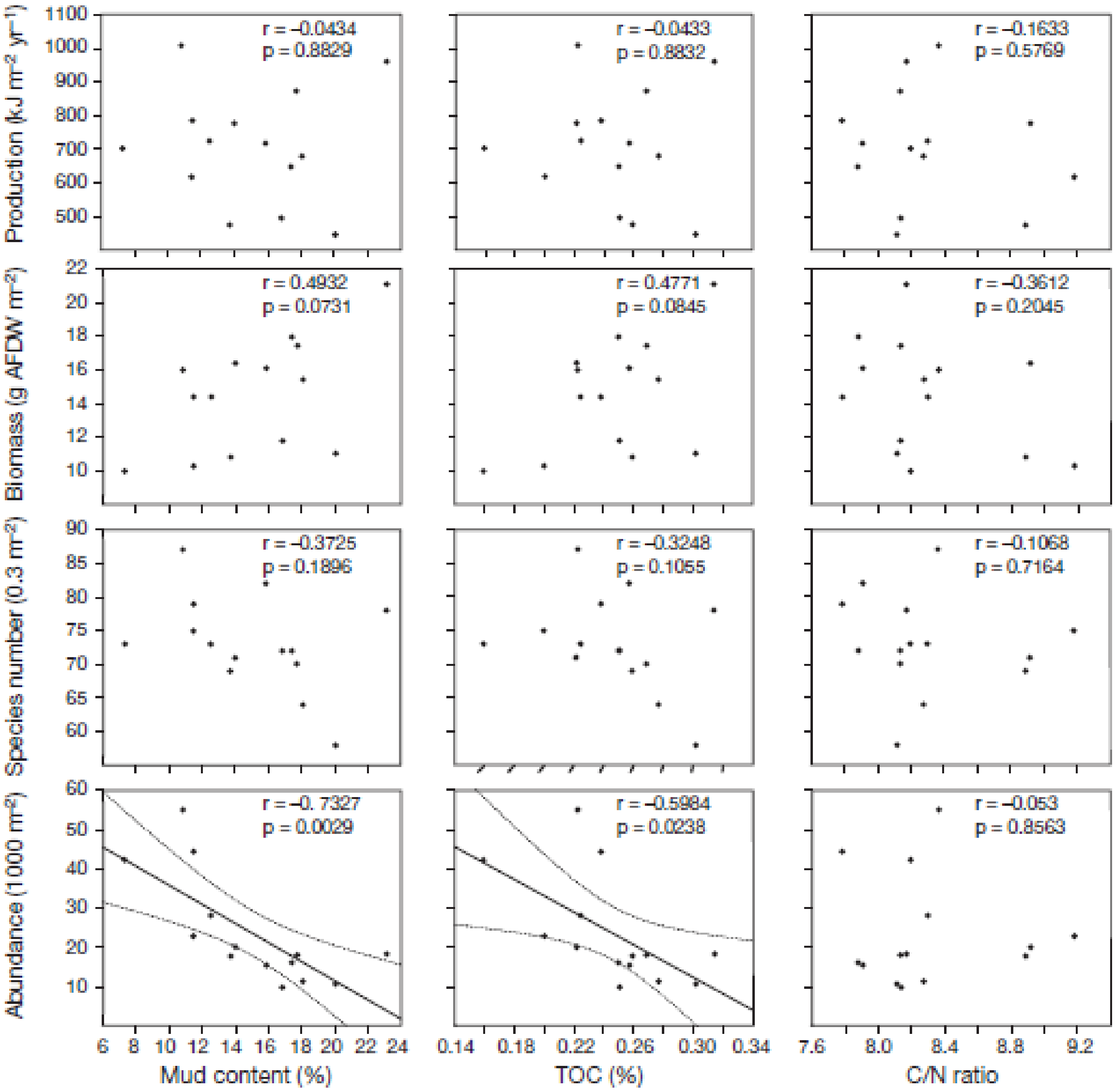


Figure 5.11. Relationships between secondary production, biomass, species numbers, abundance and selected environmental variables (mud content, total organic carbon content and C/N ratio). Trend lines and 95% confidence limits are given for significant linear Relationships (Modified from Reiss et al., 2009).

5.3.3.3. Effects on fish species

All types of fishing gear affect the productivity of the fish community. The effects of fishing upon the production of fish species is assessed yearly by ICES. Currently the landings are foremost the baseline data for this assessment. Integration of fish discards (see above) in these estimates of productivity, biomass or stocks is discussed. In this section, the direct effects of fisheries on changes in fish production are not discussed. However, the focus is on the indirect effects of fisheries on changes in benthic production and consequently in changed fish populations.

The most important target species for **beam trawlers** in the Southern North Sea are plaice and sole. Rijnsdorp and Vingerhoed (2001) have investigated their feeding behaviour in relation to beam trawling. The diet of plaice and sole comprises mainly short-lived, highly productive benthic organisms (infauna, polychaetes…). Rijnsdorp and Vingerhoed (2001) could not find a difference between the diets of fish sampled at grounds with different trawling intensities. The comparison of the present-day diet and the diet at the beginning of the 20th century however, suggested that the preponderance of polychaetes has increased and that of bivalves decreased. These results confirm 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 changes in diet may also be related to eutrophication and pollution. However, Rijnsdorp et al. (2004) also examined the changes in productivity of the Southeastern North Sea as a reflection of the growth of plaice and sole. In this sense, they concluded that flatfish productivity has decreased over the last two decades, possibly in relation to a decrease in the inflow of nutrients and an overall change in the North Sea ecosystem. Other factors than trawling are therefore confounding the changes in productivity of flatfishes.

Another recent investigation by Van Keeken et al. (2007) also suggested that **beam trawling** alters the food availability for flatfishes, namely plaice, and therefore supports the hypothesis that trawling increases the productivity. Van Keeken et al. (2007) describe this as follows: To protect the main nursery area of plaice, an area called the 'Plaice Box' was closed to trawl fisheries with large vessels in 1989, with the expectation that recruitment, yield and spawning stock biomass would increase. However, since then the plaice population has declined and the rate of discarding outside the Plaice Box has increased, suggesting an offshore shift in spatial distribution of juvenile plaice. An offshore shift in the distribution of young plaice occurred in the 1990s most likely in response to higher water temperatures that may have exceeded the maximum tolerance range or increased the food requirements above the available food resources. A decrease in competition with larger plaice offshore, possibly in combination with increased inshore predation by cormorants and seals, may also have played a role. Van Keeken et al. (2007) have thus mentioned that an increased benthic production might be important in fish productivity.

Hiddink et al. (2008) examined the effect of benthic productivity upon fish productivity in more detail for the Plaice Box. The diet of plaice was dominated by several species of infaunal polychaetes, and small plaice ingested especially the smaller prey than larger plaice. This outcome was related with their model predictions. The model showed that the total production of the whole benthic community was at its highest without trawling, but the production of animals <0.5g peaked at trawling frequencies of 0.25 $year^{-1}$. The production of small (<500mg) soft- and hard-bodied invertebrates reacted differently to trawling disturbance (Figure 5.12).

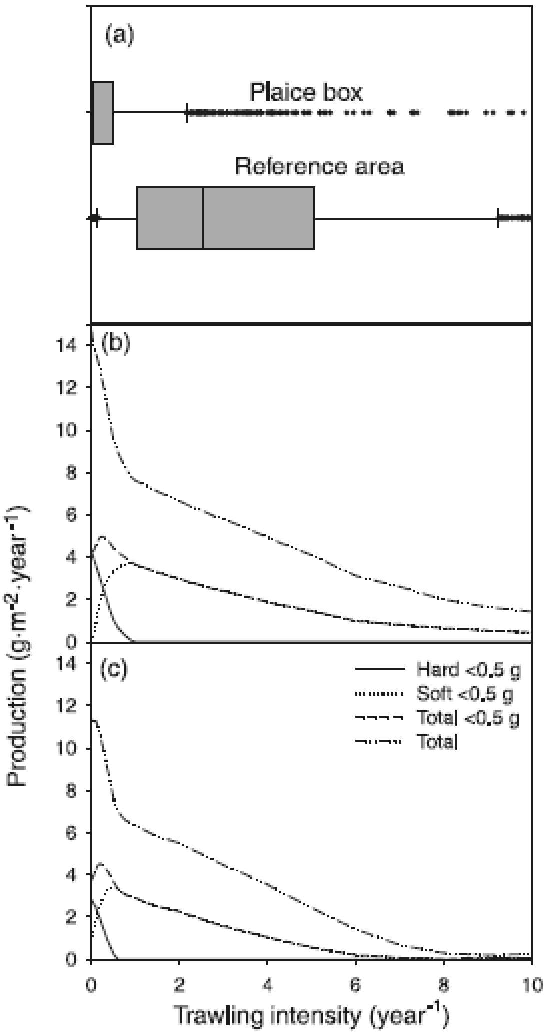


Figure 5.12. (a) Box and whisker plot of trawling frequency (international effort 2000–2004) in the plaice box and the reference area. The boundaries of the boxes indicate the 25th and the 75th percentiles, the line within the box marks the median, and the whiskers indicate the 90th and 10th percentiles. Outlying points are plotted as individual points; outliers over 10 are not shown. The median for the plaice box is 0. (b) The average modelled relationship between trawling frequency and benthic production in the plaice box. (c) The average modelled relationship between trawling frequency and benthic production in the reference area in the southeastern North Sea. (Modified from Hiddink et al., 2008).

The production of hard-bodied invertebrates decreased strongly with trawling to virtually nothing at a trawling frequency of 0.5 year^{-1}. Production of soft-bodied invertebrates was low at very low trawling frequencies, but increased to a maximum at trawling frequencies of 0.5-1 year^{-1} and decreased slowly with further increasing trawling frequencies. Without going into details in this paragraph, Hiddink et al. (2008) concluded that the total benthic production was higher in the plaice box, while production of small, soft-bodied benthic invertebrates was higher outside the box. Hiddink et al. (2008) supports the hypothesis that the reduction of fishing effort in the plaice box has led to a decrease in bottom disturbance and may lead to a concordant reduction of the production of flatfish food in the plaice box. Decreasing trawling disturbance favours large, inedible (for plaice), benthic invertebrates over small, edible invertebrates. As a result of this indirect effect, production of small, soft-bodied invertebrates (and food availability for plaice) is predicted to be higher outside the plaice box. These model results thus provide support for the idea that disturbing the seabed with bottom trawls may increase food production for fish species that feed on small invertebrates. Hiddink et al. (2008) illustrate that closed areas may not be a suitable management measure to protect juvenile plaice, but does not suggest that bottom trawling has a net positive effect on this species, the ecosystem, or the exploitation in general. The net effect of bottom trawling disturbance on plaice populations depends on the balance between the positive effect on food supply of juvenile plaice versus the negative effect of increased juvenile bycatch mortality. Even though bottom disturbance by trawling may improve feeding conditions for plaice, bottom trawling can have undesirable effects on the ecosystem and other commercial fisheries (e.g., on fish species that feed on large invertebrates, such as Atlantic cod). Over time, there seems to have been a shift in the Southeastern North Sea from fish that eat large benthic invertebrates (such as Atlantic cod and rays) to ones that eat small worms (such as plaice, dab (*Limanda limanda*), and common sole (*Solea solea*)).

Reiss et al. (2008) found that higher intensities of trawling were related to lower levels of production of the larger infauna that are likely to be predated by adult flatfish (4 mm sieve fraction), while there was no significant relationship of production with fishing intensity for the smallest size fraction (likely to be predated on by juvenile flatfish), although an increasing trend occurred. Especially for r-selected species, such as *Phoronis muelleri* and the polychaetes *Owenia fusiformis* and *Lagis koreni*, the highest abundances were found in the heavily trawled areas. Nevertheless, the most affected and abundant species *P. muelleri*, is not at all used as a food source by benthivorous fish due to their chemical defence mechanisms against predators (Larson & Stachowicz (2009) in Reiss et al. (2008), S. Schückel unpubl. Data in Reiss et al. (2008)). Thus, their results do not confirm the hypothesis that intensive trawling may directly lead to an increase in the production of food for commercial species such as flatfish; however, the range of trawling intensity covered in our study did not extend to levels as low as those recorded in for instance the Plaice Box.

It is clear that trawling influences the productivity of fish species in a positive or negative way, depending on a range of factors such as fishing effort, community structure (large or small invertebrates), the diet of fish species, etc. Changes in the use of certain fishing gears with other effect on the benthos, changes in the level of fishing effort and changes in the spatio-temporal distribution of fishing should therefore be well deliberated.

5.3.4. Productivity by fishing methods

There are different aspects of productivity. Different fishing methods affect the different spatial units of the ecosystem in different ways. Direct measurements of changes in productivity in specific habitats exist (see above for the individual studies), but they cannot be easily expanded to generic conclusions. The same idea account for fishing gears. The effects on productivity are studied by the different levels of fishing effort of beam trawls and/or otter trawls. Those fishing methods are most easily studied due to its wide-spread use. The effects of other fishing methods are difficult to predict as their use is not fully covering a certain region. For evaluation purposes and discrimination between different gears in different habitats, it is crucial to investigate the following issues of which descriptions are detailed elsewhere:

- Physical disturbance, including nutrient fluxes and potential impact on the primary productivity.
    - Fishing techniques such as otter trawls and by extension twin trawls, are differently rigged and depending on those characteristics, their impacts on the seafloor are different (e.g. (Durrieu de Madron et al., 2005)).
    - The impact is also different according to habitats, which are still limitedly studied. Generalization of study results to other habitats might be plausible, if the community structure and the sediment is taken into account (e.g. free-living organisms in a sandy habitat), although very different results can be expected in areas where the habitat complexity increases or in areas where there has not been any fishing activity before. In these areas, massive changes in production processes and trophic structure can be expected.
- Changes in densities, i.e. tow path mortality and consequently, changes community structure (which species, which size ranges, etc).

The effects on benthic species (incl. meio-, macro- and megafauna) and communities (e.g. in biogenic habitats, structured by bioturbators) is related to the different gears, which result in a different productivity and to the different vulnerabilities of the species that constitute a community (e.g. Cartes et al. (2009)).

- Identification of key species and their ecosystem function (e.g. Can this species be substituted by other species or is it paramount in the well-functioning of the system?).

Hereby are local fishing intensities and local differences in ecosystem structure essential, such as the habitat characteristics, community differences, etc. Moreover, the investigation of the effects of a fishery upon a certain ecosystem component must coincide with the spatial scale at which the component acts.

5.4. Recovery and long-term impacts

5.4.1. Introduction

Ecosystem effects are in a first instance always assessed on a local, short-term scale and generally in a direct sense. Effects are then split up into the structural ecosystem components such as fish, benthic invertebrates, habitats, etc. and the functional aspects of an ecosystem attribute, e.g. boulders on the seabed (= ecosystem attribute) increase habitat complexity (=functionality) and therefore provide shelter and increase the local species diversity. However, the ecological pillar of sustainability must also be regarded on a different, longer timescale or even within a relatively short time scale of typically 5 to 20 years, wherein the ability of the ecosystem to withstand fishing disturbance is looked upon, and especially fishing disturbance of a certain kind (beam trawling, fly-shooting, etc). This implies additional mortality is inherent to fishing, i.e. mortality additional to the mortality of the target commercial species is nearly unavoidable. A crucial concept is therefore the consideration of long-term impacts of fisheries on those non-target ecosystem attributes and the ability of an ecosystem to recover from disturbances within a reasonable time frame. A certain pressure, e.g. fishing disturbance, can be acceptable as long as "sustainability" is met. This fishing pressure depends on the effects of the disturbance type, e.g. different types of gears, as well as the level of pressure, in case of fisheries where the fishing effort for a certain gear is an internationally accepted measure. And finally, acceptable fishing pressure also depends on the resilience of the ecosystem itself. Resilience is herein defined by Hughes et al. (2005) as: "*the extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping into alternate states*".

Direct, short-term impacts are assessed in the chapters above. In this chapter, the focus is upon the implications of those short-term direct effects, i.e. upon the concept of "*recovery*". The core investigation of this chapter should be the application of the "*recovery*" concept on the North Sea ecosystem and the fishing gears in focus of this document. However, as scientific understanding of short-term effects is not fully understood, so are the predictions about recovery. Therefore, two parts can be discriminated in this chapter: (1) a conceptual framework which links *recovery* with fishing pressure (ICES, 2010) and (2) linkages between long-term effects and fishing pressures of different fishing methods in the North Sea ecosystem. The first part is essential for the estimation of how large a fishing pressure for a certain gear can be in a certain ecosystem/habitat. However, this type of deductive reasoning needs a whole lot of premises to be validated and therefore much progress is still to be made. Its application to the North Sea ecosystem is not within the scope of this document, although some examples will illustrate its meaning. The value of this framework must be understood as an illustration of the concepts which are still poorly illustrated with quantitative data, but which are indispensible if the management of the North Sea ecosystem is to be ecologically sustainable. The second part of this chapter approaches *recovery* indirectly and is based on a more empiric approach. The complexity here is that it is very hard to establish direct cause and consequence linkages between the evolution of the ecosystem and fishing as a multiple range of factors is generally influencing the system into sometimes contrasting ways.

5.4.2. A framework to link recovery and fishing pressure (based on ICES, 2010)

The term "*Recovery*" covers many aspects and is not clearly defined or is at least interpreted differently in several policy documents and scientific papers in the context of the marine ecosystems (e.g. WGECO-report 2009). WGECO defines the concept as follows:

> *"A population or higher level ecosystem property is considered recovered if the necessary pieces for 'normal' structure and function are present, even if some species historically observed are no more present or have modified abundance, biomass or age composition; this recovered state is not likely to be impaired by perturbations within the normal range of environmental variability and sustainable use, and can be attained and maintained without any special management measures"*

WGECO recently created a conceptual framework to examine the relationship between recovery and perturbation, caused by for instance fishing pressure of a certain fishing gear. They state that when setting reference levels that should reflect the policy objective "sustainable use", it is necessary to apply a line of consistent ecological reasoning about what level of alternation of the attributes being measured by the indicator is *not* sustainable, and set the reference level to avoid that level of alteration. Evaluation of the degree to which perturbations are sustainable always have to consider at least two factors: the degree to which recovery of ecosystem attribute from the perturbation is rapid and secure, and the degree to which functions served by the ecosystem attribute and ecosystem processes in which the attribute plays a key role are altered (e.g. long-term effects of fishing in the North Sea: chapter below). "Rapid" is always interpreted relative to the life history parameters of the population of concern; rapid for a small pelagic is not the same rapid for a large cetacean. "Secure" is interpreted relative to the likelihood that recovery would start immediately when the pressures causing the mortality reduced, and that in its current status, the population is not at increased risk of major further losses due to stochastic factors and likely scales of natural pressures.

The concept of recovery is in its most simple case applied to single species populations (e.g. Dickey-Collas et al., 2010). Although WGECO put forward one single definition for recovery, the terminology for its application to single species populations comes across several, other definitions. Sometimes it is used in a sense that after a decline, any increase in population size could be interpreted as some sort of recovery, for example for overfish fish stocks (Hutchings, 2000). Other sources, however, may stress that even substantial improvements in the status of badly depleted stocks should not be called, "recovery", but at most it should be stated that progress *towards* recovery has been made (DFO, 2009). For some (but not all) fish stocks distinct thresholds (like B_{lim} or B_{pa}) are used as reference levels or thresholds, for management action. These become *de facto* benchmarks for recovery, to the extent that rebuilding plans for stocks below these reference levels often use B_{pa} as the target for rebuilding. Recently, stock recovery is increasingly recognized as not being synonymous with stock rebuilding. The term recovery tends to be used relatively indiscriminately and often simply denotes recovery of bulk biomass, i.e., stock tonnage. On the other hand, rebuilding should be regarded as a more complex goal to achieve, aiming to reconstitute a previously evident age-structure which has been truncated by excessive fishing pressure, modified behavioural traits, changed structure of the stock's gene pool and evolutionary mechanisms. The ICES stock assessments can be referred to as one is to assess the recovery potential of a single commercial fish population in relation to its biomass and fishing effort. For marine mammals, ASCOBANS has adopted an interim goal of restoring the population of harbor porpoises in the Baltic Sea to at least 90% of its carrying capacity (ASCOBANS, 2009). The capacity to recover for an individual population is almost always evaluated by taking some measure of the population's ability to produce recruits. In fish stock assessments this has traditionally been done by looking at how recruitment has varied with mature biomass. However, any measure of population status and any measure of the ability of the population to replace itself can be used as independent and dependent variables (the "x- and y-axes", respectively).

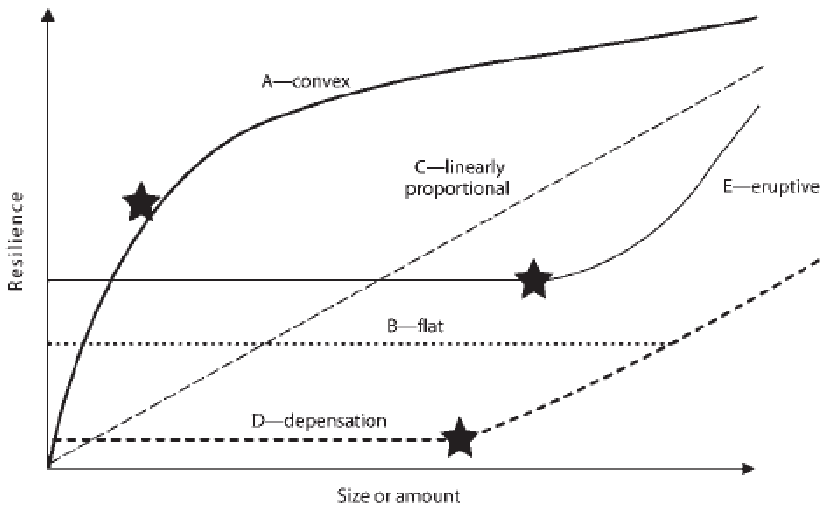


Figure 5.13. Schematic of the five conceptual types of relationship between productivity, resilience/recovery, or functional significance of the ecosystem feature and the amount of the ecosystem feature. The additional stars show the general position of rate of change in the dependence of the y-axis factor on the x-axis factor in these types of functional relationship (Modified from Rice (2009).

The next step is to seek the functional relationship and to find some point (inflection point) in the relationship that can serve as a consistent standard for identifying the position on the population indicator below which its ability to replace itself is at risk of being impaired. An example is presented in Rice (2009), where the concept has been explained more profoundly (Figure 5.13).

The concept can be applied to all ecosystem attributes with a capacity to recover from perturbations, to estimate the level of the indicator below which replacement likelihood or ability is impaired one needs an ecological rationale for why the “x-axis” indicator reflects the status of the ecological attribute of concern and why the “y-axis” indicator reflects the potential of that ecological attribute to increase. Next to the indicators of ecosystem attributes that have the capacity to recover from perturbation, there are also ecosystem attributes that have no capacity to recover from perturbations. Reference levels for sustainable impact have to be set based on impairment of the functions served by those attributes. A clear example is the three-dimensional structure of a seabed habitat or the amount of gravel, which may not have a capacity to recover from damage or removal. These impacts must be measured by the alteration in the functions that those 3D-habitat structures play. How this item is addressed is clearly shown in the WGECO-report (ICES, 2010).

However, the actual question in management (and of the ICES-WGECO framework) is not only about the current state of the ecosystem and how this relates to its recovery. The framework is designed to estimate reference levels for state indicators; whether the state of populations, communities or habitats. Because the first-order policy and management questions are likely to be about what level of a pressure is sustainable, it is essential that pressures be integrated into this framework for setting reference levels. Therefore, one needs some knowledge of which ecosystem attributes will be impacted by a fishing pressures (e.g. beam trawling, modified beam trawling, fly-shooting, etc) and also of how the impact on the ecosystem attribute varies with the intensity of the pressure. Then one must go through the process for population and community indicators of determining if there is some ecological basis for setting a reference level of the population or community indicator, based on its ability to recover and/or the functions it serves in the ecosystem. Once a reference level is identified (and justified) the mapping onto the level of the pressure associated with that level of ecosystem attribute is direct. WGECO demonstrates the use of their framework for instance for populations with the following example:

Seabirds have frequently been used as indicators of the state of the marine food webs that support them (Furness and Greenwood, 1993; Monaghan et al., 1989; Harris and Wanless, 1990; Furness and Camphuysen, 1997). In the northwestern North Sea, breeding kittiwakes *Rissa tridactyla* feed primarily on, and provision their chicks with, sandeels *Ammodytes marinus* (Harris and Wanless, 1997; Furness and Tasker, 2000; Lewis et al. 2001). Approximately 40km offshore of an important kittiwake colony, the Isle of May in the Firth of Forth, lies a complex of sandbanks, most notably the Wee Bankie, where a major sandeel fishery started in 1990. The fishery peaked during the early 1990s before being closed in 2000 following concern over the impact of the fishery on sandeel supplies to marine top predators. In this example, the perturbation is the level of sandeel landings and chick production is a direct measure of the capacity of the kittiwake colony to recover. Kittiwake breeding success was significantly (R^2=0.293, P<0.01) negatively related to the sandeel landings (Figure 5.14).

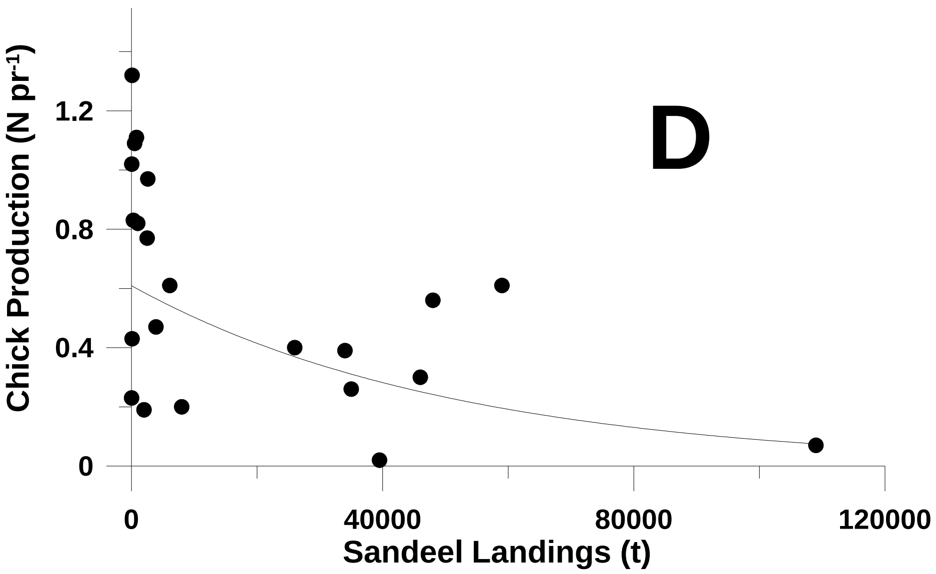


Figure 5.14. Relationship between kittiwake breeding success and sandeel landings (modified from WGECO, 2010).

The application of the concept of recovery and its relation with perturbation can also be applied above the level of single populations. Examples are given in the WGECO-report. The main conclusion of this framework is that recovery is a key concept in the evaluation of long-term effects of fishing. However, it is quite harsh to apply the concept to all populations of all ecosystem components, including other ecosystem attributes and attributes which cannot replace themselves but do serve an important ecological function. However, evaluation of the relationship of a fishing pressure with recovery and capacity to recover will contribute to our understanding of how a pressure is to be managed sustainably.

5.4.3. Long-term effects of fishing in the North Sea

Short-term direct effects of demersal fishing have been clearly identified on the densities of benthos, physical habitats, benthic productivity, fish populations, etc (see above). Long-term impacts however have not. Two main problems occur in evaluating long-term effects of bottom fisheries on benthic and by enlargement the total ecosystem. Those are that: (1) current experimental work refers to short-term effects because of the lack of appropriate experimental reference areas; and (2) consistent long-term series on the abundance of non-commercial species are scarce (Rumohr and Kujawski, (2000)).

1. Experimental attempts to study long-term effects, including recovery and resilience of the ecosystem, should include the use of large, homogeneous, and permanent non-fished areas. These are not available in the heavily exploited Southern North Sea (Duineveld et al. (2007)). Bergman et al. (1998 in Duinveld et al., 2007) and Craeymeersch et al. (2000 in Duinveld et al., 2007) also stated earlier that “attempts to correlate patterns in fishing effort and benthos to distinguish long-term impacts from experimental work have been largely unsuccessful, because strong natural gradients exist in the Southern North Sea that govern distributions of benthos and fish, and hence fishing effort”. The same holds true for other marine ecosystems in the North-East Atlantic, e.g. the Irish Sea ((Ball et al., 2000). However, some recent studies have investigated long-term effects through the use of sampling around wrecks, offshore installations (oil platforms) or other fishery exclusion zones which act as unfished pseudo-control sites (e.g. Ball et al., 2000; Bergman et al., 2007). These studies point out what long-term effects might include for benthic invertebrates (which can be studied in a rather small-scale experiments). For ecosystem components such as marine mammals or seabirds, such experimental areas cannot be identified in the North Sea.
2. Another method to evaluate long-term impacts includes long-term data series. This method is utile especially for commercial fish species. For commercial fish species, long-term data series might be reconstructed from commercial landings. However, caution is recommended as the historic information is generally correlated to the occurrence of fishing. Callaway et al. (2007) (Figure 5.18) illustrate with landings data that a sustained high trawling activity in the North Sea is taking place already since a century ago. The limited number of long-term data series can be used to evaluate the effects of fishing on benthic invertebrates, fish and the entire marine ecosystem. For the benthic communities, the effects of fishing can be approached from classic benthic time series analysis, modeling and comparison of historic (mostly qualitative or semi-quantitative) records of an ecosystem component and fishing (Frid et al., 2001). Mostly, no quantitative historical benthic data are available for the period prior to fishing, although qualitative data exist.

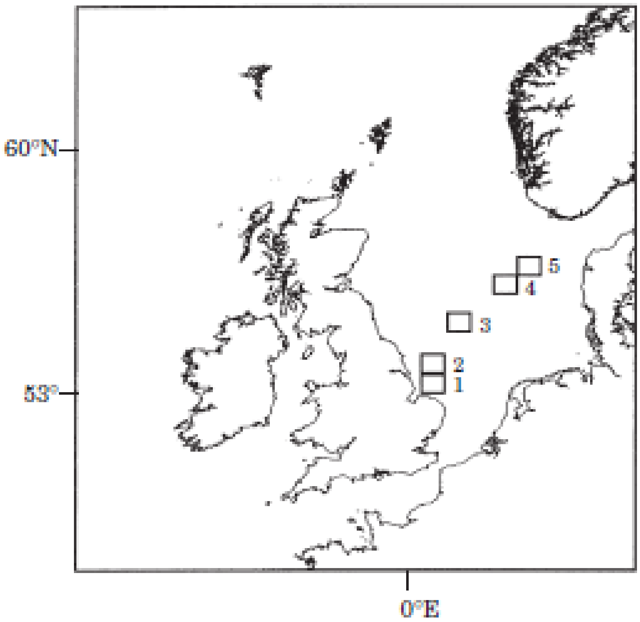


Figure 5.15. Locations of the ICES statistical rectangles used: 1. 35F1 – Dowsing Shoal; 2. 36F1 – Great Silver Pit; 3. 38F2 – Dogger Bank; 4. 40F4 – Inner Shoal; and 5. 41F5 – Fisher Bank (Modified from Frid et al., 2000).

Our review considers the arguments from scientific literature of benthic ecologists, fish biologists, etc. according to experimental data or evaluation of long-term data series. This way, a light is shed onto the limited knowledge about long term effects of fishing. Implications for recovery from disturbance of a certain fishery or for the resilience of a certain ecosystem, should be deducted from those general conclusions. Obviously a harsh discrimination between the long-term effect of beam trawling, otter/twin trawling, fly-shooting and technically modified fishing gears is not possible, nor can straightforward conclusions about resilience of different spatial distinct ecological regions. The elucidation of the current understanding of the long-term effects and a coupling with short-term effects (see above) might point management in a certain direction.

One of the long-term data series that have been collected for benthic invertebrates are focusing on the Western North Sea (Frid et al., 1999; Frid et al., 2000; Frid, 2001).

Frid et al. (2000) clearly introduces the issue of detecting changes in the benthic communities in the long-term. The authors state that further evidence is required to whether anthropogenic influences, as opposed to natural or cyclical events affecting the benthos, are responsible for any changes. This is albeit the proposal of several causes for these long-term changes, such as the impacts of towed fishing gears, effects of climatic and salinity fluctuations, eutrophication, and changes in zooplankton abundances. Although Frid et al. (2000) acknowledges fishing activity exists for many centuries (e.g. Desse and Desse-Berset, 1993; Barrett et al., 2004), but stresses that fishing intensity increased since the early 1900s[1] by the introduction of improvements in both fishing vessels and trawling gears. Their study area includes 5 fishing grounds (Figure 5.15).

In two of these (Dogger Bank and Inner Shoal), there was no significant difference in community composition between the early 1920s and late 1980s. In the remaining three areas (Dowsing Shoal, Great Silver Pit, and Fisher Bank) significant differences were observed.

Table 5.5. The significance of changes in abundance (Kruskall– Wallis) between the 1920s and 1986–1993 for taxa considered a priori to be sensitive to fishing or opportunistic in behavior (Bray-Curtis) in three ICES rectangles (see Figure 15 for legend) (Modified from Frid et al., 2000).

Taxa	35F1	36F1	41F5
"Sensitive" species			
Cnidaria	n.s.	n.s.	0.001
Arctica	—	n.s.	0.012
Echinocardium	n.s.	n.s.	n.s.
Echinocyamus	0.001	n.s.	—
Sabella	n.s.	n.s.	n.s.
"Opportunistic" species			
Capitella	0.001	n.s.	0.012
Notomastus	n.s.	n.s.	<0.001

However, these were the result of changes in abundance of many taxa rather than large-scale losses of sensitive organisms. Frid et al. (2000) draws this conclusion from the following result: Five taxa were considered *a priori* to be sensitive to fishing impacts. These were burrowing echinoderms, slow-growing bivalves (*Arctica*), and structure-building species (sea pens and *Sabella*). In only three out of the 13 valid comparisons did they show a significant change in abundance over time, and in each case they increased in abundance. Of the two opportunistic taxa (the polychaetes *Capitella* and *Notomastus*), there was a significant increase in both taxa on the Fisher Bank, no significant change in either species in the Great Silver Pit, and a significant increase in *Capitella* at Dowsing Shoal (Table 5.5). The authors suggest that the results are due to fisheries, as the lack of detection of fishery-induced changes at the Dogger Bank and Inner Shoal could have occurred prior to the 1920s. Hard evidence is absent due to missing control areas and fishing intensity data (at that time). However, the long-term changes of the benthos are mostly likely prone to fishing impacts, as the timing coincides with the mechanization of the fishing fleet and as the prevalence of the changes rules out other explanations such as climatic variation and eutrophication (Kröncke (1990) in Frid et al. (2000).

[1] Other sources (Barrett et al., 2004) suggest from historical ecological research, that zooarchaeological evidence shows that the clearest changes in marine fishing in England between AD 600 and 1600 occurred rapidly around AD 1000 and involved large increases in catches of herring and cod.

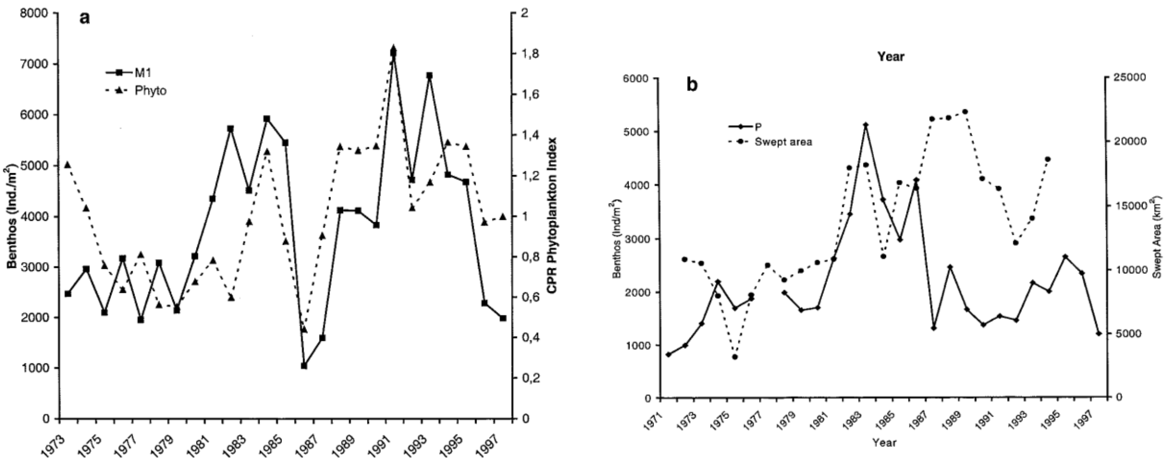


Figure 5.16. The Northumberland benthic time-series: (a) macrofaunal abundance (ind.m-2) at the unfished Station M1 and CPR phytoplankton index, (b) macrofaunal abundance (ind.m-2) at the fishged Station P and fishing effort (swept area) in ICES statistical rectangle 39E8. (Modified from Frid et al., 1999).

Frid et al. (1999; 2001) clarify the fishing effects for two benthic stations, off the Northumberland coast, NE England. One is at 80m and the other at 55m depth. The 80m station is located within a *Nephrops norvegicus* fishing ground (otter trawling ground), while the 55m station is located outside of the main fished area. Frid et al. (1999; 2001) demonstrated that changes in macrofaunal abundance at the station outside the fishing ground reflected changes in organic input. An earlier study by Buchanan (1993 in Frid et al., 1999; 2000) confirms that benthic productivity was controlled by organic matter input. This was also the case at the fished station, at least in the years prior to 1986. From 1986 until 1990 there was an increase in fishing effort. During this period of highest fishing activity the relationship between organic matter and benthic productivity broke down. This suggests that the dynamics of the macrobenthos at this station were influenced by fishing activity (Figure 5.16). Fishing is thus responsible for a decline in benthic productivity at station P (Figure 5.16b) and large-scale year-to-year changes in community structure (Frid et al., 2001). This decrease in benthic productivity is in line with the conclusions above (this report).

Philippart (1998) assessed long-term impact of bottom trawl fisheries in the south-eastern North Sea. Data originated from deliveries of commercial fishermen to the Zoological Station in the Netherlands in the periods 1946-1955, 1956-1965, 1966-1975 and 1976-1985. The main conclusion focused on catch efficiency. Otter trawlers caught relatively more fish than invertebrates, whilst beam trawlers caught proportionally more invertebrate species (i.e. velvet swimming crab, slender spindle shell) that were rarely delivered during periods of greatest otter trawling effort (Philippart, 1998). On average, the catch efficiency of the beam trawl fleet appeared to be 10 times higher than that of the otter trawl fleet. The long-term effects are discussed for elasmobranchs, greater weever (*Trachinus draco*) and whelks (*Buccinum undatum*). A relationship with fisheries is hypothesized, although not confirmed. During the past century, elasmobranchs and the greater weever generally disappeared from the coastal waters along the continent (Rijnsdorp et al., 1996 in Philippart, 1998). In addition to this decline, the average length of thornback ray (*Raja clavata*) also decreased (Walker and Heessen, 1996 in Philippart, 1998) which indicates overexploitation by fisheries (Myers et al., 1996 in Philippart, 1998). This sharp decline of the greater weever is considered to be either an effect of the severe winter of 1962/1963 and/or the introduction of beam trawlers in 1960 (Nijssen and de Groot, 1987 in Philippart, 1998; Rijnsdorp et al., 1996 in Philippart, 1998). The results of the model suggest that the observed long-term trend for this species could also be attributed to high fishing mortality associated with otter trawling. From the mid-1920s onwards, the common whelk started to decline and has now completely disappeared from the Dutch Wadden Sea. The disappearance is thought to be caused by fisheries followed by reproduction failures due to tributyltin-based (TBT) antifouling paints that came into use from the early 1970s onwards (ten Hallers-Tjabbes et al., 1994 in Philippart, 1998; Cadée et al., 1995 in Philippart, 1998).

Another interesting long-term data series covers the North Sea ecosystem as a whole. This data series is discussed in Rumohr and Kujawski (2000) and Callaway et al. (2007). The database used by both papers is described in Stein et al. (1990). Only North Sea epibenthos data are available. They date from 1902 to 1912 and were made available from preserved material at the Zoological Museum of Kiel. For details about the history of the surveys, preserved museum specimens, and construction of the database see Stein et al. (1990), Rumohr & Kujawski (2000) and Callaway et al. (2007).

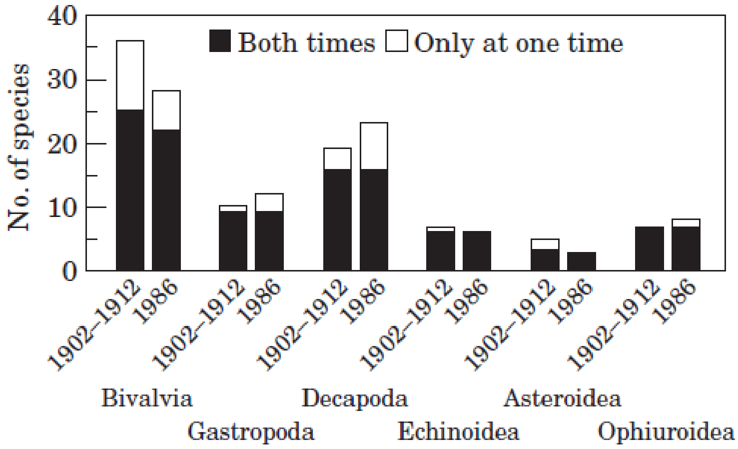


Figure 5.17. Number of species in the selected area for the six major taxa. (Modified from Rumohr and Kujawski, 2000).

Rumohr and Kujawski (2000) detail the changes in numbers of different faunal groups, whereas Callaway et al. (2007) compare these results with the changes of fishing effort over three survey periods. Rumohr and Kujawski (2000) reveal some distinct changes between the early twentieth century benthos and the sampling from the eighties: among the bivalves, eleven species were not reported in 1986, and three species seem to be new. Among the decapoda, four were not reported in 1986 and eight new species had appeared. In general, species observed only in one data set occurred on fewer than 15% of the stations, apart from some exceptions. Statistical data analysis revealed that the stations in the early and "late" twentieth century differ significantly in species composition. Details are presented in Figure 5.17. For further details, we refer to Rumohr and Kujawski (2000), as actual links with fisheries have not been discussed in that paper.

Callaway et al. (2007) related the changes in benthic abundances of 1902-1912, 1982-1985 and 2000 with the knowledge about trawling in these periods. Given the complications with data on effort per se, their paper uses, as a proxy for total international bottom fishing effort in the North Sea, the total international landings by fishing region (northern, central and southern) for the 3 main roundfish and 4 flatfish species as listed in official fisheries statistics. A full description of how their database is handled is crucial for further data analysis, and can be found in their paper. We limit ourselves to a review of their main conclusions and a description of the response variables used. Because of different sampling methods, common benthic indices could not be reasonably calculated. Two uncommon, but sensible (i.e. independent from sampling effort) indices have yielded interesting results, namely biogeography and taxonomic distinctness. The first relates to the spatial presence of a species, i.e. the number of rectangles where the occurrence of a species at least doubled or halved. The latter is calculated from information on presence or absence of taxa as well and is the mean taxonomic path length through the taxonomic tree connecting every pair of species in a list. It is a measure of the average degree to which individuals in an assemblage are related to each other.

Interestingly, the landings as proxy of fishing effort in northern, central and southern North Sea are presented in Figure 5.18. Roundfish landings per unit area showed long-term fluctuations but were generally similar in the 3 divisions, with highest roundfish abundance in the northen and lowest in the southern North Sea. In absolute numbers, landings were highest in 1969 and 1970, after the "gadoid outburst". From the mid-1980 landings declined to current levels. Roundfish landings suggest that during the earlier years of the century, roundfish otter trawling was less intensive in the northern North Sea but increased with vessel improvements. Flatfish landings per unit area were far higher in the southern and central North Sea than in the north. In absolute numbers, landings from 1945 and 1960 were considerably higher than before. A second increase occurred in the 1960s, denoting a period of landings, 2 to 3 times higher as to pre-war levels. They declined during the last decade of the twentieth century. An important notice is that flatfish landings per unit area were already of a magnitude similar to that of the 1990s in the southern North Sea. In the central North Sea those were lower in 1906-1912 but became 3 to 4 times higher in the second half of the century.

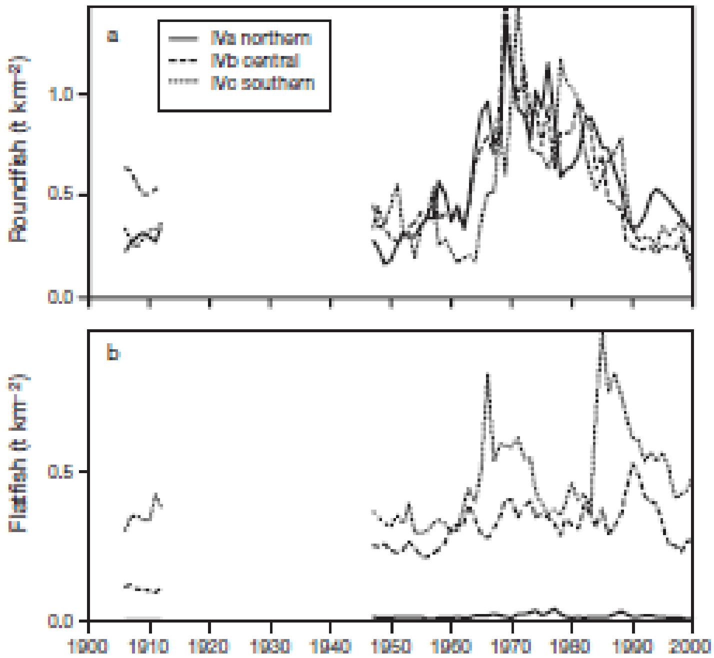


Figure 5.18. Long-term changes in landings per area of (a) roundfish and (b) flatfish for the northern, central and southern North Sea throughout the 20th century (no data by ICES division for 1913 to 1946) (Modified from Callaway et al., 2007).

The spatial presence of epibenthos in the North Sea could be analyzed for 48 species, occurring in each of the 3 surveys conducted. From the beginning to the end of the 20th century, biogeographical changes were found for 27 epibenthic taxa (Table 5.6). Callaway et al. (2007) conclude that most of the changes in biogeography of individual species had happened by the 1980s and the presence of only a few species declined or increased in the study rectangles between 1982-1985 and 2000. Four species declined in spatial presence in the central and southern North Sea. Increases, on the other hand, were about equal in both areas (11 in the central southern area, 13 in the north).

The index of taxonomic distinctness does not put forward clear conclusions. It suggests that there may be a link between beam trawling and a diminishing taxonomic diversity, although the data of Callaway et al. (2007) do not provide enough evidence to substantiate the hypothesis. The mean average taxonomic distinctness was significantly lower in 2000 than in the 1980s, but not lower than at the beginning of the 20th century. This indicates a change in community characteristics in the last 2 decades of the century, while at the same time it signals long-term persistence in terms of epibenthic taxonomic diversity. Generally the use of taxonomic distinctness indices for epibenthos studies in the North Sea seems limited and can only be one facet of a more complex analysis.

Evidence from Callaway et al. (2007) suggests that fishing is the most probable cause for the changes in benthos, because of (1) the nature of the species suffering from declining presence, (2) the area in which most reductions were recorded, (3) the timing of changes in the benthos. Details about species and the effects of gears are not listed here, as they are also discussed in the review of Duineveld et al. (2007) (see below). Generally trawling removes large-bodied fauna, damages species with fragile shells and removes and injures long-living bivalves. Small, robust species as the sea urchin appear to survive the impact of fishing gear better. However, as also denoted by Duineveld et al. (2007) below, reproductive turnover or increased food availability might outweigh the fishery-induced mortality rates.

The conclusions of Callaway et al. (2007) are highly relevant for inducing implications of resilience of the current North Sea benthic ecosystem and are therefore integrally repeated here:

> *"Over the century, the biogeography of many epibenthic species changed, with species' presence variously spreading and declining in the different areas. Reductions in spatial presence occurred especially in the central and southern North Sea, where beam trawl effort has been highest. The affected species are known to be sensitive to damage by fishing gear. Conversely, the benthic species expanding their distribution over the last century are relatively tolerant to fishing gear or likely to benefit from reduced competition by other species and high numbers of damaged species suitable as prey. Overall, the most profound changes in the epibenthos appear to have taken place before the 1980s; since then there has been further change, but the communities of recent decades probably reflect faunal assemblages adapted to long-term impacts. Climate change, eutrophication and other factors are highly likely to have contributed to the observed changes. The nature of the changes, however, indicates that to a considerable extent, and especially in the central and southern North Sea, long-term changes in epibenthos can be linked to a century of sustained, high trawling effort."*

Table 5.6. Trends in spatial presence. A total of 40 ICES rectangles were sampled in each of the 3 surveys (Survey 1: 1902–1912; Survey 2: 1982–1985; Survey 3: 2000), values are the number of ICES rectangles in which the species were recorded. Area IV: entire North Sea; area IVa,b,c: northern, central, and southern North Sea, respectively (Modified from Callaway et al., 2007).

Species	Survey 1	Survey 2	Survey 3	Trends in spatial presence: North Sea-wide (Area IV)	Area IVa	Areas IVb,c pooled
Arctica islandica	16	7	5	≥ 50% reduction in spatial presence from Survey 1 to Surveys 2 or 3	↔	↓
Aequipecten opercularis	15	3	8		↔	↓
Modiolus modiolus	9	11	1			↓
Phaxas pellucidus	23	0[a]	7		↔	↓
Anomia ephippium	22	0[a]	1		↓	↓
Pisidia longicornis	5	0[a]	2			↓
Velutina velutina	5	0[a]	1			↓
Echinocyamus pusillus	14	0[a]	1			↓
Spatangus purpureus	20	16	7		↓	↓
Brissopsis lyrifera	6	2	3			↓
Amphiura spp.	21	0[a]	5			↓
Ophiothrix fragilis	20	6	14		↓	↓
Ophiura affinis	11	0[a]	2			↓
Hippasteria phrygiana	12	0[a]	4		↓	
Henricia sanguinolenta	7	3	1			↓
Aphrodita aculeata	4	13	24	≥ 100% increase in spatial presence from Survey 1 to Surveys 2 or 3	↑	↑
Aporrhais spp.	4	12	15			↑
Colus spp.	11	0[a]	35		↑	↑
Liocarcinus holsatus	9	0[a]	27		↑	↑
Liocarcinus depurator	1	4	11			↑
Pagurus prideaux	2	6	13		↑	↑
Corystes cassivelaunus	4	14	16			↑
Ebalia spp.	4	1	10		↑	↑
Echinocardium cordatum	8	22	15		↑	↑
Ophiura ophiura	10	21	27		↑	↑
Ascidiella spp.	9	9	20		↑	↓
Astarte sulcata	5	5	4	< 20% change in spatial presence between Surveys 1 and 3	↔	↔
Crangon allmanni	21	18	26			↔
Echinus acutus	14	12	16		↔	
Echinocardium flavescens	19	0[a]	16		↔	
Asterias rubens	30	29	35		↔	
Luidia sarsi	18	0[a]	19		↔	↔
Ophiura albida	22	19	20		↑	
Buccinum undatum	13	13	23	Unclear trend		
Euspira spp.	17	0[a]	13			↔
Neptunea antiqua	14	19	24		↑	↔
Pagurus pubescens	18	0[a]	23			↔
Pagurus bernhardus	24	37	39		↑	
Spirontocaris spp.	8	7	15		↑	
Galathea spp.	10	7	16		↑	↓
Pandalus montagui	11	11	15			
Hyas coarctatus	14	19	20		↔	
Astropecten irregularis	23	30	35			
Leptasterias muelleri	10	0[a]	6		↔	↓

[a]Species were possibly not identified or noted in this survey

Duineveld et al. (2007) used a different approach and predicted the long-term effects of beam trawling by comparison of a fished and an unfished site near the Frisian front in the Southern North Sea. Recovery and resilience of the site are not treated as such. However, one of the author's main conclusions pinpoints to the specific observation that the fishery affects deep-living mud shrimps, which may indicate consequences for the functioning of the benthic ecosystem other than simple loss of biodiversity. This clearly indicates that recovery is not solely dependent on the changes in abundance of a particular species, but also on the species-specific interactions with the ecosystem. Duineveld et al. (2007) concluded that their results, especially those obtained with the Triple-D dredge show a distinct difference between the fauna in the closed fishery subarea near the platform and the other regularly trawled subareas. The triple-D hauls taken in the platform subarea had on average significantly greater species richness and lower dominance. The reverse seems to be true for one of the reference subareas, although the differences were not significant. Differences in diversity between subareas are illustrated by notched box and whisker plot confidence intervals for the medians by means of notches (Figure 5.19).

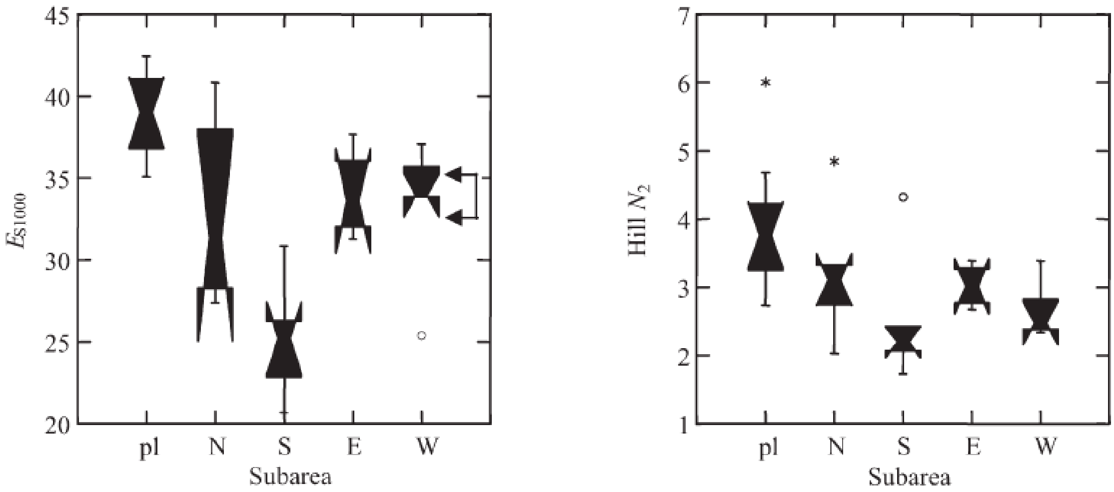


Figure 5.19. Notched box and whisker plots comparing median species richness (Hurlbert's ES1000) and the reciprocal of dominance (Hill N2) of the Triple-D hauls in the platform subarea (pl) and the reference subareas (N, S, E, and W). Non-overlapping notches denote a significant difference. The notch (narrow part) of the box to the right of the left panel is indicated by the two connected arrows that are drawn alongside. The notch represents the 95% simultaneous confidence interval of the median. Because the lower quartile in this case is greater than the lower confidence limit, the notch appears folded back on itself. The whiskers have a maximum length equal to 1.5 times the length of the box (the interquartile range, IR). If there are data outside this range, such points are marked as asterisks if the values fall within 3 IR from the end of the box, or as circles if the values are outside this range. (Modified from Duineveld et al., 2007).

Species that were more abundant in the Triple-D hauls near the platform included the bivalves *Artica islandica, Thracia convexa, Dosinia lupinus,* and *Cardium echinatum*. All are relatively large fragile species in reach of the trawl that are known to be vulnerable to beam trawling (see above). The same holds for the fragile, but small, bivalves *Abra nitida* and *Cultellus pellucidus*. For these species, Bergman and van Santbrink (2000) reported direct trawling mortalities of 18–38% and 27–29%, respectively, in the trawl path of a single beam trawl haul in silty sediments. The lack of clear patterns in the box core samples of Duineveld et al. (2007) is attributed to the dominance of polychaetes (average 30% of the species and 40% of the individuals in a sample). The effects on polychaetes and small benthic invertebrates in the chapters above confirm these results, e.g. Jennings et al. (2001) showed no relation between the abundance of infaunal polychaetes and trawling frequency.

However, not all long-term changes can be readily explained by the studies on short-term mortality. Mud shrimps such as *Upogebia sp.* and *Callianassa sp.*, are not reported to have high direct short-term mortalities. However, there are significant differences in their long-term abundances between fished and unfished sites. Destruction of burrows by beam trawls leading to extra energetic costs for *C. subterranea* to reconstruct its tunnels is regarded as not significant in the document on the following website: http://www.marlin.ac.uk/biotopes/Bio_Sensexp_CMS.AfilEcor.htm. The results of Duineveld et al. (2007) suggest they can be significant. Moreover, as mud shrimps are considered to be engineering species with an important impact on sediment bioturbation, mineralization, and the erosion threshold of the seabed (Rowden and Jones, 1993; Howe et al., 2004; Amaro, 2005 in Duineveld et al., 2007), the "wider ecosystem effect" of trawling may be more far-reaching than a simple reduction in abundance (Coleman and Williams, 2002 in Duineveld et al., 2007). Other unexpected results are the higher abundance of *Echinocardium cordatum*, a species vulnerable to trawling, in the fished area. Rumohr and Kujawski (2000) argued that *E. cordatum* has a scavenging feeding mode, which helped the species to thrive in a grossly fished area where dead and wounded benthic creatures are available as food resource (Callaway et al., 2007). Another important notice from Duineveld et al. (2007) highlight that juvenile *A. islandica* are scarcely abundant in the platform (unfished) area. Although Witbaard and Bergman (2003) suggest beam trawling as one of the factors responsible for the infrequent recruitment, Duineveld et al. (2007) suggest direct trawling mortality among juveniles is likely not the main factor preventing successful recruitment. This latter observation is said to be of relevance in any discussion about establishing a MPA at the Frisian Front as long-living bivalves in general and *A. islandica* in particular are frequently mentioned as conservation targets.

More recent insights (Frid et al., 2009a; Frid et al., 2009b) have put these conclusions about fishing impacts into perspective and explain why prophecies about appropriate management measures for fisheries cannot easily be determined. Albeit the evidence that changes in benthic composition are driven by fishing impacts (e.g. Frid et al., 1999; Callaway et al., 2007; Duineveld et al., 2007), several authors (e.g. Rees and Elefteriou, 1989; Reise et al., 1989; Suchanek, 1993; Holte and Aug, 1996; Callaway et al., 2002; Nunes and Jangoux 2004; Kirby et al., 2007;

Neumann et al., 2008; Frid et al., 2009a; 2009b) illustrate that changes can also be influenced by the trend in climate warming, altered fluxes of phytoplankton, eutrophication, etc. The real challenge is managing human impacts on the system against a background of natural resilience (Frid et al., 2009b). Therefore the key drivers must be identified, as well as the sustainability limits of the North Sea ecosystem. That is to say, what are the natural drivers on the system and how does the system vary over time in response to these factors and what are the types and levels of human activities that can be sustained without compromising the functioning of the ecosystem (Frid et al., 2009b)?

In this report, we summarize the main statements of Frid et al. (2009b) (see box), as to their and our knowledge, the Dove benthic time series represents the most comprehensive data set on temperate shelf sea benthic dynamics as they illustrate the benthic dynamics together with natural and anthropogenic variations. This leaves the option of interpreting the conclusion on fishing effects on the long-term at North Sea scale, as this study is only at a local scale. However, Frid et al. (2009b) demonstrate how the conclusions about long-term fisheries impacts should be balanced at North Sea scale with other natural and anthropogenic factors in order to guide future management of the North Sea benthic ecosystem.

Box: Observing change in a North Sea benthic system: a 33 year time series (modified from Frid et al., 2009b)

Studies undertaken at a number of scales across the North Sea have identified a role for climatic forcing in the structuring of both zooplankton and benthic invertebrate communities (for an extensive list of references, see Frid et al. (2009b)). Previous analyses of the Dove time series datasets have revealed some trends that parallel the pattern of variation in the climatic indices, but the high resolution of the series also suggests the operation of smaller scale complex mechanisms of community control, involving extrinsic drivers, intrinsic biotic feedback and anthropogenic forcing. Ideally, the level of understanding of the relationships between particular drivers and the associated response in ecosystem components should allow the forecasting of trends given particular scenarios. Their data show that over the 33 year period a total of 537 taxa have been recorded, over 380 if you aggregate them to genera level. In common with most benthic habitats, while the assemblage is taxa rich, there is also a high degree of dominance with 10 taxa accounting for over 40% of the individuals. At the nearby Station P sampling is annual and the dynamics have been constrained due to the effects of fishing disturbance on the sea floor (see above: Frid et al.,1999, 2000, 2001). However, the analyses of Frid et al. (2009b) suggest that the dynamics of the system are not strongly coupled to one driver but rather respond at different times to a number of controlling factors. In fact it appears that the system undergoes quasi-decadal (6–10 years) periods of coupling with a factor before a sudden shift to a new dynamic. These dynamics are superimposed on a longer term trend in the system. The multivariate analyses of Frid et al. (2009b) show a clear trend over time in the taxonomic composition of the fauna; however, this trend is not reflected in a trend in the total numbers of organisms in the system, nor is it the result of changes in a few taxa. The richness of the system increased between the 1970–1980s and the 1990s–2000s, which coincides with the widely reported ‘phase shift’ in the North Sea plankton (Lees et al., 2006 in Frid et al., 2009b). In fact the greater longevity (most taxa live a few years and some around a decade, or longer) may explain the observed patterns of variation. While the composition of the plankton responds to climatic drivers through changes in growth and reproductive output of species with different environmental requirements, in the benthos, organisms literally sit in the mud and integrate these variations. When water column conditions favour a species and there are available resources in the benthos it settles and a population establishes. This then persists for a number of years, riding out any ‘poor’ years. As the population goes into decline it is replaced either by individuals of the same species or of a different one depending on conditions. As different species might be expected to respond to different drivers it would appear that the system flips between states. This model is overly simplistic. Changes in the dominant species are not what are observed, in fact the same few species have been dominant through the series. Rather the biological changes driving the changes in the emergent properties (diversity, abundance, species composition) are the result of small changes in many species. Such changes raise interesting questions about how the delivery of ecological functions varies over time. Is it simply a case that as the dominant species remain they also deliver the bulk of the ecological functions or, as seems likely (Bremner et al., 2003, 2006 in Frid et al., 2009b), do small changes in the assemblage cause large changes in some ecological functions? Buchanan first characterized the benthos of this area of the western central North Sea (Buchanan, 1963; Buchanan and Warwick, 1974 in Frid et al., 2009b). Now over 40 years after his initial studies our understanding of the system has grown. Initially, winter temperature was seen as a key factor (Buchanan, 1963 in Frid et al., 2009b), this was eclipsed by density dependent processes (Buchanan et al., 1978 in Frid et al., 2009b) and then phytoplankton flux (Buchanan and Moore, 1986b; Buchanan, 1993 in Frid et al., 2009b). The authors themselves also proposed fishing as a crucial driving factor (Frid et al., 1999, 200, 2001). It is now clear that each of these factors does play a role but in a complex, decadal, pattern of dynamics. But the system is also shifting. After 33 years we can say that the benthos of Northumberland are undergoing long term changes, possibly related to climate, but they also show periods of relative stability, for up to a decade, before undergoing sudden changes. Such parameter rich systems with complex dynamics will present a challenge if ecosystem models are to be developed to compliment the hydrodynamic and process models available and to provide predictive capabilities using the data generated by modern ocean observing systems.

Another interesting study includes a meta-analysis of the status of the ICES fish stocks during the past half century (Sparholt et al., 2007). They summarized their main results as follows:

> *"Based on a meta-analysis of time-series of stock size, recruitment, and fishing mortality, the general status of fish stocks within the ICES Area (i.e. the Northeast Atlantic) is evaluated. The analysis is based on data for 34 (7 pelagic, 27 demersal) commercial stocks. The stocks were selected based on the quality of the data and the length of the time-series. The analysis indicates that most pelagic stocks recovered to sustainable levels with high productivity after several had collapsed in the 1960s and 1970s. In contrast, most demersal stocks have continued to decline over the past half century and are now recruitment-overfished. By reducing fishing mortality on demersal stocks on average by half and building up the stocks by a factor of about two, management could be brought in line with international agreements. If recruitment-overfishing is avoided for all demersal stocks and discarding is minimized, their yield might be almost doubled over the current yield. Among the major management initiatives during the past half century, only the closure of the pelagic fisheries in the mid-1970s can be clearly identified in the time-series as having had a direct effect on stock status."*

Most studies included above are focused upon the benthic ecosystem, such as infaunal, epifaunal invertebrates and demersal fish. However, as indicated above, fishing can influence primary productivity and other ecosystem components as well (and vice versa) (e.g. chapter on productivity). As a final remark about recovery, resilience and a sustainable impact of whatever fishing gear is used, we summarize the conclusions of Kirby et al. (2009), who put recovery and the evolutions of the status of different ecosystem components into perspective.

These authors have investigated the synergistic effects of climate and fishing on trophodynamics of the North Sea ecosystem. In contrast to earlier mentioned studies, Kirby et al. (2009) consider the complete ecosystem, inclusive of interactions between ecosystem components. Their analyses suggest that the ecology of the North Sea has shifted between two different ecological states with the coincident decline of cod and the increase in *sea surface temperature* (SST) in the mid 1980s as the tipping point. Prior to the tipping point, decapods abundance was mainly controlled by cod predation and the plankton and the benthic fauna (bivalves and echinoderms) were more affected by changes in the hydroclimatic environment than trophic interactions. Following the decline of North Sea cod, the abrupt ecosystem shift and onset of warmer temperatures have resulted in an increase in decapods that has altered the trophodynamics of the plankton and benthos. In the plankton, increased SST and predation by decapod larvae may now be influencing the holozooplankton and chlorophyll abundance. In the benthos the decline in bivalves due to decapod predation may be enabling detritivores like *E. cordatum* to benefit from warmer conditions and an increased food supply (attributed to fishing in e.g. Rumohr and Kujawski, 2000). This is also confirmed by studies, earlier mentioned in this chapter, e.g. Frid et al. (2000); Callaway et al. (2007).

Kirby et al. (2009) summarize that in the absence of fishing, a cod dominated North Sea ecosystem might have been more resilient to climate change. This implies that the influence of climate on both recruitment and the geographical distribution of cod would have eventually brought about a change in community structure, similar to the current existing change. However, when overfishing in the North Sea and the climatic effects are combined, they are a particularly powerful driver of ecosystem structure that shortens the period of change. This is because overfishing is known to simplify food webs, trigger trophic cascades and promote the proliferation of jellyfish, which feed on fish eggs, fish larvae, and zooplankton (Pauly et al., 1998 in Kirby et al., 2009; Daskalov and others 2007 in Kirby et al., 2009). The net result of these changes has been to create a simplified ecology focused on lower trophic level invertebrates. The proliferation of jellyfish that can exert both top-down and bottom-up control of fish recruitment may signal the ecological climax of these changes. Figure 5.20 shows how Kirby et al. (2009) interpret the synergistic effects of climate and fishing on the ecology and trophodynamics of the North Sea.

Kirby et al. (2009) propose that at the scale of the ecosystem both top-down and bottom-up control modulate the trophodynamics and ecosystem structure. Their strength in turn is modulated by both climate and fishing. The extent of the synergistic effects of fishing and climate in the North Sea suggests that management may be unable to reverse current climate and human-induced changes. Rather, Kirby et al. (2009) argue to adapt to the new ecological regimes. This requires the adoption of new approaches to fisheries management that incorporate fully the influence of environmental change. In other words, traditional top-down approaches to fisheries management (controlling fishing effort) are unlikely to be successful when fishing is coupled with long-term climate effects.

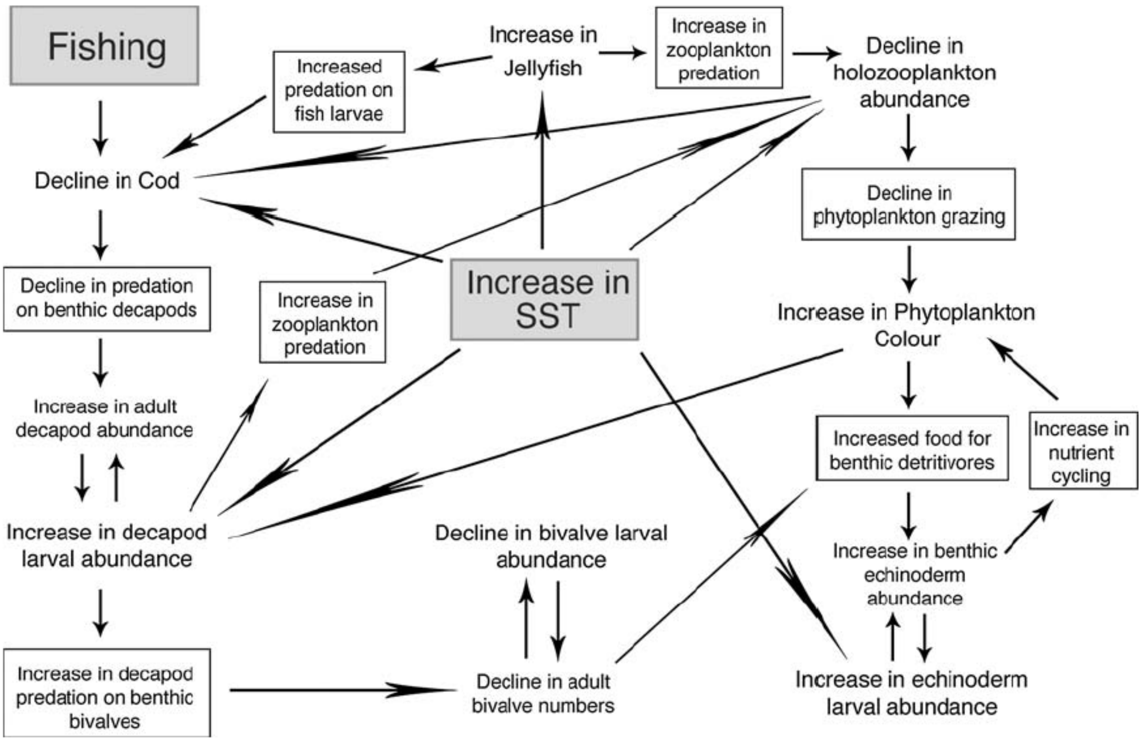


Figure 5.20. Sketch diagram summarizing the potential mechanisms affecting ecological interactions between cod, plankton, and benthic organisms in the North Sea. A decline in cod, driven by fishing, climate change, and consequent changes in the holozooplankton, releases benthic decapods from top-down control. SST influences the larval abundance of benthic decapods, echinoderms, and bivalves positively. Reduced top-down predation and increased SST therefore benefit decapods abundance. Decapod predation on holozooplankton may affect cod recruitment favoring decapods further. In the benthos, decapod predation on bivalves reduces bivalve abundance, despite warmer temperatures. Reduced holozooplankton grazing contributes to the increased Phytoplankton Color Index, which benefits decapod larvae and benthic detritivores like E. cordatum. A decline in adult bivalve numbers may also increase the food supply to benthic detritivores. Macroinvertebrate bioturbation enhances nutrient cycling to support increased primary production in the plankton. A proliferation of jellyfish in the North Sea, which can exert top-down and bottom-up control of fish recruitment, may signal the climax of these changes. (Modified from Kirby et al., 2009).

6. CONCLUDING REMARKS

There is ample scientific evidence that fisheries can compromise the structure and functioning of marine ecosystems. Discussions on the origin of the problem often focus on the choice of the fishing gear. The sustainability of a fishery is, however, determined by a combination of factors such as the state of the commercial fish stocks, the carrying capacity of the ecosystem where the fishery is carried out, the quality of the fisheries management and the responsibility fishermen take to contribute to the ecological dimension of sustainability. In and around the North Sea, it is reasonable to state that fisheries management is well organized and self critical, the health of the fish stocks is improving, impact of fisheries is an issue that is taken seriously and the fishing industry is increasingly involved in the management of the fishery. In general, North Sea fisheries are moving towards more sustainability and may deserve a better public image than it has today.

The environmental impact of fishing is still a widely discussed issue with conflicting opinions. The disagreement is usually based on a misunderstanding or different interpretation of the scientific information available and on a different perception of acceptable exploitation of the marine environment. Whereas primary production on land has a long standing organizational history, this is still in an early stage at sea and the process is strongly driven by emotion and economics.

Despite of these considerations, the choice of the fishing method (and its characteristics) is crucial for its direct impact. It will determine the potential negative side effects of a fishery, i.e. discarding of commercial and non-commercial animals, by-catch of charismatic species, risk of ghost fishing and seafloor impact. The variation in magnitude and intensity of these side effects is depending on the circumstances in which the gear is deployed. There are no fishing methods free from bad practice. Angling e.g. is generally perceived as a sustainable fishery. Recreational angling, as it is carried out in the North Sea, however, can hardly be called sustainable because it targets an endangered species like cod, the fishery is not regulated, catches are not reported and often are sold on the black market. Set nets have a negligible seafloor impact but can in certain circumstances be a threat to marine mammal population and can cause ghost fishing by lost and discarded nets. Diving is regarded as an “environment friendly” fishing method but several ship wrecks in the southern North Sea have depleted lobster populations due to overfishing by recreational divers.

As for towed gears, the scientific evidence is quite conclusive that these fishing gears can seriously harm and alter the marine environment in the short and the long term. This does not mean that these fishing method equal bad practice. The impact of the gear strongly depends on the habitat in which it is deployed.

Within this report, focused on the specific environment of the North Sea, the intention was to provide a broad overview of current knowledge on the impact of different fishing gear in relation to different environmental boundaries. A general ranking of fishing methods according to their ecosystem effects is a very intricate and delicate task, although attempts have been made and are valuable for a general conception. The authors felt, however, that there is a serious imbalance in the amount of scientific studies available for the different fishing gears and a fair ranking is difficult. In addition, it is impossible to break the link between the gear and the fishing practice which depends on the fisherman.

The attitude of the fisherman plays a central role in sustainable fishing but the idea of a better spatial planning of fisheries may facilitate the transition to sustainability. This spatial planning should be based on the type of fishing gear in relation with type of habitat and occurrence of animals unwanted for by-catch like juvenile fish or marine mammals. How to move forward with this issue is an important matter of debate but is not addressed in this report.

REFERENCES

5NSC, 1997. Assessment report on Fisheries and Fisheries related Species and Habitat Issues. In: M., S., Aarefjord, H., Heir, H.T., Øverland, S.s (Eds.), Intermediate Ministerial Meeting on the integration of Fisheries and Environmental Issues .Fifth North Sea Conference Secretariat. Ministry of Environment, Norway, Bergen, Norway, p. 127.

Allen, J.I., Clarke, K.R., 2007. Effects of demersal trawling on ecosystem functioning in the North Sea: a modelling study. Mar. Ecol.-Prog. Ser. 336, 63-75.

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, SA., 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. Rome, FAO. 233pp.

Anderson, J., Curtis, H., Boyle, R., Graham, K., 2008. 2005 Economic Survey of the UK Fishing Fleet. Seafish Economic. Sea Fish Industry Authority. 227pp.

Anon., 1991. Workshop on cod-end selectivity – Marine Laboratory, Aberdeen 4-6 June 1991. Commission of the European Communities Directorate General for Fisheries.

Anon., 1997. The Final Report on the “Mylene H” Cod Bycatch Reduction Scottish Seine Experiment. 1997. Nordsea Internal Report.

Anon., 1998. A study of the effects of water jet dredging for razor clams and a stock survey of the target species in some Western Isles populations. Marine Laboratory, Aberdeen, Report No. 8/98.

Anon., 2002. Selective Seine net trials MFV Fiona Patricia – December- January 2000/2001. BIM Internal Report. 6pp.

Anon., 2003. Report of Scottish trials assessing the selectivity of trawls and seines – Volume 1. Fisheries Research Services Industry/ Science Partnership 2001-2002.136pp.

Anon., 2006. Report of trials with a trouser seine net MFV Rosie Catriona. BIM Internal Report.

Anon., 2008. International Workshop on Seine Net Fishing, 29 – 30 May 2008. Summary by Ken Arkley, SEAFISH UK. Published at SEAFISH website, http:\\www.seafish.org.

Arkley, K., 1990. The use of square mesh selector panels as a means of improving selectivity of demersal towed fishing gears RV Clupea, MFV Kestrel and MFV St Kilda. Seafish Report No. 378. 26pp + appendices.

Arntz, W.E. and Weber, W., 1970. Cyprina islandica (Mollusca: Bivalvia) als Nahrung von Dorsch und Kliesche in der Kieler Bucht. Ber. Deut. Wissen. Komm. Meeresf. 21, pp. 193–209.

ASCOBANS. 2009. Recovery Plan for Baltic Harbour Porpoises – Jastarnia Plan (Revision) (2009).Ashcroft, B.A., 1991. Selectivity trials using square mesh panels in a Scottish seine – Preliminary Sea Trials mfv Kiloran – EC Funded project TE 2-411. Sea fish Industry authority Consultancy Report No. 47.

Auster, P.J., Langton, R.W., 1999. The effects of fishing on fish habitat. p. 150-187. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22. Benaka, L., Bethesda, Maryland.

Auster, P.J., Malatesta, R.J., Langton, R.W., Watling, L., Valentine, P.C., Donaldson, C.L.S., Langton, E.W., Shepard, A.N., Babb, I.G., 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): Implications for conservation of fish population. . Reviews in Fisheries Science 4, 185-202.

Ball, B.J., Fox, G., Munday, B.W., 2000. Long- and short-term consequences of a Nephrops trawl fishery on the benthos and environment of the Irish Sea. ICES Journal of Marine Science 57, 1315-1320.

Barrett, J.H., Locker, A.M., Roberts, C.M., 2004. The origins of intensive marine fishing in medieval Europe: the English evidence. Proceedings of the Royal Society of London Series B-Biological Sciences 271, 2417-2421.

Baum, J.K., Worm, B., 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology 78, 699-714.

Bergman, M.J.N.D., G.C.A.; Lavaleye,M.S.S. , 2005. Long term closure of an area to fisheries at the Frisian front (SE North Sea): effects on the bottom fauna. NIOZ-RAPPORT 2005-6, p. 18.

Blom, W.C., 1990. Some remarks about the beam trawl. In: Effects of beam trawl fishery on the bottom fauna in the North Sea. BEON report 8: 26-31.

Bouwer Utne, I., 2007. System evaluation of sustainability in the Norwegian cod-fisheries. Marine Policy 31 (2007) 390–401.

Braber, L., De Groot, S.J., 1973. The food of five flatfish species (Pleuronectiformes) in the southern North Sea. Neth. J. Sea Res. 6, 163–172.

Bradshaw, C., Veale, L. O., Hill, A. S. and Brand A. R. (2000) The effects of scallop dredges on gravely seabed communities. In Kaiser and de Groot 2000. Effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues: 399 p

Brown, C.J., Collier, J.S., 2008. Mapping benthic habitat in regions of gradational substrata: An automated approach utilising geophysical, geological, and biological relationships. Estuarine, Coastal and Shelf Science 78, 203-214.

Brylinsky, M., Gibson, J., Gordon, D., 1994. Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. Canadian Journal of Fisheries and Aquatic Science 51, 650-661.

Caddy, J. F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging in a scallop ground. J. Fisher. Res. Bd, Can. 30: 173–180.

Callaway, R., Alsva°g, J., de Boois, I., Cotter, J., Ford, A., Hinz, H., Jennings, S., Kröncke, I., Lancaster, J., Piet, G., Prince, P., and Ehrich, S. 2002. Diversity and community structure of epibenthic invertebrates and fish in the North Sea. – ICES Journal of Marine Science, 59: 1199–1214.

Callaway, R., Engelhard, G.H., Dann, J., Cotter, J., Rumohr, H., 2007. One century of North Sea epibenthos and fishing: comparison between 1902-1912, 1982-1985 and 2000. Marine Ecology Progress Series 346, 27-43.

Chapman, C. J., Mason, J. and Kinnear, J. A. M. (1977) Diving observations on the efficiency of dredges used in the Scottish fishery for the scallop, Pecten maximus (L.) Scot. Fisher. Res. Rep. 10.

Churchill, J.H. 1989. The effect of commercial trawling on sediment resuspension and transport over the middle Atlantic Bight. Continental Shelf Research, 9: 841–865.

Collie, J.S., Hall, S.J., Kaiser, M.J., Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69, 785-798.

Cotterell, S.P., Stevens, T.F., 2007. An Independent Evaluation of Issues Relating to Twin-Rig Trawling in the Southwest. In: (SWIMRA)., R.f.t.S.I.M.R.A.s (Ed.). The Marine Institute, University of Plymouth., Plymouth, UK, pp. 14 p, plus appendices.Graham, N., Kynoch, R.J. and Fryer, R.J. 2003. Square mesh panels in demersal trawls: further data relating haddock and whiting selectivity to panel position. Fisheries Research 62, 361–375.

Coull, B. C. 1999. Role of meiofauna in estuarine soft-bottom habitats. Australian J. Ecology 24(4): 327-343

Coull, K.A., and Robertson, J.H.B., 1986. Scottish Seine Net Codend selection data collected in August 1985. Working Report No6/86.

Crowder, L.B., Hazen, E.L., Avissar, N., Bjorkland, R., Latanich, C., Ogburn, M.B., 2008. The Impacts of Fisheries on Marine Ecosystems and the Transition to Ecosystem-Based Management. Annu. Rev. Ecol. Evol. Syst. 39, 259-278.

Cury, P., Shannon, L. & Shin, Y.J. 2003. The functioning of the marine ecosystems: a fisheries perspective. In M. Sinclair & G. Valdimarsson, eds. Responsible fisheries in the marine ecosystem, pp. 103-123. Rome, Italy, and Wallingford, UK. FAO and CAB International.

Cury, P.M., Shin, Y.-J., Planque, B., Durant, J.M., Fromentin, J.-M., Kramer-Schadt, S., Stenseth, N.C., Travers, M., Grimm, V., 2008. Ecosystem oceanography for global change in fisheries. Trends in Ecology & Evolution 23, 338-346.

de Groot, S.J., Lindeboom, H.J., 1994. Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea. . Netherlands Institute for Sea Research. , p. 257.

de Juan, S., Demestre, M., Thrush, S., 2008. Defining ecological indicators of trawling disturbance when everywhere that can be fished is fished: A Mediterranean case study. Marine Policy In Press, Corrected Proof.

De Veen, J.F., 1976. On changes in some biological parameters in the North Sea sole. J. Cons. Int. Explor. Mer 37, pp. 60–90.

Depestele, J., Courtens, W., Degraer, S., Derous, S., Haelters, J., Hostens, K., Moulaert, I., Polet, H., Rabaut, M., Stienen, E., Vincx, M., 2008. WaKo: Evaluatie van de milieu-impact van WArrelnet- en boomKOrvisserij op het Belgisch deel van de Noordzee: Eindrapport. In: ILVO-Visserijs (Ed.). ILVO-Visserij, Oostende, België, p. 185 + Annexes.

Desse, J., and Desse-Berset, N. 1993. Peˆche et surpêche en Méditerranée: le témoinage des os. In Exploration des Animaux sauvages à Travers le Temps, pp. 327–339. Ed. By J. Desse, and F. Audoin-Rouzeau. Editions APDCA, Juanles- Pins.

DFO. 2009. Stock Assessment of Northern (2J3KL) cod in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/009.

Dickey-Collas, M., Nash, R. D. M., Brunel, T., van Damme, C. J. G., Marshall, C. T., Payne, M. R., Corten, A., Geffen, A. J., Peck, M. A., Hatfield, E. M. C., Hintzen, N. T., Enberg, K., Kell, L. T., and Simmonds, E. J. 2010. Lessons learned from stock collapse and recovery of North Sea herring: a review. – ICES Journal of Marine Science, 67: 000–000.

Dounas, C., Davies, I., Triantafyllou, G., Koulouri, P., Petihakis, G., Arvanitidis, C., Sourlatzis, G., Eleftheriou, A., 2007. Large-scale impacts of bottom trawling on shelf primary productivity. Continental Shelf Research 27, 2198-2210.

Drew & Larsen (1994) in Paschen et al. (1999)

Duineveld, G.C.A., Bergman, M.J.N., Lavaleye, M.S.S., 2007. Effects of an area closed to fisheries on the composition of the benthic fauna in the southern North Sea. ICES J. Mar. Sci. 64, 899-908.

Duineveld, G.C.A., Künitzer, A., Niermann, U., De Wilde, P.A.W.J., Gray, J.S., 1991. The macrobenthos of the North Sea. Neth. J. Sea Res. 28, 53–65.

Duplisea, D.E., Jennings, S., Warr, K.J., Dinmore, T.A., 2002. A size-based model of the impacts of bottom trawling on benthic community structure. Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat. 55, 1785-1795.

Durrieu de Madron, X., Ferré, B., Le Corre, G., Grenz, C., Conan, P., Pujo-Pay, M., Buscail, R., Bodiot, O., 2005. Trawling-induced resuspension and dispersal of muddy sediments and dissolved elements in the Gulf of Lion (NW Mediterranean). Continental Shelf Research 25, 2387-2409.

Durrieu de Madron, X., Ferré, B., Le Corre, G., Grenz, C., Conan, P., Pujo-Pay, M., Buscail, R., Bodiot, O., 2005. Trawling-induced resuspension and dispersal of muddy sediments and dissolved elements in the Gulf of Lion (NW Mediterranean). Continental Shelf Research 25, 2387-2409.

Einarsson, H.A., 2008. Environmental impact of Danish seine. Presentation at an International Workshop on Seine Net Fishing Keflavík, Iceland 29.-30. May 2008.

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

Eno, N. C. MacDonald D. S. and Amos, S. C. 1996. A study of the effects of fish (Crustacea/Mollusca) traps on benthic habitats and species. King's Lynn. Eastern Sea Fisheries Joint Committee.

FAO, 2003. Fisheries management. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries, 4 (Suppl. 2). 112 pp.

FAO, 2009. Report of the FAO/UNEP expert meeting on impacts of destructive fishing practices, unsustainable fishing, and illegal, unreported and unregulated (iuu) fishing on marine biodiversity and habitats, Rome, 23–25 September 2009. FAO Fisheries and Aquaculture Report No. 932,

Fonds, M. and Groenewold, S., 2000. Food subsidies generated by beam trawl fishery in the southern North Sea. In: Kaiser, M.J. and De Groot, S.J., Editors, 2000. Effects of Fishing on Non-target Species and Habitats, Blackwell, Oxford, pp. 130–150.

Fonteyne, R. 1994. Physical impact of a 4m beam trawl. In: de Groot, S.J., Lindeboom, H.J., 1994. Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea. . Netherlands Institute for Sea Research. , p. 257.

Fonteyne, R. 2000. Physical impact of beam trawls on seabed sediments, in: Kaiser, M.J.; de Groot, S.J. 2000. The effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. Fishing News Books, : pp. 15-36

Fonteyne, R., 1999. In situ experiments of seabed disturbance by beam trawls. ILVO-Fisheries, Oostende, Belgium, p. 14.

Fonteyne, R., 2000. Physical impact of beam trawls on seabed sediments. In: Effects of fishing on non-target species and habitats: biological conservation and socio-economic issues (ed. M. J. Kaiser and S. J. de Groot), pp. 3-14. Blackwell Science, Oxford.

Franco, J., 2007. Environmental effects of fishing gears and the socioeconomic consequences of their modification, substitution or suppression. European Commission, IP/B/PECH/IC/2006-179.

Frid, C.L.J., Clark, R.A., Hall, J.A., 1999. Long-term changes in the benthos on a heavily fished ground off the NE coast of England. pp. 13-20.

Frid, C.L.J., Garwood, P.R., Robinson, L.A., 2009a. The North Sea benthic system: a 36 year time-series. Journal of the Marine Biological Association of the United Kingdom 89, 1-10.

Frid, C.L.J., Garwood, P.R., Robinson, L.A., 2009b. Observing change in a North Sea benthic system: A 33 year time series. J. Mar. Syst. 77, 227-236.

Frid, C.L.J., Harwood, K.G., Hall, S.J., Hall, J.A., 2000. Long-term changes in the benthic communities on North Sea fishing grounds. ICES J. Mar. Sci. 57, 1303-1309.

Frid, C.L.J., Paramor, O.A.L., Brockington, S., Bremner, J., 2008. Incorporating ecological functioning into the designation and management of marine protected areas. Hydrobiologia 606, 69-79.

Frid, C.L.J.C., R.A.; Percival, P. , 2001. How far have the ecological effects of fishing in the North Sea ramified? Senckenb. Marit. 31, 313-320.

Friedlander, A. M. Boehlert G. W. Field M. E. Mason J. E Gardner J. V. and Dartnell P. 1999. Sidescan-sonar mapping of benthic trawl marks on the shelf and slope off Eureka, California. Fishery Bulletin 97: 786–801.

Galbraith, R.D., and Rice, A., 2004. An introduction to commercial Fishing gear and methods used in Scotland. Scottish Fisheries Information Pamphlet No. 25. 43pp

Gaspar, M. B., Castro, M. and Monteiro C. C., (1999) Effect of tooth spacing and mesh size on the catch of the Portuguese clam and razor clam dredge. ICES Journal of Marine Science 56 (1): 103–110.

Gilkinson, K., Dawe, E., Forward, B., Hickey, B., Kulka, D., Walsh, S., 2006. A Review of Newfoundland and Labrador Region Research on the Effects of Mobile Fishing Gear on Benthic Habitat and Communities. In: Secretariat, C.S.A.s (Ed.), Research Document 2006/055. Department of Fisheries and Oceans, Science Branch and Fisheries and Aquaculture Management Branch, St-John, Canada, p. 26.

Gilkinson, K., Paulin, M., Hurley, S. and Schwinghamer, P. 1998. Impacts of trawl door scouring on infaunal bivalves: results of a physical trawl door model/dense sand interaction. Journal of Experimental Marine Biology and Ecology 224(2): 291–312.

Gordon, D.C.J., Kenchington, E.L.R., Gilkinson, K.D., 2006. A review of Maritimes Region research on the effects of mobile fishing gear on benthic habitat and communities. In: Secretariat, C.S.A.s (Ed.), Research Document 2006/056, p. 45.

Gray, J.S., Dayton, P., Thrush, S. and Kaiser, M.J., 2006. On effects of trawling, benthos and sampling design. Marine Pollution Bulletin 52 (2006) 840–843.

Gray, J.S., Dayton, P., Thrush, S. and Kaiser, M.J., 2007. Fishing for facts on the environmental effects of trawling and dredge fisheries: Reply to Løkkeborg. Marine Pollution Bulletin, Volume 54, Issue 4, April 2007, Pages 497-500.

Guyonnet, B., Grall, J., Vincent, B., 2008. Modified otter trawl legs to reduce damage and mortality of benthic organisms in North East Atlantic fisheries (Bay of Biscay). J. Mar. Syst. 72, 2-16.

Hall, J.A., 1999. The Effects of Fishing on Marine Ecosystems and Communities. Blackwell Science, Oxford.

Hall, K., Paramor, O.A.L., L.A., R., Winrow-Giffin, A., C.L.J., F., Eno, N.C., Dernie, K.M., Sharp, R.A.M., Wyn, G.C., Ramsay, K., 2008. Mapping the sensitivity of benthic habitats to fishing in Welsh waters- development of a protocol. In: [8/12], C.P.R.R.N.s (Ed.). University of Liverpool, Liverpool, UK, p. 85.

Hall, S.J. and Harding, M. 1997. Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna. Journal of Applied Ecology 34: 497–517.

Hall-Spencer, J. M., Froglia, C., Atkinson, R. J. A. and Moore, P. G. 1999. The impact of Rapido trawling for scallops, Pecten jacobaeus (L.), on the benthos of the Gulf of Venice. ICES Journal of Marine Science 56(1): 111–124.

Harrison, P.H., Strong, K.W., Jenner, K.A., 1991. A review of fishing related seabed disturbance on the Grand Banks of Newfoundland. Maritime Testing (1985) Limited, Dartmouth, Nova Scotia.

Harvey, T.-W., Stuart, I.R., Charlotte, E.M., Keith, H., 2009. A method to assess the sensitivity of sedimentary communities to fishing activities. pp. 285-300.

Heath, M., 2005. Changes in the structure and function of the North Sea fish foodweb, 1973–2000, and the impacts of fishing and climate. ICES J. Mar. Sci. 62, 847–868.

Hiddink, J.G., Jennings, S., Kaiser, M.J., 2007. Assessing and predicting the relative ecological impacts of disturbance on habitats with different sensitivities. Journal of Applied Ecology 44, 405-413.

Hintzen, N.T., Piet, G. and Brunel, T. (2010). Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. Fisheries Research 101 (2010) 108–115

Hinz, H., Hiddink, J.G., Forde, J., Kaiser, M.J., 2008. Large-scale responses of nematode communities to chronic otter-trawl disturbance. Canadian Journal of Fisheries and Aquatic Sciences 65, 723-732.

Hinz, H., Kroncke, I., Ehrich, S., 2004. Seasonal and annual variability in an epifaunal community in the German Bight. Marine Biology 144, 735-745.

Hinz, H., Prieto, V., Kaiser, M.J., 2009. Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecological Applications 19, 761-773.

Hinz, H., Prieto, V., Kaiser, M.J., 2009. Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecological Applications 19, 761-773.

Hixon, M.A., Tissot, B.N., 2007. Comparison of trawled vs untrawled mud seafloor assemblages of fishes and macroinvertebrates at Coquille Bank, Oregon. Journal of Experimental Marine Biology and Ecology 344, 23-34.

Holte, B. & Oug, E., (1996). Soft-bottom macrofauna and responses to organic enrichment in the subarctic waters of Tromsoe, northern Norway. Journal of Sea Research, 36, 227-237.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., Wilson, J., 2005. New paradigms for supporting the resilience of marine ecosystems. Trends in Ecology & Evolution 20, 380-386.

Humborg, C., Conley, D.J., Rahm, L., Wulff, F., Cociasu, A., Ittekkot, V., 2000. Silicon retention in river basins: far reaching effects on biogeochemistry and aquatic food webs in coastal marine environments. Ambio 29, 45–50.

Hutchings J.A. 2000 Collapse and recovery of marine fishes. Nature. 406, 882–885. doi:10.1038/35022565

ICES, 1988. Report of the study group on the effects of bottom trawling. ICES CM 1988 B:56

ICES, 2006. Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO). ICES CM 2006/ACE:05, Copenhagen (Denmark).

ICES, 2006a. Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour. ICES WGFTFB, Izmir, April 2010.

ICES, 2006b. Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO), 5 12 April 2006, ICES Headquarters, Copenhagen. ACE:05. 174 pp

ICES, 2010. Draft report of the Working Group on Fishing Technology and Fish Behaviour. ICES WGFTFB, Copenhagen, May 2010.

ICES. 2010. Report of the Working Group on the Ecosystem Effects of Fishing Activities (WGECO). In press. Copenhagen, Denmark. 205p.

Ivanovic, A., Zhu, J.F., Neilson, R., O'Neill, F., 2008. Physical Impact of a Roller Clump on the Seabed. 27th International Conference on Offshore Mechanics and Arctic Engineering. Amer Soc Mechanical Engineers, Estoril, PORTUGAL, pp. 723-727.

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

Jennings, S., Warr, K. J., Greenstreet, S. P. R. & Cotter, A. J., 2000. Spatial and temporal patterns in North Sea fishing effort. In: Effects of fishing on non-target species and habitats: biological conservation and socio-economic issues (ed. M. J. Kaiser and S. J. de Groot), pp. 3-14. Blackwell Science, Oxford.

Kaiser, M.J. and Spencer, B.E., 1994. Fish scavenging behaviour in recently trawled areas. Mar. Ecol. Prog. Ser. 112, pp. 41–49.

Kaiser, M.J., 1998. Significance of Bottom-Fishing Disturbance. Conservation Biology 12, 1230-1235.

Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V.S., Somerfield, P.J., Karakakkis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. . Mar. Ecol. Progr. Ser. , 1-14.

Kaiser, M.J., de Groot, S.J., 2000. The effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. Fishing News Books.

Kaiser, M.J., Hiddink, J.G., 2007. Food subsidies from fisheries to continental shelf benthic scavengers. Mar. Ecol. Prog. Ser. 350, 267–276.

Kenchington, E.L., Kenchington, T.J., Henry, L.-A., Fuller, S., Gonzalez, P., 2007. Multi-decadal changes in the megabenthos of the Bay of Fundy: The effects of fishing. Journal of Sea Research 58, 220-240.

Kenchington, T.J., 1995. A summary of the published evidence relating to habitat modification by fish draggers. In: The Canadian Maritimes Fishing: Let's Fix It, An Action Plan. SW Nova Fixed Gear Association, Shelburne, Nova Scotia, Canada, pp. 109–116.

Kirby, R. R., Beaugrand, G., Lindley, J. A., Richardson, A. J., Edwards, M. and Reid, P. C. (2007) Climate effects and benthic-pelagic coupling in the North Sea. Marine Ecology Progress Series, 330 : 31-38.

Kirby, R.R., Beaugrand, G., Lindley, J.A., 2009. Synergistic Effects of Climate and Fishing in a Marine Ecosystem. Ecosystems 12, 548-561.

Krost, P., Bernhard, M., Werner, F. & Hukriede, W. 1990. Otter trawl tracks in Kiel Bay (Western Baltic) mapped by side-scan sonar. Meeresforschung, 32: 344–353.

Künitzer, A., Basford, D., Craeymeersch, J.A., Dewarumez, J.M., Dörjes, J., Duineveld, G.C.A., Eleftheriou, A., Heip, C., Herman, P., Kingston, P., Niermann, U., Rachor, E., Rumohr, H., De Wilde, P.A.W.J., 1992. The benthic infauna of the North Sea: species distribution and assemblages. ICES J. Mar. Sci. 49, 127–143.

Larsen, T.H., Williams, N.M., Kremen, C., 2005. Extinction order and altered community structure rapidly disrupt ecosystem functioning. Ecol. Lett. 8, 538–547.

Lindeboom, H.J., 2005. Comparison of Effects of Fishing with Effects of Natural Events and Non-Fishing Anthropogenic Impacts on Benthic Habitats. In: Benthis Habitats and the Effects of Fishing (Eds. P.W. Barnes & J.P.Thomas) American Fisheries Society Sympsium.

Lindeboom, H.J., de Groot, S.J., 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. . RIVO-DLO Report C003/98, p. 404.

Lindeboom, H.J., de Groot, S.J., 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. . RIVO-DLO Report C003/98, p. 404

Linnane, A., Ball, B., Munday, B., van Marlen, B., Bergman, M., Fonteyne, R., 2000. a review of potential techniques to reduce the environmental impact of demersal trawls. Dublin, p. 43.

Madsen, N., Holst, R. and Foldager, L., 2002. Escape windows to improve the size selectivity in the Baltic cod trawl fishery. Fisheries Research, Volume 57, Issue 3, September 2002, Pages 223-235

Main, J. and Sangster, G. I. 1981. A study of sand clouds produced by trawl boards and their possible effects on fish capture. Scottish Fisheries Research Report No 20. Department of Agriculture and Fisheries for Scotland, Aberdeen, Scotland. 19 p.

Marchini, A., Munari, C., Mistri, M., 2008. Functions and ecological status of eight Italian lagoons examined using biological traits analysis (BTA). Marine Pollution Bulletin 56, 1076-1085.

McBreen, F., Wilson, J., Mackie, A., Nic Aonghusa, C., 2008. Seabed mapping in the southern Irish Sea: predicting benthic biological communities based on sediment characteristics. Hydrobiologia 606, 93-103.

McKay, D. W. 1992. Report on a survey around Scotland of potentially exploitable burrowing bivalve molluscs. Fisheries Research Services Report No. 1/92.

Moore, P.G., Jennings, S., 2000. Commercial fishing: the wider ecological impacts. Blackwell Science, Cambridge. 66pp.

Moritza, C., Loeuille, N., Guarinia, J.-M., Guiziena, K., 2009. Quantifying the dynamics of marine invertebrate metacommunities: What processes can maintain high diversity with low densities in the Mediterranean Sea? ecological modelling.

Nunes C de AP, Jangoux M (2004) Reproductive cycle of the spatangoid echnoid Echinocardium cordatum (Echinodermata) in the southwestern North Sea. Invertebr Reprod Dev 45:41–57

of position registration data

Olsgard, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A., Austen, M.C., 2008. Effects of bottom trawling on ecosystem functioning. Journal of Experimental Marine Biology and Ecology 366, 123-133.

Olsgard, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A., Austen, M.C., 2008. Effects of bottom trawling on ecosystem functioning. Journal of Experimental Marine Biology and Ecology 366, 123-133.

O'Neill, F. G. and Kynoch, R. J., 1996. The effect of cover mesh size and cod-end catch size on cod-end selectivity. Fisheries Research, Volume 28, Issue 3, October 1996, Pages 291-303

O'Neill, F.G., Summerbell, K., Breen, M., 2009. An underwater laser stripe seabed profiler to measure the physical impact of towed gear components on the seabed. Fisheries Research 99, 234-238.

Pálsson, O.K., 2003. A length-based analysis of haddock discards in Icelandic fisheries. Fish. Res. 59(3) pages 437-446.

Paschen, M., Richter, U., Köpnick, W., 1999. Trawl Penetration in the Seabed (TRAPESE). . Draft Final Report EC-Study Contract No. 96-006. University of Rostock, Rostock, Germany, p. 150.

Paschen, M., Richter, U., Köpnick, W., 2000. Trawl Penetration in the Seabed (TRAPESE). . Final Report EC-Study Contract No. 96-006. University of Rostock, Rostock, Germany, p. 150.

Philippart, C.J.M., 1998. Long-term impact of bottom fisheries on several by-catch species of demersal fish and benthic invertebrates in the south-eastern North Sea. ICES J. Mar. Sci. 55, 342-352.

Piet, G.J., van Hal, R., Greenstreet, S.P.R., 2009. Modelling the direct impact of bottom trawling on the North Sea fish community to derive estimates of fishing mortality for non-target fish species. ICES Journal of Marine Science 66.

Piet, G.J., van Hal, R., Greenstreet, S.P.R., 2009. Modelling the direct impact of bottom trawling on the North Sea fish community to derive estimates of fishing mortality for non-target fish species. ICES Journal of Marine Science 66.

Pitcher, C.R., Burridge, C.Y., Wassenberg, T.J., Hill, B.J., Poiner, I.R., 2009. A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia. Fisheries Research 99, 168-183.

Pitcher, C.R., Burridge, C.Y., Wassenberg, T.J., Hill, B.J., Poiner, I.R., 2009. A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia. Fisheries Research 99, 168-183.

Pitkitch, E.K., Santora, C., Babcock, E.A., Bakun, A., others, a., 2004. Ecosystem-based fishery management. Science 305, 346–347.

Polet, H., Tidd, A., van Hal, R., van Marlen, B., Madsen, N., Buisman, E. and Soma, K., 2010. Scientific advice concerning the impact of the gears used to catch plaice and sole. Final report to the European Commission, Tender contract no. SI2.507720.

Poos, J-J, 2010. Effort allocation of the Dutch beam trawl fleet. PhD-thesis, Rijksuniversiteit Groningen, Netherlands.

Proctor, R., Holt, T.J., Allen, J.I., Blackford, J., 2003. Nutrient fluxes and budgets for the North West European Shelf from a three-dimensional model. Sci. Total Environ. 314–316, 769–785.

Rabaut, M. (2009). Lanice conchilega, fisheries and marine conservation: towards an ecosystem approach to marine management. PhD Thesis. Ghent University: Gent, Belgium. ISBN 978-90-8756-025-6. xvii, 354 pp.

Rabaut, M., Braeckman, U., Hendrickx, F., Vincx, M., Degraer, S., 2008. Experimental beam-trawling in Lanice conchilega reefs: Impact on the associated fauna. Fisheries Research 90, 209-216.

Rabaut, M., Guilini, K., Van Hoey, G., Vincx, M., Degraer, S., 2007. A bio-engineered soft-bottom environment: The impact of Lanice conchilega on the benthic species-specific densities and community structure. Est., coast. and shelf sci. 75, 525-536.

Rabaut, M., Guilini, K., Van Hoey, G., Vincx, M., Degraer, S., 2007. A bio-engineered soft-bottom environment: The impact of Lanice conchilega on the benthic species-specific densities and community structure. Est., coast. and shelf sci. 75, 525-536.

Rabaut, M., Vincx, M., Degraer, S., 2009. Trawling reefs: impacts of habitat modification. In: Mees, J.S., J.s (Ed.), VLIZ Young Scientists' Day: book of abstracts. VLIZ Special Publication, 41. Vliz, Brugge, Belgium, p. 59.

Rabaut, M., Vincx, M., Degraer, S., 2009. Trawling reefs: impacts of habitat modification. In: Mees, J.S., J.s (Ed.), VLIZ Young Scientists' Day: book of abstracts. VLIZ Special Publication, 41. Vliz, Brugge, Belgium, p. 59.

Ramsay, K., Kaiser, M.J. and Hughes, R.N., 1998. The response of benthic scavengers to fishing disturbance by towed gears in different habitats. J. Exp. Mar. Biol. Ecol. 224, pp. 73–89.

Reise K, Herre E, Sturm M 1989 Historical changes in the benthos of the Wadden Sea around the island of Sylt in the North Sea. Helgol Meeresunters 43:417-433

Reiss, H., Greenstreet, S.P.R., Sieben, K., Ehrich, S., Piet, G.J., Quirijns, F., Robinson, L., Wolff, W.J., Kroncke, I., 2009. Effects of fishing disturbance on benthic communities and secondary production within an intensively fished area. Mar. Ecol.-Prog. Ser. 394, 201-213.

Rice, J., 2006. Impacts of Mobile Bottom Gears on Seafloor Habitats, Species, and Communities: A Review and Synthesis of Selected International Reviews. In: Secretariat, C.S.A.s (Ed.), Research Document 2006/057. Canadian Science Advisory Secretariat, Science Branch, Ottawa, Canada, p. 39.

Rice, J.C., 2009. A generalization of the three-stage model for advice using the precautionary approach in fisheries, to apply broadly to ecosystem properties and pressures. pp. 433-444.

Rijnsdorp, A. D., Buys, A. M., Storbeck, F. and Visser, E. G., 1998. Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. ICES Journal of Marine Science, 55: 403–419. 1998

Rijnsdorp, A.D. and Van Beek, F.A., 1991. Changes in growth of plaice Pleuronectes platessa L. and sole Solea solea (L.) in the North Sea. Neth. J. Sea Res. 27, pp. 441–457.

Rijnsdorp, A.D., Vingerhoed, B., 2001. Feeding of plaice Pleuronectes platessa L. and sole Solea solea (L.) in relation to the effects of bottom trawling. J. Sea Res. 45, 219–229.

Robinson, L., Rogers, S.I., Frid, C.L.J., 2008. A marine assessment and monitoring framework for application by UKMMAS and OSPAR - Assessment of Pressures (Contract No: F90-01-1075). University of Liverpool, Liverpool, UK, p. 109.

Rumohr, H., Kujawski, T., 2000. The impact of trawl fishery on the epifauna of the southern North Sea. ICES J. Mar. Sci. 57, 1389-1394.

Rúnarsson, G., 2008. Danish Seine Net - Fuel Costs in Seine Netting. Presentation given at International Seine Net Seminar, May 2008, Keflavík, Iceland.

Sainsbury, J.C., 1996. Commercial fishing methods: an introduction to vessels and gears. Third Edition. Fishing News Books. Oxford.

Sangster and Breen. 1998. G.I. Sangster and M. Breen, Gear performance and catch comparison trials between a single trawl and a twin rigged gear, Fisheries Research 36 (1998), pp. 15–26.

Schratzberger, M., Dinmore, T.A., Jennings, S., 2002. Impacts of trawling on the diversity, biomass and structure of meiofauna assemblages. Mar. Biol., 83-93.

Schratzberger, M., Jennings, S., 2002. Impacts of chronic trawling disturbance on meiofaunal communities. Marine Biology 141, 991-1000.

Schratzberger, M., Lampadariou, N., Somerfield, P., Vandepitte, L., Vanden Berghe, E., 2009. The impact of seabed disturbance on nematode communities: linking field and laboratory observations. Marine Biology 156, 709-724.

Schratzberger, M., Lampadariou, N., Somerfield, P., Vandepitte, L., Vanden Berghe, E., 2009. The impact of seabed disturbance on nematode communities: linking field and laboratory observations. Marine Biology 156, 709-724.

Schwinghamer, P., Guigné, J.Y. & Siu, W.C. 1996. Quantifying the impact of trawling on benthic habitat structure using high resolution acoustics and chaos theory. Canadian Journal of Fisheries and Aquatic Science, 53: 288–296.

Seafish, IFREMER & DIFTA 1993. Otterboard performance and behaviour. Research project funded by Committee E.C. within the frame of the EEC research programme in the fisheries sector (FAR) Contract TE 1214.

Sommer, U., Stibor, H., Katechakis, A., Sommer, F., Hansen, T., 2002. Pelagic food web configurations and different levels of nutrient richness and their implications for the ratio fish production: primary production. Hydrobiologia 484, 11–20.

Sparholt, H., Bertelsen, M., Lassen, H., 2007. A meta-analysis of the status of ICES fish stocks during the past half century. Ices Journal of Marine Science 64, 707-713.

Spingle, J., 2001. Reducing Retention of Small Fish in 3Ps Danish Seine Fishery for Witch Flounder. FDP Project No. 284. 8pp.

STECF, 2008. Report of the Scientific, Technical and Economic Committee for Fisheries – Evaluation of the STECF/SGMOS 07-04 Working Group on Discards. SEC (2008) 14-18 April 2008, Hamburg.156pp + Annexes.

Stecf, 2010. Scientific, Technical and Economic Committee for Fisheries (STECF) - Report of the SGMOS-09-05 Working Group on Fishing Effort Regimes Regarding, Annex IIA of TAC & Quota Regulations and Celtic Sea. JRC Scientific and Technical reports, EUR 24369 EN - 2010.

28 September – 2 October, ISPRA, ITALY

Stein U, Hukriede W, Rumohr H (1990) Historische Benthosdaten aus Nord- und Ostsee in den Jahren 1902–1912. Mitt Zool Mus Univ Kiel (Suppl 3) p 1–189

Stelzenmuller, V., Rogers, S.I., Mills, C.M., 2008. Spatio-temporal patterns of fishing pressure on UK marine landscapes, and their implications for spatial planning and management. ICES J. Mar. Sci. 65, 1081-1091.

Strange, E. S. (1981) An introduction to commercial fishing gear and methods used in Scotland. Scottish Fisheries Information Pamphlet Number 1.

Suchanek, T.H., (1993). Oil impacts on marine invertebrate populations and communities. American Zoologist, 33, 510-523.

Thórarinsdóttir, G.G. Einarsson, H.A., Ólafsdóttir; S.H. and Ragnarsson, S. Á. 2010. The impact of a fly-dragging fishery on the bottom community in Skagafjörður. Marine Research in Iceland (in press).

Thrane, M., 2005. Environmental Impacts from Danish Fish Produces – Hot spots and environmental policies. Department of Development and Planning Aalborg University, Denmark. 490pp.

Thrush, S.F., Dayton, P.K., 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annu. Rev. Ecol. Syst. 33, 449-473.

Thrush, S.F., Hewitt, J.E., Cummings, V.J., Dayton, P.K., 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? Marine Ecology Progress Series 129, 141-150.

Tuck, I., Hall, S., Roberston, M., Armstrong, E., Basford, D., 1998. Effects of physical trawling disturbance in a previously unfished sheltered Scottish sea loch. Marine Ecology Progress Series 162, 227-242.

Tulp, I., Piet, G., Quirijns, F., Rijnsdorp, A., & Lindeboom, H., 2005. A method to quantify fisheries induced mortality of benthos and fish. RIVO-Netherlands Institute for Fisheries Research, Report No: C087/05.

Turner, S.J., Thrush, S.F., Hewitt, J.E., Cummings, V.J., Funnell, G., 1999. Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology 6, 401-420.

Tyler-Walters, H., Arnold, C., 2008. Sensitivity of Intertidal Benthic Habitats to Impacts Caused by Access to Fishing Grounds. In: (MarLIN)., R.t.C.C.G.C.C.C.f.W.f.t.M.L.I.N.s (Ed.). Marine Biological Association of the UK, Plymouth, UK, p. 48.

Valdermarsen, J.W., and Nakken, O., 2002. Discards in Norwegian Fisheries. Utkast I norske fiskerier. Workshop om utkast I nordiske fiskerier. Sophienberg Slot, Rungsted, Denmark.

Valiela, I., 1984. Marine Ecological Processes. Springer-Verlag, New York. 546 pp.

Van Hoey, G., Guilini, K., Rabaut, M., Vincx, M., Degraer, S., 2008. Ecological implications of the presence of the tube-building polychaete Lanice conchilega on soft-bottom benthic ecosystems. Marine Biology 154, 1009-1019.

Vanderperren, E. 2008. Project report Outrigger II: introduction of outriggers in the beam trawl fisheries to save fuel: scientific final report VIS/06/C/02/DIV, January 2008 [Projectrapport Outrigger II: Introductie van bordenvisserij in de boomkorvloot met het oog op brandstofbesparing: Wetenschappelijk eindrapport VIS/06/C/02/DIV, Januari 2008]. Stichting voor Duurzame Visserijontwikkeling (SDVO)/Instituut voor Landbouw en Visserij-onderzoek (ILVO), Sectie Technisch Visserijonderzoek: Oostende, Belgium. 126 pp. (In Dutch).

Vanhee, J. 2008. Inktvisrapport. Instituut voor Landbouw en Visserij-onderzoek (ILVO), Sectie Technisch Visserijonderzoek: Oostende, Belgium. 17pp. (In Dutch)

Verfaillie, E., 2008. Development and validation of spatial distribution models of marine habitats, in support of the ecological valuation of the seabed [Ontwikkeling en validering van een ruimtelijke verspreidingsmodellen van mariene habitats, ter ondersteuning van het ecologisch waarderen van de zeebodem]. PhD Thesis. Instituut voor de Aanmoediging van Innovatie door Wetenschap en Technologie in Vlaanderen/Universiteit Gent/RCMG, Brussel, Belgium, p. 207.

Watling, L., 2005. The global destruction of bottom habitats by mobile fishing gear. In: Norse, E.A., Crowder, L.B.s (Eds.), Marine conservation biology: the science of maintaining the sea's biodiversity., pp. 198-210.

Watling, L., Norse, E.A., 1998a. Disturbance of the seabed by mobile fishing gear: a comparison with forest clear-cutting. Marine Conservation Biology Institute, Redmond, WA (USA), p. 37.

Watling, L., Norse, E.A., 1998b. Special section: effects of mobile fishing gear on marine benthos. Conservation Biology 12, 1178-1179.

Wayte, S., Hobday, A., Fulton, E., Williams, A., Smith, A., 2004. Draft Ecological Risk Assessment for the Effects of Fishing: South East Trawl and Danish Seine Fishery. In Hobday, A., A.D.M. Smith and I. Stobutzki. Ecological Risk Assessment for Australian Commonwealth Fisheries. Final Report - Stage 1. Hazard identification and preliminary risk assessment, July 2004. Report to the Australian Fisheries Management Authority, Canberra, Australia

Willems, W., Goethals, P., Van den Eynde, D., Van Hoey, G., Van Lancker, V., Verfaillie, E., Vincx, M., Degraer, S., 2008. Where is the worm? Predictive modelling of the habitat preferences of the tube-building polychaete Lanice conchilega. Ecological modelling 212, 74-79.

Witbaard, R., and Bergman, M. J. N. 2003. The distribution and population structure of the bivalve Arctica islandica L. in the North Sea: what possible factors are involved. Journal of Sea Research, 50: 11–25.

LIST OF FIGURES

LIST OF TABLES